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A Transparent and Ecologically Sustainable DLT-based Approach for Tendering Processes

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Abstract Tendering processes aim to provide transparency in the trade of services or goods but often fall short, leading to corruption and loss of trust. The emergence of Distributed Ledger Technologies (DLTs), such as blockchain, has prompted research into their application for enhancing transparency in tendering. However, adopting DLT usually incurs extra costs, network fees, and high carbon footprints. This paper conducts a Multi-Criteria Decision Making (MCDM) process to select the most suitable DLT for tendering processes. As a result, a novel tendering process based on IOTA is proposed, which improves transparency, ensures ecological sustainability, and avoids extra costs. The IOTA-based approach also fosters collaboration between human and computer capabilities in selecting the tender winner. Our method is compared with existing approaches, demonstrating the highest transparency.

Keywords: Transparency, Ecological Sustainability, Tendering, DLT, IOTA
Categories: C.2.4, H.4.0, K.4.2, K.6.5
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1 Introduction

Tendering is a process used by governmental organizations to acquire services or goods, aiming to select the best option among various offers [Mantzaris 2014]. While the lowest bid typically wins, it may not be accepted if it underestimates costs and risks project completion [Kamil et al. 2018]. This scenario can lead to additional costs and delays, necessitating a new tender process. Conversely, not awarding the lowest bid can raise concerns of abuse or corruption [Kamil et al. 2018]. Therefore, enhancing transparency in tendering processes is crucial for public oversight and trust [Mezquita 2020].

Recent advancements in Distributed Ledger Technologies (DLTs) offer promising solutions for enhancing transparency in various fields such as smart environments

[Atlam et al. 2020, Moya et al. 2023, Ramos-Cruz et al. 2024], healthcare [Moya et al. 2023a, Muñoz-Higueras et al. 2024], and tendering processes [Kamilaris et al. 2019, Kassen 2022]. DLTs provide decentralized, immutable, tamper-proof, and timestamped data storage, enabling stakeholders to trace processes confidently [Ramamurthy 2020]. Several approaches have applied DLTs to tendering systems. Ethereum-based solutions utilize smart contracts for automation and auditability [Hardwick et al. 2018, Čeke et al. 2022, Weingärtner et al. 2021]. These approaches enhance security and transparency but face challenges like high costs, scalability issues, and limited confidentiality. Alternatively, Hyperledger Fabric (HLF) [Cachin 2016] addresses some Ethereum limitations by offering permissioned access, which enhances confidentiality and scalability [Mustafa and Waheed 2019, Pranav et al. 2021, Wang et al. 2021]. However, this permissioned access limits transparency within the tendering process. In summary, existing tendering approaches rely on blockchain, presenting the mentioned limitations. These issues can be mitigated using Directed Acyclic Graph (DAG)-based DLTs, like IOTA [Conti et al. 2022], which offers scalability and ecological sustainability, aligning with initiatives like the European Green Deal [European Green Deal 2019].

This paper conducts a MCDM process to select the most suitable Distributed Ledger Technology Infrastructure (DLTI) focused on transparency, confidentiality, decentralization, and ecological sustainability without incurring additional technology costs. As a result, we propose a novel IOTA-based tendering process that combines intelligent human and computer capabilities, allowing citizens to audit and participate in a fair, trusted, and sustainable tendering process.

The rest of the paper is structured as follows. Section 2 describes the basics of tendering processes and DLTs. Section 3 outlines the requirements for selecting a DLTI and details our MCDM selection process. Section 4 introduces the proposed IOTA-based tendering approach. An illustrative example is presented in Section 5. In Section 6, our approach is compared with others, and limitations are discussed. Section 7 summarizes our contributions and identifies future research directions.

2 Background

In this section, we introduce the basics of tendering processes and DLTs, focusing, for the latter, on *blockchain* and DAGs.

2.1 Tendering Processes

In the public sector, *procurement* refers to acquiring services or goods for citizens and administration. *Public procurement* involves government actions to acquire these from the private sector [Lloyd et al. 2004]. The earliest evidence of procurement dates back to 2800 B.C. in Syria, where an order for 50 jars of oil was recorded on a clay tablet [Thai and Grimm 2000]. Over time, procurement processes have increased globally, often involving significant sums, which can lead to corrupt practices like extortion, bribery, and embezzlement [Woods and Mantzaris 2012].

To mitigate these issues, procurement processes, especially for valuable goods, often use *tendering*. According to the Cambridge Dictionary [Cambridge University Press 2023], *tendering* is "*the process of choosing the best or cheapest company to supply goods or do a job by asking several companies to make offers*". The main goal of tendering is to ensure impartiality and fairness, allowing stakeholders to participate with equal opportunities. Traditionally, offers were submitted in a tender box using a double envelope system to maintain confidentiality until a specified deadline. In recent decades, tendering has shifted to e-tendering, enhancing cost-effectiveness and efficiency [Siciliani et al. 2023]. Procurement through tendering includes the following key characteristics to ensure fairness, transparency, and value for money [Mantzaris 2014]: (i) the lowest tender wins if all points are equal among bids; (ii) bids are kept secret until the deadline; and (iii) no negotiation is allowed before or after awarding the contract.

Tendering processes must adapt to local jurisprudence and may vary between countries [Hardwick et al. 2018]. However, most traditional processes share the following phases (see Figure 1):

1. *Advertising the tender*: An organization creates and publishes a request for tender via official channels, detailing terms, conditions, deadlines, requirements, and evaluation criteria.

2. *Bid submissions*: Interested parties gather necessary documentation, prepare a bid, and submit it to the tendering organization. A stamped copy is provided as proof of submission.

3. *Evaluation of bid submissions*: After the deadline, the organization reviews all bids, verifies documentation, and assesses each bid based on the advertised criteria. The winner is selected, and results are published.

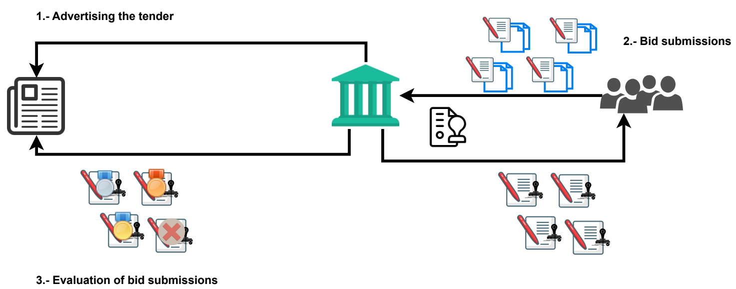

Figure 1: Phases of a traditional tendering process.

Traditional tendering processes are controlled by a central authority responsible for overseeing their integrity. This centralization requires participants to trust the authority, but suspicious results can lead to a lack of trust [Woods and Mantzaris 2012]. Central databases storing tender data are vulnerable to manipulation by those with access. To enhance transparency, this paper proposes using DLTs to decentralize the tendering process, ensuring no single authority can control or manipulate it.

2.2 Distributed Ledger Technology

The concept of DLT is based on cryptographic principles [Raikwar et al. 2019] and distributed database systems [Özsu and Valduriez 1999]. Cryptography ensures data integrity and non-repudiation, while the distributed nature involves a network of peers (*nodes*) recording data without a central authority. In recent years, DLTs have gained popularity due to their characteristics [Ramamurthy 2020]: (i) *immutability*, data is permanent and unalterable); (ii) *decentralization*, no central authority controls the network; (iii) *distribution*, all participants have a copy of the ledger, ensuring transparency; (iv) *tamper-proof*, data cannot be altered, ensuring authenticity; (v) *provenance*, every transaction is recorded chronologically, providing an auditable trail; (vi) *consensus mechanism*, network status is agreed upon by participants; and (vii) *security*, decentralization eliminates single points of failure, and encryption ensures participants cannot repudiate transactions. Below, we describe the most popular types of DLTs: *blockchain* and DAGs.

Blockchain

Blockchain, first used in Bitcoin [Nakamoto 2008], is the most well-known DLT, enabling Peer-to-Peer (P2P) transactions without a central authority. Each transaction contains data about the sender, recipient, and amount [Ramamurthy 2020], and transactions are grouped into *blocks*, each identified by a *hash* of its content [Damgård 1989]. A hash function is a one-way function producing a fixed-length string from an input, where a small input change produces a different output, and the input cannot be derived from the hash due to computational limitations. Blocks are linked by including the previous block's hash in the current block, forming a chain that starts with the *Genesis* block. Without a central authority, consensus algorithms ensure network integrity. The two most common are Proof of Work (PoW) [Gervais 2016] and Proof of Stake (PoS) [Nguyen et al. 2019].

Blockchains can be: (i) *public*: open to everyone; (ii) *private*: access restricted to authorized users; and (iii) *federated*: access restricted to pre-selected participants with equal power.

Ethereum, a public blockchain released in 2015, extended blockchain's applications beyond payments to include decentralised Applications (dApps) [Buterin 2014]. The core of a dApp is the Smart Contract (SC), a piece of code executed on the blockchain that automates digital asset exchanges between parties [Infante 2019]. Ethereum transactions require a fee in Ether (ETH).

Despite benefits like decentralization and immutability, public blockchains have limitations [Conti et al. 2022]: (i) *limited throughput* due to block size constraints; (ii) *transaction costs* from fee payments; (iii) *confirmation delays* due to block addition times; and (iv) *inequity* between peers and miners.

HLF, a federated blockchain, addresses some of these issues [Cachin 2016]. It requires no transaction fees and offers faster transaction processing, though its semi-private nature limits transparency.

Directed Acyclic Graphs

A DAG is a graph with directed edges and no closed loops, ensuring no path starts and ends at the same vertex. In DLT, a DAG structures each transaction as a vertex linked by edges, differing from blockchain's linear structure [Živić et al. 2020] (see Figure 2). DAGs eliminate the need for blocks and miners, resulting in no transaction fees and lower energy consumption [Sori et al. 2020]. IOTA is the most popular DAG-based DLTI [Popov 2018].

IOTA, developed for Internet of Things (IoT) devices, uses a DAG-based ledger called *the Tangle* to address blockchain limitations like scalability and confirmation

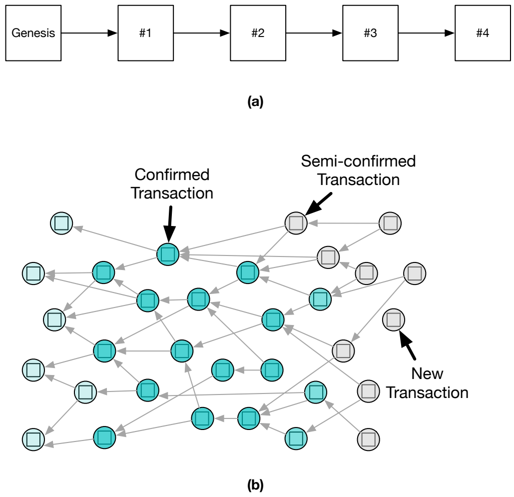

Figure 2: a) Blockchain topology; b) Tangle topology; (Adapted from [Sealey 2022]).

delays, while enhancing energy efficiency [Popov 2018]. IOTA's consensus mechanism, Fast Probabilistic Consensus (FPC) [Popov and Buchanan 2021], does not rely on PoW, thus no mining or fees are required. Each new transaction approves at least two existing ones, forming a DAG (see Figure 2), and avoiding the bottleneck of linear structures. A small PoW is used to prevent spam, which can be delegated to more powerful devices if needed [Popov 2018].

Recent studies [Fartitchou et al. 2023, Glicoric 2024, Sori et al. 2021] show IOTA's high performance and scalability in data-intensive projects, while maintaining low energy consumption. Since 2021, the EU has incorporated IOTA technology into sustainable and efficient platforms for data recording [EBSI 2021], improving EU-wide transaction efficiency, citizen mobility, and reducing carbon footprints.

2.3 Multi-criteria Group Decision-Making Framework

This section briefly describes the multi-criteria group decision-making framework to find the best sustainable DLTI option for developing a DLT-based tendering decision support system. The framework is composed of two stages: (i) criteria weight determination and (ii) ranking of the alternatives. Typically, multi-criteria group decision-making problems can be mathematically described as follows:

- A group of experts $E = \{E_1, E_2, ..., E_K\}$, $(K \geq 2)$
- A finite set of $m(\geq 2)$ alternatives: $A = \{A_i \mid i \in I\}$, where $I = \{1, 2, \ldots, m\}$
- A fixed set of criteria: $C = \{C_j \mid j \in J\}$ where $J = \{1, 2, \ldots, n\}$. Generally, C comprises both benefits and cost criteria. J_B and J_C denote the index sets for benefit and cost criteria, respectively.
- The weight vector of the criteria provide by the k-th decision-maker: $w^k = (w_1^k, w_2^k, \ldots, w_n^k)$ such that $w_j^k \geq 0$ and $\sum_{j=1}^{n} w_j^k = 1$

- The alternatives are assessed over the criteria by the Decision Maker (DM) E_k and the evaluations are summarised in the following decision matrix:

$$D^k = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{pmatrix} x_{11}^k & x_{12}^k & \dots & x_{1n}^k \\ x_{21}^k & x_{22}^k & \dots & x_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1}^k & x_{m2}^k & \dots & x_{mn}^k \end{pmatrix} \end{array}$$

where x_{ij}^k denotes the performance measure of alternative A_i against criterion C_j given by DM E_k.

2.3.1 Criteria weight determination

The Best Worst Method (BWM) [Rezaei 2015] is a popular prioritisation tool, which attempts to determine the weight of the criteria by focusing on two specific criteria, namely the Best and Worst criteria, and comparing them with the rest of the criteria. The weight determination process starts with the choice of the best and worst criteria (say, C_B^k and C_W^k) from the set C by the DM E_k. Afterwards, the DM compares the best object C_B and C_W to other criteria in the set C in the pairwise fashion using Saaty's $1-9$ numeric scale [Saaty 1977] and summarises as vectors BC and WC in the following:

$$\begin{array}{rl} & \begin{array}{ccccccccc} C_1 & C_2 & \cdots & C_B & \cdots & C_W & \cdots & C_n \end{array} \\ BC^k = & (\begin{array}{ccccccccc} a_{B1} & a_{B2} & \cdots & a_{BB} & \cdots & a_{BW} & \cdots & a_{Bn} \end{array}) \end{array}$$

$$\begin{array}{rl} & \begin{array}{ccccccccc} C_1 & C_2 & \cdots & C_B & \cdots & C_W & \cdots & C_n \end{array} \\ CW^k = & (\begin{array}{ccccccccc} a_{1W} & a_{2W} & \cdots & a_{BW} & \cdots & a_{WW} & \cdots & a_{nW} \end{array}) \end{array}$$

where $a_{Bj}, a_{jW} \in \{1, 2, ..., 9\}$ with $a_{BB} = 1$ and $a_{WW} = 1$. The weight vector can be obtained by solving the following optimization problem:

$$\begin{aligned} &\min\ \zeta \\ &\text{s.t.} \begin{cases} \frac{w_B^k}{w_j} - a_{Bj}^k \leq \zeta, \forall\, j = 1, 2, ..., n \\ \frac{w_j^k}{w_W} - r_{jW}^k \leq \zeta, \forall\, j = 1, 2, ..., n \\ \sum_{j=1}^n w_j^k = 1, \\ w_j^k \geq 0,\ \forall\, j = 1, 2, ..., n. \end{cases} \end{aligned} \qquad \text{(NLP-M)}$$

Solving the optimization problem, we obtained the criteria's decision-maker E_k's weight vector $w^k = (w_1^k, ..., w_n^k)$. From the obtained weight vector for criteria w^k of the k-th decision maker E_k, we obtained the group weight vector $w = (w_1, ..., w_n)$ for the criteria where $w_i = \frac{1}{K} \sum_{k=1}^K w_i^k, i = 1, ..., n$.

2.3.2 Fuzzy TOPSIS

In this section, we describe briefly the steps of the fuzzy TOPSIS [Nădăban et al. 2016] to obtain the ranking of the alternatives under fuzzy evaluation. We will assume that the evaluation of the alternative A_i against the criteria is represented by a linguistic term, which is encoded via a triangular fuzzy number, i.e., $x_{ij}^k = (b_{ij}^k, c_{ij}^k, d_{ij}^k)$ for all $i = 1, .., m, j = 1, ..., n, k = 1, ..., K$.

Step 1 Aggregated decision matrix: From the K decision makers fuzzy decision matrices D_k $(k = 1, 2, ..., K)$, the aggregated group fuzzy decision matrix $D = (x_{ij})_{m\times n}$ is computed, in which $x_{ij} = (b_{ij}, c_{ij}, d_{ij})$ is given by $b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ij}^k$, $c_{ij} = \frac{1}{K}\sum_{k=1}^{K} c_{ij}^k$ and $d_{ij} = \frac{1}{K}\sum_{k=1}^{K} d_{ij}^k$

Step 2 Normalization of aggregated decision matrix: In order to facilitate the inter-criteria comparison, the aggregated fuzzy decision matrix $D = (x_{ij})_{m\times n}$ is normalized. Let $N = (e_{ij})_{m\times n}$ be the normalized aggregated decision matrix. The normalized aggregated rating of the alternative A_i against the criterion C_j, can be obtained as follows:

$$e_{ij} = \begin{cases} (\frac{b_{ij}}{d_j^{max}}, \frac{c_{ij}}{d_j^{max}}, \frac{d_{ij}}{d_j^{max}}) & \text{if } j \in J_B \\ (\frac{a_j^{min}}{d_{ij}}, \frac{a_j^{min}}{c_{ij}}, \frac{a_j^{min}}{b_{ij}}) & \text{if } j \in J_C \end{cases} \tag{1}$$

where $d_j^{max} = \max_i d_{ij}$ and $a_j^{min} = \min_i a_{ij}$.

Step 3 Formation of weighted normalized decision matrix: By incorporating the group weight vector of the criteria, a weighted normalized fuzzy decision matrix $V = (v_{ij})_{m\times n}$ is constructed, where

$$v_{ij} = e_{ij} \odot w_j = (v_{ij1}, v_{ij2}, v_{ij3}) \tag{2}$$

Here $\odot$ denotes the scalar multiplication operation on a fuzzy number.

Step 4 Computation of ideal solutions: From the weighted normalized decision matrix, the positive ideal solution $v_{PIS} = (v_1^+, v_2^+, ..., v_n^+)$ is computed as follows:

$$v_j^+ = (v_{j1}^+, v_{j2}^+, v_{j3}^+) \tag{3}$$

where $v_{j1}^+ = \max_i v_{ij1}$, $v_{j2}^+ = \max_i v_{ij2}$ and $v_{j3}^+ = \max_i v_{ij3}$. The negative ideal solution can be obtained from a weighted normalized decision matrix as follows:

$$v_j^- = (v_{j1}^-, v_{j2}^-, v_{j3}^-) \tag{4}$$

where $v_{j1}^- = \min_i v_{ij1}$, $v_{j2}^- = \min_i v_{ij2}$ and $v_{j3}^- = \min_i v_{ij3}$.

Step 6. Computation of separation measures: The separation measures of an alternative A_i $(i = 1, 2, ..., m)$ from the positive and negative ideal solutions can be computed as follows:

$$d_i^+ = \sum_{j=1}^{n} d(v_j^+, v_{ij}) \tag{5}$$

and

$$d_i^- = \sum_{j=1}^{n} d(v_j^-, v_{ij}) \tag{6}$$

Step 7. Computation of closeness coefficients: From the separation measures each of the alternative A_i closeness coefficient can be computed as follows:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \tag{7}$$

Step 8. Rank the alternatives: Based on the relative closeness coefficient, alternatives are ranked. The lesser value of relative closeness coefficient makes the better rank of the alternative.

3 DLTI Selection for Ecologically Sustainable Tendering Processes

In this section, we analyze three DLTIs - Ethereum, HLF, and IOTA - considering the requirements for developing a useful, transparent, and ecologically sustainable DLT-based tendering system. We then describe the MCDM process used to select the DLTI for this paper.

3.1 Criteria Determination

Considering the tendering scenarios described in Section 2.1, the digital transformation of these processes using DLTs should mirror traditional methods while enhancing transparency, avoiding extra costs, and maintaining ecological sustainability. Additionally, the proposed tendering process should foster collaboration between human and computer capabilities. Based on relevant literature on tendering and DLTIs, we evaluate the following criteria [Hardwick et al. 2018, Ambegaonker et al. 2018, Goswami et al. 2020, Kajewski and Weippert 2004]:

- *Transparency*: Stakeholders must trace the process to verify bid submission periods and evaluation results. Permissionless DLTs are preferred for their open access.
- *Decentralization*: The process should not rely on a central authority. All DLTIs are suitable due to their distributed nature.
- *Confidentiality*: The process must protect participant privacy. Permissioned DLTs offer higher confidentiality but may seem less transparent. Additionally, it is important to avoid storing sensitive data on DLTIs due to their immutability.
- *Costs*: Ethereum requires transaction fees, while HLF and IOTA are feeless.
- *Support for SCs*: Ethereum, HLF, and IOTA support SCs, but full automation is not possible due to human supervision needs. Developing SCs for each tender involves extra costs and fees.

- *Scalability and Speed*: Tendering processes usually involve a dozen bidders and require transactions to be committed within seconds. Any DLTI meeting these needs is sufficient.
- *Ecological Sustainability*: Table 1 shows the carbon footprint of Ethereum, HLF, and IOTA. Ethereum has higher energy consumption and Greenhouse Gas (GHG) emissions compared to HLF and IOTA.

Platform	**Avg. CPU usage for blockchain operation** (%)	**Energy consumed for blockchain operation** (kWh)	**GHG emission per blockchain operation** ($kgCO_2 - eq$)
Ethereum	0.658%	444×10^{-6}	292.88×10^{-6}
HLF	0.625%	375×10^{-6}	203×10^{-6}
IOTA	0.61%	366×10^{-6}	198×10^{-6}

Table 1: Carbon footprint of DLTIs in the German market per hour (extracted from [Nguyen et al. 2022] and adapted with Ethereum consumption using PoS).

3.2 MCDM DLTI Selection Process

This section describes the MCDM process used to select the DLTI for the proposed tendering approach. A group of three decision-makers[1] $DM = \{DM_1, DM_2, DM_3\}$ evaluated potential DLTI alternatives $A = \{A_1$: Ethereum, A_2 : HLF, A_3 : IOTA$\}$ based on the criteria in Section 3.1: $C = \{C_1$: Transparency, C_2 : Decentralization, C_3 : Confidentiality, C_4 : Cost, C_5 : SCs, C_6 : Scalability, C_7 : Ecological Sustainability$\}$. The criteria weights were computed using BWM, and fuzzy TOPSIS was employed to rank the alternatives.

Weights Computation

Each DM was asked to identify the best and worst criteria from the criteria set C. Subsequently, they were asked to compare the best-selected criterion to others using Saaty's $1 - 9$ scale and provide the pairwise comparison vector BC^k $(k = 1, 2, 3)$. Similarly, they have provided pairwise comparison vectors for others to the worst criterion WC^k $(k = 1, 2, 3)$. DMs preferences are summarized in Table 2.

From the Best-Worst preferences of the DMs, we obtain the weights of the criteria by employing the optimization model (NLP-M) and the weights are summarized in Table 3. Finally, we obtain the group weights of the criteria by aggregating individual weights of DMs and given in Table 3.

Fuzzy TOPSIS

The most criteria being subjective in nature, the DMs are asked to evaluate the alternatives against the criteria using the linguistic terms, whose semantics are represented via triangular fuzzy numbers. Such linguistic terms could effectively capture the subjectivity

[1] Professional consultants from enterprises dealing with DLT applications.

DMs	Best/Worst criterion	Pairwise comparison vectors C_1	C_2	C_3	C_4	C_5	C_6	C_7
DM_1	Best criterion: C_1	1	2	2	4	5	2	1
	Worst criterion: C_2	5	4	4	2	1	4	5
DM_2	Best criterion: C_7	2	3	3	4	4	3	1
	Worst criterion: C_5	4	3	3	2	2	2	5
DM_3	Best criterion: C_7	2	3	3	2	4	3	1
	Worst criterion: C_4	4	3	3	3	2	3	5

Table 2: Best-Worst Preferences of the DMs

DMs	weights of the criteria (w^k)
DM_1	w^1=(0.21, 0.16, 0.16, 0.04, 0.04, 0.16, 0.23)
DM_2	w^2=(0.21, 0.13, 0.13, 0.08, 0.06, 0.1, 0.28)
DM_3	w^3=(0.22, 0.13, 0.13, 0.07, 0.08, 0.13, 0.24)
Group Weight	w=(0.21, 0.14, 0.14, 0.06, 0.06, 0.13, 0.25)

Table 3: Weight of the criteria

of human judgements and ease the preference elicitation. Specifically, the DMs use the five linguistic terms represented in Table 4. The evaluation provided by the DMs are summarized in Table 5.

Linguistic terms	Semantics
Very Low (VL)	$(1, 1, 3)$
Low	$(1, 3, 5)$
Moderate	$(3, 5, 7)$
High	$(5, 7, 9)$
Very High	$(7, 9, 9)$

Table 4: Linguistic scale

DMs	Alternative	Pairwise comparison vectors C_1	C_2	C_3	C_4	C_5	C_6	C_7
DM_1	A_1	VH	H	M	H	VH	L	VL
	A_2	L	H	M	M	VH	H	H
	A_3	VH	H	M	L	M	H	VH
DM_2	A_1	H	H	M	H	M	L	L
	A_2	L	M	H	L	M	VH	H
	A_3	H	H	M	L	M	H	H
DM_3	A_1	M	VH	L	VH	M	VL	VL
	A_2	L	H	M	M	M	VH	VH
	A_3	H	H	L	L	H	VH	VH

Table 5: DMs evaluation of the alternatives against the criteria

With this DM´s opinions against the alternatives and criteria weight vector, we employ the steps of the fuzzy TOPSIS algorithm to obtain the closeness measures CC_i ($i = 1, 2, 3$) of the alternatives A_i ($i = 1, 2, 3$) and the results are reported in Table 6.

Alternatives	d_i^+	d_i^-	CC_i
A_1	0.255	0.162	0.3891
A_2	0.149	0.271	0.6455
A_3	0.071	0.348	**0.8310**

Table 6: TOPSIS Results

From Table 6, it is evident that A_3 is the best alternative, followed by A_2 in second place, and finally A_1. Thus, IOTA has been chosen as the DLTI for our proposal.

4 IOTA-based Tendering Approach

Integrating DLTs into tendering processes enhances transparency and trust. This section presents a novel IOTA-based tendering system that decentralizes the process by eliminating the central authority, enabling external evaluation, and making results verifiable by all. Figure 3 depicts the sequence diagram of the proposed tendering process, detailed in the following steps.

Step 1 *Advertising the tender*. The contracting entity (tendering organization) creates a tender with the information detailed in Figure 4a and publishes it on IOTA, which serves as the official communication channel. IOTA returns a hash confirming the successful publication of the tender information.

Step 2 *Bid submissions* (see Algorithm 1). Private companies and self-employed individuals interested in the tender prepare and submit their bids on IOTA. A bid includes the technical proposal, the economic offer, and the administrative documentation, as detailed in Figure 4b. To protect sensitive personal data, we propose dividing bids into two segments: private-info and public-info. The private-info segment, which contains personal and sensitive details, must not be stored on a public DLT due to the inability to delete data, as this could violate bidders' privacy rights. Instead, this segment is securely transmitted via off-DLT channels, such as secure peer-to-peer (P2P) communication channels. Conversely, the public-info segment, intended for disclosure after the evaluation phase, is stored on IOTA. Drawing inspiration from traditional tendering procedures, where sealed envelopes preserve bid confidentiality until their public opening, our approach ensures equivalent confidentiality through encryption. Each bid segment (private-info and public-info) is encrypted before submission using a unique, one-time secret key generated by the bidder. This key remains undisclosed until the submission period concludes, ensuring that bids remain inaccessible until the designated time. To ensure tamper resistance for the public part, its immutable storage on IOTA enables effortless detection of any tampering attempts. Additionally, IOTA provides a time-stamped mechanism that guarantees traceability of all operations. For the private-info segment, a hash of its contents is stored on

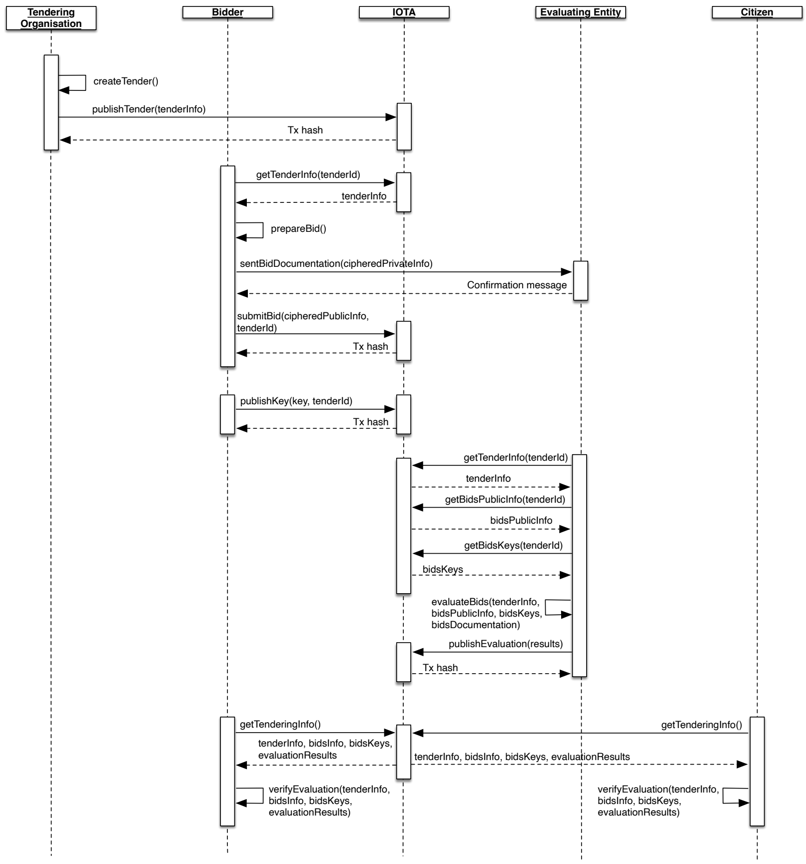

Figure 3: Sequence diagram of the proposed IOTA-based tendering process.

- Title
- Record ID
- Type of contract
- Contracting entity
- Place of execution
- Object of the contract
- Bid submission deadline
- Bid opening date
- Bidding base budget
- Documentation (contract specifications…)

(a) Advertised tender data.

- Bidder
- Representatives who sign the bid
- Authorisations
- Administrative documentation
- Bid details (technical proposal and economic offer)

(b) Required bid data.

Figure 4: Data fields of a tendering process.

IOTA at the time of submission, allowing for tamper detection while maintaining confidentiality.

Step 3 *Confirmation of bid submissions*. After the bid submission deadline, bidders confirm their bids by sharing a one-time secret key on IOTA. Bids without confirmed keys are excluded. IOTA returns a confirmation hash to bidders when the transaction with the secret key is published.

Step 4 *Bids evaluation* (see Algorithm 2). The evaluating entity retrieves the ciphered

Algorithm 1 Bid submission

```
procedure submitBid
    privateInfo, publicInfo ← prepareBidInfo(tenderId)
    key ← GenerateKey(seed)
    cipheredPrivateInfo ← Cipher(privateInfo, key)
    cipheredPublicInfo ← Cipher(publicInfo, key)
    Send cipheredPrivateInfo to evaluating entity
    confirmationHash ← sentToIOTA(cipheredPublicInfo)
    return confirmationHash
end procedure
procedure prepareBidInfo(tenderId)
    GetTenderInfo(tenderId)
    requestedPrivateDocumentation ← Fill the bid mandatory fields and prepare the requested
private documentation
    privateInfo ← Compress(requestedPrivateDocumentation)
    privateInfoHash ← ComputeHash(privateInfo)
    publicInfo ← Fill the bid form, making an offer and including the privateInfoHash
    return privateInfo, publicInfo
end procedure
procedure generateKey(seed)
    Initialize random number generator with seed
    Generate random key
    return key
end procedure
```

bids and keys from IOTA and the private bids from the secure P2P channel. Bids submitted or confirmed after the deadline are discarded. Valid bids are assessed based on the criteria, and the results are published on IOTA.

Algorithm 2 Bids evaluation

```
procedure EvaluateBids(tenderId)
    tenderInfo ← getTenderInfo(tenderId)
    cipheredBids ←getBids(tenderId)
    keys ←getKeys(tenderId)
    bids ←DecipherBids(cipheredBids,keys)
    evaluationResult ←assessBids(bids,tenderInfo)
    txHash ← sentToIOTA(evaluationResult)
    return txHash
end procedure
procedure assessBids(bids,tenderInfo)
    for bid in bids do
        Assess bid considering the criteria specified in tenderInfo
        evaluationResult ← Append bid assessment
    end for
    return evaluationResult
end procedure
```

Step 5 *Verification*[2]. Once the evaluation results are published on IOTA, any stakeholder (tendering organization, bidders, or citizens) can verify the process. They can

[2] The algorithm for this step is similar to Algorithm 2 and includes verifying the evaluation results.

retrieve the tender advertisement, ciphered bids, keys, and results from IOTA to audit the fairness and transparency of the process.

5 Illustrative Example

This section presents an illustrative example of the proposed IOTA-based tendering approach. The process is demonstrated using a governmental residence for the elderly (*Residence_A*) hiring a physiotherapist for two years, involving three bidders (*Bidder_A*, *Bidder_B*, *Bidder_C*) and evaluated by *Evaluator_A*.

5.1 Advertising the Tender

This phase includes: (i) Completing the tender details; and (ii) Publishing it on IOTA.

First, the tendering organization creates a tender with details such as the organization's information, contract object, specifications, evaluation criteria, and submission deadlines. A JSON document like JSON 1 is generated.


```
{
  "title": "Physiotherapist_2022_2024",
  "tender_id": "Physio22_01",
  "type_of_contract": "2 years - Fixed-term contract",
  "contracting_entity": "Residence_A",
  "place_of_execution": "Glasgow",
  "object_of_the_contract": "Senior Physiotherapist",
  "bid_opening_date": "2021-09-09",
  "bid_submission_deadline": "2021-10-10",
  "bid_confirmation_opening_date": "2021-10-11",
  "bid_confirmation_deadline": "2021-10-18",
  "bidding_base_budget": "£80,000",
  "documentation": {
    "contract_specifications": {
      "required_qualification":"Bachelor in Physiotherapy"
      "required_experience": "More than 5 years"
    }
  },
  "evaluation_criteria": "Lowest economic offer"
}
```


JSON 1: Tender data.

Next, the JSON content is submitted as the message payload of an IOTA transaction, creating a channel for the tender. If successful, the transaction ID becomes the channel's root, and a confirmation transaction hash is returned.

5.2 Bid Submissions

Bidders submit their offers by: (i) generating a one-time secret key; (ii) preparing the bid with private and public data; (iii) encrypting the bid's data; and (iv) submitting the bid.

First, each bidder generates a one-time secret key using AES [Dworkin et al. 2001] (e.g., "*passwordA*", "*passwordB*", "passwordC") to encrypt the bid and attached documentation.

Next, bids are prepared by separating private data (e.g., contact details, administrative documents) from public data (e.g., qualifications, experience, economic offer). Each bidder is assigned a Universally Unique Identifier (UUID) to link their data (e.g., *623A0B64-3BAA-4735-B7D4-EC5EE1B565F4*).

Private data is compressed into a .zip file, and a SHA3 [Dworkin et al. 2015] hash is generated to ensure data integrity, as it addresses vulnerabilities detected in SHA1

[Eastlake and Jones 2001, Stevens et al. 2017]. Public data includes the UUID and the private data hash, as shown in JSONs 2, 3, and 4.

```
{
  "bidder_id": "623A0B64-3BAA-4735-B7D4-EC5EE1B565F4",
  "bid_details": {
    "technical_proposal": {
      "qualifications": "Bachelor in Physiotherapy",
      "experience": "10 years",
      "economic_offer": "£78,500"
    }
  },
  "pd_hash": "61e7be0ddc59d04ea3661e538ab8665139ecc9384e8fed7a92712201902589
       c14645e42f99c841b74b01f37ef539357b"
}
```

JSON 2: Bidder_A's public data.

```
{
  "bidder_id": "E5A44E39-34F6-40C2-9A14-3228726081C2",
  "bid_details": {
    "technical_proposal": {
      "qualifications": "Bachelor in Physiotherapy",
      "experience": "5 years",
      "economic_offer": "£77,750"
    }
  },
  "pd_hash": "cf7eec086c1fea742e221f0a68f86490305764c1aabe9743f735f8d65d9
       dd95bf6fe1a32460e1f3dc54374e81f47c74c"
}
```

JSON 3: Bidder_B's public data.

```
{
  "bidder_id": "280F6783-E7E1-4A1F-AFB1-CE227550F9C7",
  "bid_details": {
    "technical_proposal": {
      "qualifications": "Master in Physiotherapy",
      "experience": "6 years",
      "economic_offer": "£79,750"
    }
  },
  "pd_hash": "847118ffad990b30981515f679a208884e458a34288e7e30884749d4bd5fbfc3f
       aed7289484e07c42f8f4053d3a0a7b5"
}
```

JSON 4: Bidder_C's public data.

Both the compressed private data file and the JSON public data are encrypted using the secret key. Public data is submitted to the Tangle via an IOTA transaction, while private data is sent to the evaluating entity through a P2P communication channel. In the latter we used Elliptic Curve Cryptography (ECDH) [IEEE Std 1363-2000, NIST FIPS186-5] to sign and verify the private data submission in order to ensure integrity and authenticity.

5.3 Confirmation of Bid Submissions

After the bid submission deadline, bidders share their one-time secret key to allow decryption of their data. They send a new IOTA transaction to the tender's channel, including the tender ID and secret key. JSONs 5, 6, and 7 show the confirmation data.

```
{
  "bidder_id": "623A0B64-3BAA-4735-B7D4-EC5EE1B565F4",
  "secret_key": "passwordA"
}
```

JSON 5: Bidder_A's confirmation data.

```
{
  "bidder_id": "E5A44E39-34F6-40C2-9A14-3228726081C2",
  "secret_key": "passwordB"
}
```


JSON 6: Bidder_B's confirmation data.


```
{
  "bidder_id": "280F6783-E7E1-4A1F-AFB1-CE227550F9C7",
  "secret_key": "passwordC"
}
```


JSON 7: Bidder_C's confirmation data.

Bidders who do not share their keys or publish them late will be automatically discarded due to the timestamped nature of DLTI records.

5.4 Bids Evaluation

After the confirmation period, the evaluating entity retrieves the tender advertisement, encrypted bids, and keys from IOTA. Bids are evaluated based on the criteria, and private documentation is verified. The results are published on the tender's IOTA channel in a new transaction. JSON 8 shows the evaluation results.


```
{
  "tender_id": "Physio22_01",
  "ranking_of_admitted_bidders": {
    1: "E5A44E39-34F6-40C2-9A14-3228726081C2",
    2: "623A0B64-3BAA-4735-B7D4-EC5EE1B565F4",
    3: "280F6783-E7E1-4A1F-AFB1-CE227550F9C7"
  },
  "excluded_bidders": {}
}
```


JSON 8: Evaluation results.

5.5 Verification

Since all records of the tendering process are stored on IOTA, anyone (the tendering organization, bidders, or the public) can verify the process. They can evaluate the results against the criteria and the content of each bid, ensuring fairness and transparency.

6 Discussion

This section compares the proposed IOTA-based tendering approach with existing methods and highlights some limitations.

6.1 Comparison with other approaches

The proposed IOTA-based approach distinguishes itself from traditional and other DLT-based tendering systems by utilizing IOTA's unique characteristics. Table 7 summarizes the features of our approach compared to traditional systems, Ethereum-based approaches [Hardwick et al. 2018, Čeke et al. 2022, Weingärtner et al. 2021], and HLF approaches [Mustafa and Waheed 2019, Pranav et al. 2021, Wang et al. 2021].

	Traditional system	Ethereum approaches	HLF approaches	Proposed IOTA-based approach
Confidentiality	Medium	High	High	High
Availability	Low	High	Medium	High
Immutability	Low	High	High	High
Traceability	Low	High	Medium	High
Smart Contracts	Not used	Used	Used	Not used
Cost	Low/Medium	Medium/High	Medium	Low
Ecological Sustainability	-	Medium/High	High	High
Transparency	Low	High	Medium	High

Table 7: Comparison of IOTA-based tendering and current systems.

Confidentiality is crucial in tendering to protect participants' identities and bids. Traditional processes have medium confidentiality due to potential pre-deadline access by tendering organizations. In contrast, DLT-based approaches use cryptography, ensuring high confidentiality by revealing data only when necessary.

Availability in traditional systems is low as data access depends on the tendering organization's discretion and server reliability. Ethereum and IOTA approaches offer high availability due to their decentralized nature, whereas HLF approaches have medium availability, restricted by permissioned access and network size.

Immutability in traditional systems is low due to potential data alterations by tendering organizations. All DLT-based approaches ensure high immutability with tamper-proof ledgers.

Traceability in traditional processes is limited by partial information disclosure, resulting in low traceability. DLT-based systems maintain comprehensive transaction records. HLF approaches have medium traceability due to limited access, while Ethereum and IOTA provide high traceability, open to the public.

Smart contracts are used in Ethereum and HLF approaches but not in the proposed IOTA-based approach, which relies on intelligent human capabilities for evaluating bids instead of full automation.

Cost-wise, traditional processes incur low to medium costs due to human resources and advertising expenses. Ethereum and HLF approaches involve medium to high costs for smart contract development and deployment. The IOTA-based approach has low costs due to free data storage on the Tangle and no need for expert developers for each new tender.

Ecological sustainability varies significantly. Traditional processes' impact is undefined but assumed to be medium/high. Ethereum's energy consumption has improved with PoS compared to PoW, resulting in medium/high sustainability. In contrast, HLF and IOTA approaches are more efficient, offering high sustainability.

Transparency in traditional processes is low due to centralized control and potential data manipulation. DLT-based approaches enhance transparency through decentralization, immutability, and accessibility. Publicly accessible systems like Ethereum and IOTA achieve high transparency, while HLF has medium transparency due to restricted access.

6.2 Limitations

Despite its advantages, the proposed IOTA-based approach has limitations. Sensitive documentation submitted by bidders is not stored on the IOTA network but sent directly to the tendering organization via a secure P2P connection. This places the responsibility for data protection on the organization.

Data stored on the DLT is permanent and immutable. Only essential bid information is stored on IOTA, encrypted, but shared keys during validation can expose data. Using new keys for each tender is recommended. Mistakenly submitted sensitive data must be discarded by withholding the encryption key and resubmitting the bid.

IOTA's maturity is a concern. The prototype used IOTA 1.0, while IOTA 2.0 offers significant updates. However, stability is expected as the IOTA Foundation works towards this, supported by the European Union [EBSI 2021].

7 Conclusions and Future Work

This paper conducted a MCDM process to select the most suitable DLT for tendering processes. As a result, we present a novel tendering process implemented on IOTA, designed to provide an open, fair, and ecologically sustainable scheme. By shifting from a centralized to a decentralized model, the proposed architecture mirrors traditional processes while avoiding additional costs associated with transaction fees and the need for experts to develop smart contracts. To our knowledge, this is the first tendering system implemented with IOTA, enabling both tendering organizations and bidders to freely participate. The main contribution of this work is demonstrating how DLT can facilitate the digital transformation of traditional tendering processes, ensuring they are open, transparent, and sustainable, while effectively integrating human and computer capabilities.

Future research will focus on optimizing human intervention by integrating generative artificial intelligence [Fui-Hoon 2023] and smart contracts [Infante 2019] into the process, thus enhancing hybrid intelligence.

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References

[Ambegaonker et al. 2018] Ambegaonker, A., Gautam, U., & Rambola, R. K. (2018). Efficient approach for Tendering by introducing Blockchain to maintain Security and Reliability. In *2018 4th International Conference on Computing Communication and Automation (ICCCA)* (pp. 1–4). IEEE.

[Atlam et al. 2020] Atlam, H. F., Azad, M. A., Alzahrani, A. G., & Wills, G. (2020). A Review of Blockchain in Internet of Things and AI. *Big Data and Cognitive Computing*, 4(4), 28.

[Buterin 2014] Buterin, V. (2014). A next-generation smart contract and decentralized application platform. *White paper*, 3(37), 2–1.

[Cachin 2016] Cachin, C. (2016). Architecture of the hyperledger blockchain fabric. In *Workshop on distributed cryptocurrencies and consensus ledgers* (Vol. 310, pp. 1–4). Chicago, IL.

[Cambridge University Press 2023] Cambridge University Press & Assessment. (2023). *Cambridge Dictionary*. https://dictionary.cambridge.org/dictionary/. Accessed: 2024-07-04.

[Čeke et al. 2022] Čeke, D., Buzadija, N., & Kunosić, S. (2022). Enhancing transparency and fairness in public procurement process with the support of blockchain technology: a smart contract based approach. In *2022 21st International Symposium INFOTEH-JAHORINA (INFOTEH)* (pp. 1–6). IEEE.

[Conti et al. 2022] Conti, M., Kumar, G., Nerurkar, P., Saha, R., & Vigneri, L. (2022). A survey on security challenges and solutions in the IOTA. *Journal of Network and Computer Applications*, 103383.

[Damgård 1989] Damgård, I. B. (1989). A design principle for hash functions. In *Conference on the Theory and Application of Cryptology* (pp. 416–427). Springer.

[Dworkin et al. 2001] Dworkin, M. J., Barker, E. B., Nechvatal, J. R., Foti, J., Bassham, L. E., Roback, E., & Dray Jr, J. F. (2001). Advanced encryption standard (AES). *Federal Inf. Process. Stds. (NIST FIPS)*, NIST Pubs.

[Dworkin et al. 2015] Dworkin, M. J. (2015). SHA-3 standard: Permutation-based hash and extendable-output functions.

[Eastlake and Jones 2001] Eastlake, D., & Jones, P. (2001). US secure hash algorithm 1 (SHA1). Network Working Group.

[EBSI 2021] IOTA Foundation. (2021). EBSI – Building a Distributed Ledger Technology for Europe. https://blog.iota.org/ebsi-building-a-distributed-ledger-technology-for-europe/. Accessed: 2024-07-20.

[European Green Deal 2019] European Commission. (2019). European Green Deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en. Accessed: 2024-07-09.

[Fartitchou et al. 2023] Fartitchou, M., Boussouf, J., El Makkaoui, K., Maleh, Y., & El Allali, Z. (2023). IOTA Tangle 2.0: An Overview. *EDPACS*, 68(5), 15–26.

[Fui-Hoon 2023] Fui-Hoon Nah, F., Zheng, R., Cai, J., Siau, K., & Chen, L. (2023). Generative AI and ChatGPT: Applications, challenges, and AI-human collaboration. Journal of Information Technology Case and Application Research, 25(3), 277-304.

[Gervais 2016] Gervais, A., Karame, G. O., Wüst, K., Glykantzis, V., Ritzdorf, H., & Capkun, S. (2016). On the security and performance of proof of work blockchains. In *Proceedings of the 2016 ACM SIGSAC conference on computer and communications security* (pp. 3–16).

[Glicoric 2024] Gligoric, N., Escuín, D., Polo, L., Amditis, A., Georgakopoulos, T., & Fraile, A. (2024). IOTA-Based distributed ledger in the mining industry: Efficiency, sustainability and transparency. *Sensors*, 24(3), 923.

[Goswami et al. 2020] Goswami, Y., Agrawal, A., & Bhatia, A. (2020). E-Governance: A Tendering Framework Using Blockchain With Active Participation of Citizens. In *2020 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS)* (pp. 1–4). IEEE.

[Hardwick et al. 2018] Hardwick, F. S., Akram, R. N., & Markantonakis, K. (2018). Fair and transparent blockchain based tendering framework-a step towards open governance. In *2018 17th IEEE International Conference On Trust, Security And Privacy In Computing And Communications/12th IEEE International Conference On Big Data Science And Engineering (TrustCom/BigDataSE)* (pp. 1342–1347). IEEE.

[IEEE Std 1363-2000] IEEE Standard Specifications for Public-Key Cryptography," in IEEE Std 1363-2000 , vol., no., pp.1-228, 29 Aug. 2000, doi: 10.1109/IEEESTD.2000.92292.

[Infante 2019] Infante, R. (2019). *Building Ethereum Dapps: decentralized applications on the Ethereum blockchain*. Manning Publications.

[Kajewski and Weippert 2004] Kajewski, S., & Weippert, A. (2004). E-Tendering: Benefits, challenges and recommendations for practice. In *Clients Driving Innovation CRC Construction Innovation International Conference Proceedings* (pp. 1–11). Australian Cooperative Research Centre for Construction Innovation.

[Kamil et al. 2018] Kamil, A., Othman, N., Adnan, H., & Zaki, Z. (2018). Contractor's mistakes during tendering. In *IOP Conference Series: Earth and Environmental Science* (Vol. 117, p. 012019). IOP Publishing.

[Kamilaris et al. 2019] Kamilaris, A., Fonts, A., & Prenafeta-Boldú, F. X. (2019). The rise of blockchain technology in agriculture and food supply chains. *Trends in Food Science & Technology*, 91, 640–652.

[Kassen 2022] Kassen, M. (2022). Blockchain and e-government innovation: Automation of public information processes. *Information Systems*, 103, 101862.

[Lloyd et al. 2004] Lloyd, R. E., & McCue, C. P. (2004). What is public procurement? Definitional problems and implications. In *International Public Procurement Conference Proceedings* (Vol. 3, pp. 2–18).

[Mantzaris 2014] Mantzaris, E. A. (2014). Public procurement, tendering and corruption: Realities, challenges and tangible solutions. *African Journal of Public Affairs*, 7.

[Mezquita 2020] Mezquita, Y. (2020). Public Tendering Processes Based on Blockchain Technologies. In *International Symposium on Ambient Intelligence* (pp. 247–250). Springer.

[Moya et al. 2023] Moya, F., Quesada, F. J., Martínez, L., & Estrella, F. J. (2023). Phonendo: a platform for publishing wearable data on distributed ledger technologies. Wireless Networks, 1-15.

[Moya et al. 2023a] Moya, F., Quesada, F. J., Martínez, L., & Estrella, F. J. (2023, November). CertifIoT: An IoT and DLT-Based Solution for Enhancing Trust and Transparency in Data Certification. In International Conference on Ubiquitous Computing and Ambient Intelligence (pp. 127-138). Cham: Springer Nature Switzerland.

[Muñoz-Higueras et al. 2024] C. Muñoz-Higueras, A. Serradilla-Gil, P. Moreno-Colmenero, and F. J. Quesada-Real. (2024, November) Integrating IoT and DLT to Enhance Patient Wait Time Traceability in Radiotherapy Oncology. In Proceedings of the 16th International Conference on Ubiquitous Computing & Ambient Intelligence (932-942). Springer Nature Switzerland.

[Mustafa and Waheed 2019] Mustafa, M. K., & Waheed, S. (2019). A governance framework with permissioned blockchain for the transparency in e-tendering process. *International Journal of Advanced Technology and Engineering Exploration*, 6(61), 274–280.

[Nădăban et al. 2016] Nădăban, S., Dzitac, S., & Dzitac, I. (2016). Fuzzy TOPSIS: a general view. *Procedia computer science*, 91, 823–831.

[Nakamoto 2008] Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system. *Decentralized Business Review*, 21260.

[Nguyen et al. 2019] Nguyen, C. T., Hoang, D. T., Nguyen, D. N., Niyato, D., Nguyen, H. T., & Dutkiewicz, E. (2019). Proof-of-stake consensus mechanisms for future blockchain networks: fundamentals, applications and opportunities. *IEEE Access*, 7, 85727–85745.

[Nguyen et al. 2022] Nguyen, L. D., Bröring, A., Pizzol, M., & Popovski, P. (2022). Analysis of distributed ledger technologies for industrial manufacturing. *Scientific Reports*, 12(1), 18055.

[NIST FIPS186-5] NIST, Digital Signature Standard (DSS), FIPS186-5. Doi: https://doi.org/10.6028/NIST.FIPS.186-5

[Özsu and Valduriez 1999] Özsu, M. T., & Valduriez, P. (1999). *Principles of distributed database systems* (Vol. 2). Springer.

[Popov 2018] Popov, S. (2018). The tangle. *White paper*, 1(3).

[Popov and Buchanan 2021] Popov, S., & Buchanan, W. J. (2021). Fpc-bi: Fast probabilistic consensus within byzantine infrastructures. *Journal of Parallel and Distributed Computing*, 147, 77–86.

[Pranav et al. 2021] Pranav, H., Latha, M., Ashwin, M. S., & Chinnaiyan, R. (2021). Blockchain As a Service (BaaS) Framework for Government Funded Projects e-Tendering Process Administration and Quality Assurance using Smart Contracts. In *2021 International Conference on Computer Communication and Informatics (ICCCI)* (pp. 1–4). IEEE.

[Raikwar et al. 2019] Raikwar, M., Gligoroski, D., & Kralevska, K. (2019). SoK of used cryptography in blockchain. *IEEE Access*, 7, 148550–148575.

[Ramos-Cruz et al. 2024] B. Ramos-Cruz, F. J. Quesada-Real, M. Rodriguez-Garcia, J. Andreu-Pérez and L. Martínez. (2024, November) Combining Distributed Ledger Technologies and Differentially Private Sketching Techniques for Securing Health Monitoring. In International Conference on Ubiquitous Computing & Ambient Intelligence (920-931). Springer Nature Switzerland.

[Ramamurthy 2020] Ramamurthy, B. (2020). *Blockchain in action*. Manning Publications.

[Rezaei 2015] Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega*, 53, 49–57.

[Saaty 1977] Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, 15(3), 234–281.

[Sealey 2022] Sealey, N., Aijaz, A., & Holden, B. (2022). IOTA Tangle 2.0: Toward a Scalable, Decentralized, Smart, and Autonomous IoT Ecosystem. *arXiv preprint arXiv:2209.04959*.

[Siciliani et al. 2023] Siciliani, L., Taccardi, V., Basile, P., Di Ciano, M., & Lops, P. (2023). AI-based decision support system for public procurement. *Information Systems*, 102284.

[Sori et al. 2020] Sori, A. A., Golsorkhtabaramiri, M., & Rahmani, A. M. (2020). Cryptocurrency grade of green; iota energy consumption modeling and measurement. In *2020 IEEE Green Technologies Conference (GreenTech)* (pp. 80–82). IEEE.

[Sori et al. 2021] Sori, A. A., Golsorkhtabaramiri, M., & Sori, A. A. (2021). Green Efficiency for quality models in the field of cryptocurrency; IOTA Green efficiency. In *2021 IEEE Green Technologies Conference (GreenTech)* (pp. 357–363). IEEE.

[Stevens et al. 2017] Stevens, M., Bursztein, E., Karpman, P., Albertini, A., & Markov, Y. (2017). The first collision for full SHA-1. In Advances in Cryptology–CRYPTO 2017: 37th Annual International Cryptology Conference, Santa Barbara, CA, USA, August 20–24, 2017, Proceedings, Part I 37 (pp. 570-596). Springer International Publishing.

[Thai and Grimm 2000] Thai, K. V., & Grimm, R. (2000). Government procurement: Past and current developments. *Journal of Public Budgeting, Accounting & Financial Management*. Emerald Publishing Limited.

[Wang et al. 2021] Wang, D., Zhao, J., & Mu, C. (2021). Research on blockchain-based e-bidding system. *Applied Sciences*, 11(9), 4011.

[Weingärtner et al. 2021] Weingärtner, T., Batista, D., Köchli, S., & Voutat, G. (2021). Prototyping a Smart Contract Based Public Procurement to Fight Corruption. *Computers*, 10(7), 85.

[Woods and Mantzaris 2012] Woods, G., & Mantzaris, E. (2012). Anti-corruption reader. *ACCERUS, University of Stellenbosch*.

[Živić et al. 2020] Živić, N., Kadušić, E., & Kadušić, K. (2020). Directed acyclic graph as hashgraph: an alternative DLT to blockchains and tangles. In *2020 19th International Symposium INFOTEH-JAHORINA (INFOTEH)* (pp. 1–4). IEEE.