Utilizing AHP for smart-city development with blockchain-based solutions for Healthcare, Government and Education

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***Abstract*—Smart cities use information and communication technologies (ICT) in overcome many challenges in order to have sustainable development. Overcoming these challenges can be achieved by applying certain criteria, which can ultimately lead to the urban transformation of urban areas, with the aim to provide better services to its dwellers, and also to ensure efficient and optimal utilization of available resources. As disruptive ICT-driven technologies such as Internet of Things (IoT), big data, artificial intelligence (AI) and blockchain are generally considered key drivers in smart city progress, the decision making process in development can be indeed cumbersome.**

In this paper, we apply analytic hierarchy process (AHP) to perform a multi-criteria analysis for planning the development of smart cities, and focus on one of the disruptive technologies, namely blockchain-based solutions. Constructed to ensure the aid in re-solving the decision-making problems, and itself being a part of multi-criteria analysis, the AHP method is used to provide the most adequate solution and rank sub-criteria by its importance. Our results focus on solutions in the areas of healthcare, education, and government, three of six basic criteria groups that determine a smart city, and we consider different types of blockchain technologies.

***Index Terms*—AHP, Blockchain, Smart city, Urban Sustainability**

I. Introduction

One of the 21st century urbanization process challenges is the inclination of the population to live in city areas. With a human capital accumulation, constant economic growth and plenty of cultural opportunities, it is expected that a current 55% of the world's population living in urban areas increase to 60% by 2030 [1] and even up to 70% by 2050 [2, 3].

The idea of a smart city is designed primarily to help provide the interconnection among humans and various devices with the Internet, obtaining smart homes, smart transportation, logistics, education, banking systems, governance, agriculture, healthcare, energy consumption, and other fields as well. The ability to provide the best services, hence enhancing the citizens' participation, and improving their quality of life indicate the degree of so-called smartness for a city [4]. Technologies such as blockchain can utilize its characteristics to contribute smart city improvement, i.e. enable fully digitized cities, strengthen e-commerce, enhance cybersecurity, ease remote patient control in hospitals, and overall reduce human effort and save time [5].

In recent decades, multi-criteria decision-making (MCDM) has been applied various fields of scientific research. This method is gaining popularity in cases where it is desirable to restructure a multi-criteria problem, and further break down into separate sub-units, and afterwards select the most optimal choice or an alternative. Hence, MCDM provides a formal framework for modeling multidimensional decision-making problems, especially those that require systems analysis, including analysis of decision complexity, the relevance of consequences, and the need for accountability of decisions made.

Our main research questions (RQs) arise from the emerging blockchain-based solutions beyond cryptocurrency. Indeed, the number of proposed solutions, especially in healthcare and in the public sector are increasing, with a limited number of solutions which involve blockchain in education [6–8].

RQ1: In which areas of smart city development do we have the most blockchain-based solutions?
RQ2: What are the differences and similarities of these solutions?
RQ3: Can these solutions be sorted and ranked using MCDM, namely Analytic Hierarchy Process (AHP)?
RQ4: What insight can we gain by ranking the sub-criteria by category, and overall?

In this paper, we firstly provide a brief overview of blockchain-based solutions in various smart city development aspects, and focus on three (out of six) identified criteria groups that determine a smart city. Afterwards, we apply AHP ranking for information and communication technologies (ICT) indicators that should be considered in the implementation of the smart city concept, through a program of implementing ICT solutions. We provide insights on healthcare, education, and government.

II. Brief Blockchain overview

Blockchain technology (BCT) lead to a paradigm shift in which data is currently being stored, accessed, and processed. Furthermore, with the inherent security properties, BCT-based ICT solutions improved current data security compared with traditional, centralized ICT solutions. The blockchain itself can be viewed as a shared, append-only distributed ledger, in which all events, termed transactions are stored in cryptographically linked blocks [9]. Every transaction, apart from the data (e.g. changes to a electronic health record (EHR), learner certificate, current version of a public document), contains a unique cryptographic signature such, as a digital signature coupled with the hashed value of the data in the transaction [10–12]. This method ensures the ledger is resilient to modifications. Whereas in traditional ICT solutions, all data is often stored in a single centralized location, the blockchain ledger is simultaneously distributed across all members of the network, termed nodes. The nodes are often connected in a peer-to-peer (P2P) network.

When a validated block is added to the blockchain, a real-time network update occurs. A block can hold a single or multiple transactions, and can be viewed as a data structure. Apart from the transaction data, a block must contain a header and a hash pointer to the previous block. These blocks form a chain which can trace back to the first block, termed the genesis block. A blockchain therefore relies on P2P networks, public-key cryptography, and a consensus mechanism. These three concepts secure blockchain transactions and blocks, making them valid. Whereas in a centralized system there must exist a Trusted Third Party (TTP) which controls data flow, in a blockchain, all nodes (or a majority of them) manage transaction validation and the process of adding a block to the chain. This process is called a distributed consensus mechanism and eliminated the need for a TTP. Nodes can e.g. compete for correct transaction validation, be chosen randomly, or apply a different algorithm altogether.

It is important to note that BCTs are a class of technology; the term refers to different forms of distributed databases with variations in their technical and governance arrangements and complexity [13].

III. Methodology

Since Thomas L. Saaty created it, AHP [14] has been an effective mechanism at the hands of researchers, corresponding comparison estimates by clear values, natural numbers [15]. This method, being one of the known multi-criteria decision-making methods, has widely applied in smart city development. The AHP method is based on the following axioms: Reciprocity axiom, Homogeneity axiom, Dependency axiom, and Axiom of expectations. This method's main feature is hierarchical structure with a main goal at the top, and criteria, sub-criteria, and alternatives at the next levels, obeying the top-down direction structure and making comparisons between two elements at the same level of the hierarchy, with respect to their influence at a lower level.

With a total of $n(n-1)/2$ comparisons of often collide criteria, a square matrix $\mathbf{A} = (a_{ij})_{n\times n}$ is created, emphasizing the influence of one criteria over another. Due to inability more than seven objects to be compared simultaneously [16], Zadeh defined a symmetric scale consisting of 17 values with a highest value 9, and a lowest value $1/9$ [17]:

$$\left\{9, 8, 7, 6, 5, 4, 3, 2, 1, \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \frac{1}{5}, \frac{1}{6}, \frac{1}{7}, \frac{1}{8}, \frac{1}{9}\right\}. \quad (1)$$

The importance level of influence or priority of one criteria over another can be described using numbers: $1 =$ *Equal importance*; $3 =$ *Moderate importance*; $5 =$ *Strong importance*; $7 =$ *Very strong or demonstrated importance*; $9 =$ *Extreme importance*; 2, 4, 6, and 8 represent intermediate values.

Consistency of the estimates obtained by decision-makers subjective assessments should be under constant review to maintain mandatory precision. For matrix $\mathbf{A}$ the consistency index CI and consistency ratio CR are calculated using the following:

$$CI = \frac{\lambda_{\max} - n}{n-1}, \quad (2)$$

and

$$CR = \frac{CI}{RI}, \quad (3)$$

where $\lambda_{\max}$ represents the maximal eigenvalue of matrices $\mathbf{A}$, and RI is a known random index, as shown in Table 1.

Table I
Table of Random Index Numbers.

Matrix dimension	**three**	**four**	**five**	**six**
RI	0.58	0.90	1.12	1.24
Matrix dimension	**seven**	**eight**	**nine**	**ten**
RI	1.32	1.41	1.45	1.49

If the comparison matrices hold $CR < 0.1$, the relative importance of criteria are acceptable. Otherwise, one must find the reasons why the inconsistency of the assessment is unacceptably high, remove them by partial repetition of the comparison in pairs, and if the degree of consistency does not obey tolerable limits, repeat the whole process [18].

IV. Results

By applying the AHP method, based on the principles of decomposition, comparative judgments and hierarchic decomposition, we can rank the BCT-based solutions that could be considered when implementing ICT infrastructure in the smart city. Constructed to ensure the aid in resolving the decision-making problems, being a part of multi-criteria analysis, the AHP can provide the most adequate solution and rank criteria/sub-criteria and its alternatives by importance.

We have firstly calculated a comparison matrix and weights for each of the three groups, namely government, healthcare, and education, named G, H, and E, respectively, as shown in Table II and Fig. 1, while Tables III-V

Table II
SUB-CRITERIA NAME AND WEIGHTS.

Criteria name	ID	Weights
Digital identity	G_1	0.36833333333
Voting	G_2	0.20638888888
Public procurement	G_3	0.20638888888
Management of government contracts	G_4	0.1094444444
Pension administration	G_5	0.10944444444
Electronic health record Management	H_1	0.40173297966
Medicine supply chain management	H_2	0.2441998231
Medical staff credential verification	H_3	0.13732979664
IoT security for remote monitoring	H_4	0.13732979664
Genomics management	H_5	0.07940760389
Student records	E_1	0.31860191018
Student diplomas, certificates and badges	E_2	0.31860191018
Lessons and courses	E_3	0.18411298516
Academic research and publishing	E_4	0.11001016053
File storage	E_5	0.06867303393

Table III
SUB-CRITERIA AND RANKING FOR GOVERNMENT.

ID	G_1	G_2	G_3	G_4	G_5	Ranking
G_1	1	2	2	3	3	0.122777655
G_2	1/2	1	1	2	2	0.068796227
G_3	1/2	1	1	2	2	0.068796227
G_4	1/3	1/2	1/2	1	1	0.036481445
G_5	1/3	1/2	1/2	1	1	0.036481445

$CI = 0.00331395284073932$
$CR = 0.00295888646494582$

Table IV
SUB-CRITERIA AND RANKING FOR HEALTHCARE.

ID	H_1	H_2	H_3	H_4	H_5	Ranking
H_1	1	2	3	3	4	0.1339108593
H_2	1/2	1	2	2	3	0.0813998596
H_3	1/3	1/2	1	1	2	0.0457765531
H_4	1/3	1/2	1	1	2	0.0457765531
H_5	1/4	1/3	1/2	1/2	1	0.0264691748

$CI = 0.00827978683946129$
$CR = 0.00739266682094758$

Table V
SUB-CRITERIA AND RANKING FOR EDUCATION.

ID	E_1	E_2	E_3	E_4	E_5	Ranking
E_1	1	1	2	3	4	0.1062005305
E_2	1	1	2	3	4	0.1062005305
E_3	1/2	1/2	1	2	3	0.06137093368
E_4	1/3	1/3	1/2	1	2	0.03667001684
E_5	1/4	1/4	1/3	1/2	1	0.02289098842

$CI = 0.00912313039997126$
$CR = 0.00814565214283148$

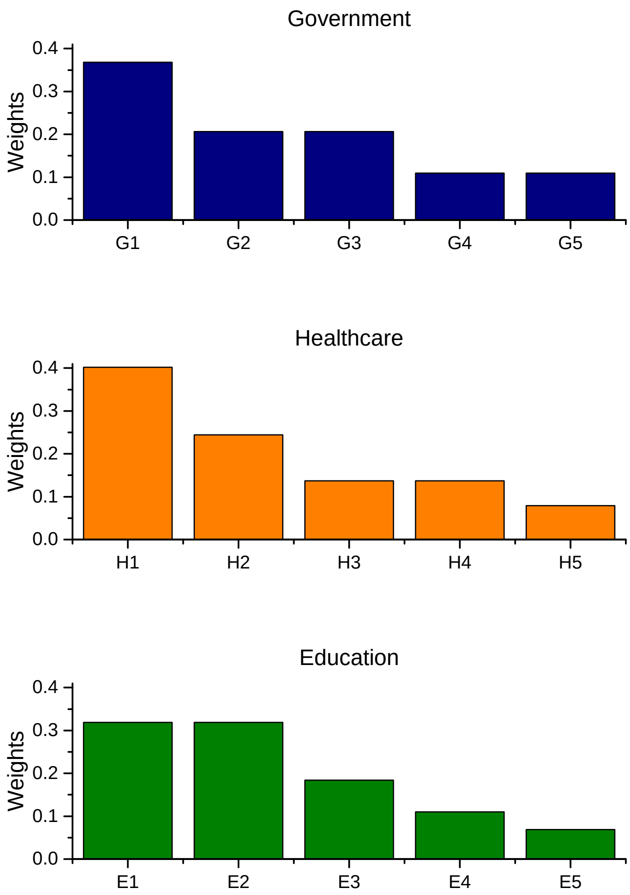

Figure 1. Sub-criteria weights for all three groups.

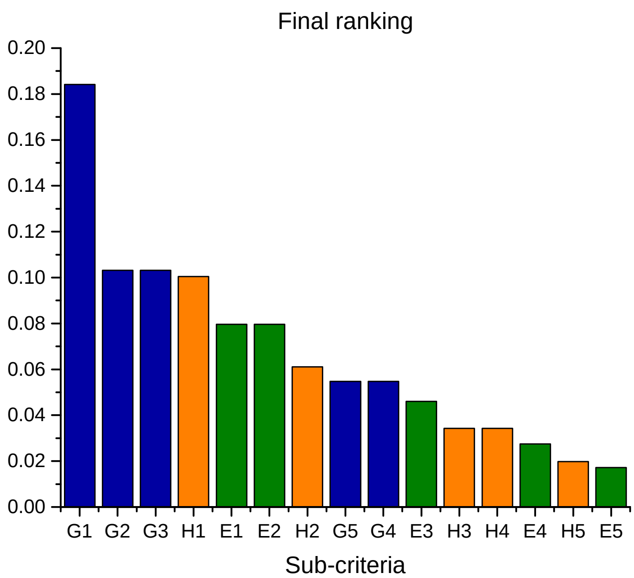

Figure 2. Final ranking for all fifteen sub-criteria.

show the rankings as well. All matrices for sub-criteria are consistent, as the corresponding CI and CR values are less than 0.1.

After calculating the weights, we can run the AHP algorithm and obtain the ranking of all sub-criteria (per group and overall). Our findings showed that overall, governance blockchain-based ICT solutions ranked highest, with the highest three (out of 15) being in this group, as shown in Fig. 2. Blockchain solutions for Digital identity (G_1) ranked highest, about 1.78 times greater than the second highest sub-criteria (G_2 and G_3), and 10.72 times greater than the least ranked criteria, File storage (E_5). EHR management ranked third, while Student records and Diplomas/Certificates/Badges ranked fifth.

V. Conclusion

In this paper, we have analyzed the opportunities for smart city development using blockchain-based ICT solutions in the areas of government, healthcare and education. As a still emerging, yet disruptive technology, BCT surely will the one of the driving forces in the development smart cities, and through this research, we highlighted a model for top-ranking solutions in three of the six major smart city criteria. The criteria are further divided into five sub-criteria in order to aid the decision-making process.

In future work, we intend to include all six groups of criteria, and and sub-criteria will be identified in detail. Furthermore, the interplay between sub-criteria will be further explored by utilizing Analytical Network Process (ANP).

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