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SELECTION OF THE GRAPHICS CARD TO BE USED IN ETHEREUM MINING WITH LINEAR BWM-TOPSIS

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Abstract

Blockchain technology is becoming more and more important and new usage areas are emerging every day. However, the most fundamental one of these usage areas is cryptocurrencies, which led to the emergence of blockchain technology. Cryptocurrency transfers are made possible with mining. Although there are many cryptocurrencies available today, a lot of them use Ethereum-based blockchain technology. The choice of the most optimal graphics card (GPU; Graphics Processing Unit) in cryptocurrency mining is very important for the efficiency and profitability of the mining operations to be performed. Since this decision problem depends on more than one criterion, it should be handled using Multiple-Criteria Decision-Making Methods (MCDM). Accordingly, the study focused on the mining of Ethereum-based cryptocurrencies and the selection of the optimal GPU to be used in mining with linear BWM-TOPSIS. As a result of the study, a model is presented in which miners can choose the most efficient GPU for them and the optimal GPU as of January 2020 has been determined.

Key words: Blockchain Mining, Cryptocurrency, GPU Hardware, MCDM

JEL Code: M1, C61, L86

1. Introduction

Fiat currencies are widely used today because central authorities and institutions are still trusted for financial transactions (Rotman, 2014). However, with the changing world conditions and globalization; the need for a reliable, low-cost, and fast transaction method increases every day (Neyer and Geva, 2017). While fiat currencies do not offer a solution for the double spending issue,

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blockchain technology serves as a remedy to overcome this problem (Tu and Meredith, 2015). In addition, blockchain technology offers the advantage of speed and low cost in financial transactions (Nguyen, 2016). Ultimately, all these advantages increase the interest in blockchain technology and cryptocurrencies. The level of investment in cryptocurrencies using blockchain and similar technologies supports this increasing interest. The total investment made in the cryptocurrency market as of January 1, 2017, was approximately $18 billion; by January 1, 2020, it had increased more than 10-fold and become approximately $190 billion. The highest total investment ever made in the cryptocurrency market was seen in January 2018 and came to about $780 billion, indicating that this market has a much higher development potential than today's market investment (CoinMarketCap, 2019). Ethereum is the second cryptocurrency that has received the most investment in the cryptocurrency market (CoinMarketCap, 2019). Furthermore, considering other Ethereum technology-based cryptocurrencies, it is possible to say that Ethereum has an important place in the cryptocurrency market. As can be seen from these data, investors' interest in Ethereum mining has increased accordingly.

An important concept of blockchain is mining (Rifi et al., 2018). Miners are needed for the transfer and recording of cryptocurrency transfers. Cryptocurrency mining involves solving the algorithm of transactions on the blockchain. Miners receive a reward for the algorithm they solve (Qin et al, 2018; Abeyratne and Monfared, 2016; Sayeed and Marco-Gisbert, 2019; Berg, 2017). Blockchain mining needs to be done with specific equipment and the ability to receive the reward is dependent on the equipment (Easley et al., 2019). Blockchain mining is highly competitive (Altman et al., 2019)]. Miners must compete with each other to get the reward (Qin et al., 2019; Weldon and Epstein, 2018). For this reason, to stand out in this competition and make it profitable, investing in the optimal GPU becomes an important decision problem (Fanning and Centers, 2016).

When the literature is examined, it is seen that there is no study related to equipment selection. The reason for this is that mining is more of a concern for people who are doing this as a profession. Furthermore, blockchain technology mostly attracts the academic world with its financial or engineering dimensions. In this case, a study looking at both academic and professional life, such as the choice of Ethereum mining equipment, has not been done before. The decision problem of this study is the selection of the graphics card (GPU, Graphics Processing Unit) to be used in Ethereum mining. The hybrid method known as BWM-TOPSIS, which is an MCDM, was chosen. In the second section, the concept of blockchain is explained including the working principle and blockchain mining. In the third section of the study, cryptocurrencies are discussed. The fourth section discusses method. The last section discusses application and the study ends with results and suggestions.

2. Blockchain Concept

Blockchain is a database containing public, sequential, and time-stamped transactions that eliminate the problem of double-spending through the cryptography it uses (Pilkington, 2016; Çarkacıoğlu, 2016). Although the usage areas of blockchain technology are not specified yet, the most widely used area is the cryptocurrency market. This technology keeps an ongoing and ever-increasing record of monetary transactions. The data for each cryptocurrency transfer made are kept on the blockchain. These data are stored in a decentralized network structure for everyone to see (Çarkacıoğlu, 2016).

Blockchain is a technology that includes cryptography, math, algorithmic and economic models, and combines them with peer-to-peer (person-to-person, end-to-end) networks thus solving the synchronization problem faced by traditional databases using the distributed compromise algorithm (Lin and Liao, 2017). Blockchain is also defined as "a technology that ensures the integrity and invariance of transactions by keeping records on diversified distributed nodes that are linked in a peer-to-peer network" (Viriyasitavat and Hoonsopon, 2019).

Blockchain technology consists of six key elements (Lin and Liao, 2017):

Decentralization: This is the main feature of blockchain. Accordingly, instead of relying on a central node, the blockchain can provide data to be recorded, stored, and updated in a distributed manner.

Transparency: Data recorded by the blockchain system is transparent for each node. This results in the blockchain being trustworthy.

Open Source: Many blockchain systems are open to everyone, logs can be checked by anyone, and people can use blockchain technology to make any application they want.

Autonomy: Due to the compromise basis, all nodes in the blockchain can securely transfer or update data.

Immutable: All data is held forever and cannot be changed unless a person has control over more than 51% of all nodes.

Anonymity: Blockchain technologies eliminate the node-to-node trust problem. It is enough to know the person's blockchain address to transfer money or data.

Blockchain is divided into three types according to people's network access status (Avunduk and Aşan, 2018):

Open Blockchains: Public blockchains are networks that are open to everyone such as Bitcoin and Ethereum. Anyone can participate in these blockchains at any level. The source codes of these chains are clear.

Permitted Blockchains: The permissions for the activities that people who participate in this chain can do on the network can be checked. It has a controlled structure. These chains can be open source depending on their structure.

Private Blockchains: They are smaller than general and permitted blockchains. They are used by organizations that store confidential information and require that users on the network be trusted.

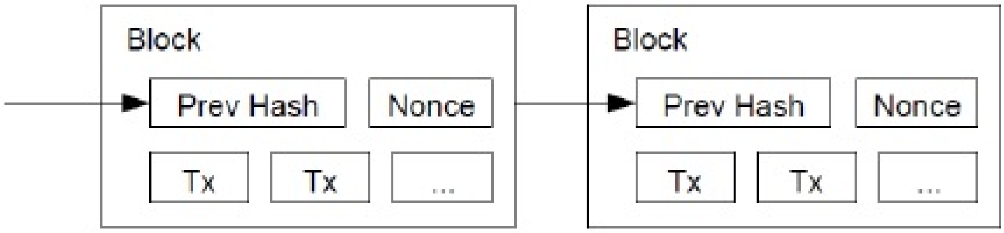
Like every technological development, Blockchain technology did not emerge suddenly. From a historical perspective, it can be said that the article first written by David Chaum in 1983 laid the foundations of Blockchain technology. Chaum mentioned in his study that the realization of electronic bank services could have a significant impact on the quality and extent of payments made for personal privacy and crime. In response, he proposed the idea of cryptography and digital signatures to prevent multiple spending and ensure personal privacy (Chaum, 1983). The declaration submitted by S. Haber and W. S. Stornetta in 1991 explains how documents can be used with timestamps and crypto signatures (Haber and Stornetta, 1990). In a paper presented by R. Anderson in 1996, he highlighted a service called Eternity Service. This service involves storing the document that you want to keep simultaneously on servers in different locations throughout the world for a certain fee. Those who want to make use of this service should upload the document and digital coins at the desired price to their servers. Although the system does not have a central server, the uploaded documents are safe from attacks and cannot be deleted by force (Anderson, 1996). In addition to blockchain, Anderson's statement also laid the foundation for cryptocurrencies, which have made this technology popular today. The paper presented by B. Schneier and J. Kelsey in 1998 focused on how encryption can be used to protect sensitive information in log files held on untrusted machines (Schneier and Kelsey, 1998).

By 2008, in the article titled "Bitcoin: A Peer-To-Peer Electronic Cash System," written by a person or group named Satoshi Nakamoto, the working logic behind Bitcoin and Blockchain was explained and the first cryptocurrency, Bitcoin, appeared. The article focused on such topics as how to transfer money from person to person without the need for financial institutions, blockchain working logic, proof of work, and blockchain codes (Nakamoto, 2008). The fact that blockchain technology has become so widespread today is because of the emergence of this article and Bitcoin. Blockchain technology is called disruptive innovation due to its features and effects (Guo and Liang, 2016; Aras and Kulkarni, 2017). Blockchain has a working principle that makes this technology unique. These working principles are discussed in the next section.

Blockchain Working Principle

Blockchain, as the concept implies, consists of a combination of block and chain structures. The first block on the blockchain is called genesis.

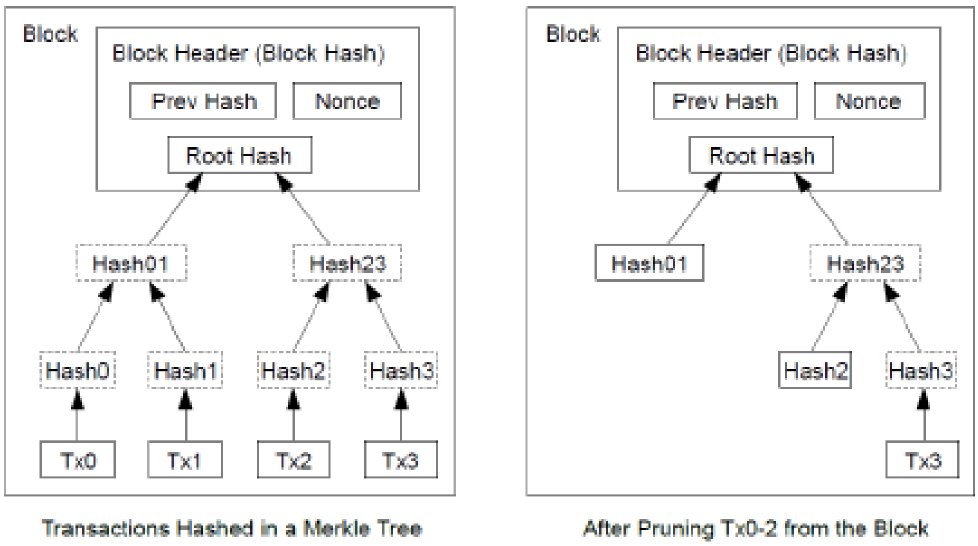
Graph 1. Blockchain Example



Source: Nakamoto, 2008

As shown in Graph 2, the data stored on the blockchain is stored on the blocks. This also causes the blockchain to have a secure structure because this structure ensures that the data held on the blocks cannot be changed. To achieve this, blockchain makes use of cryptography.

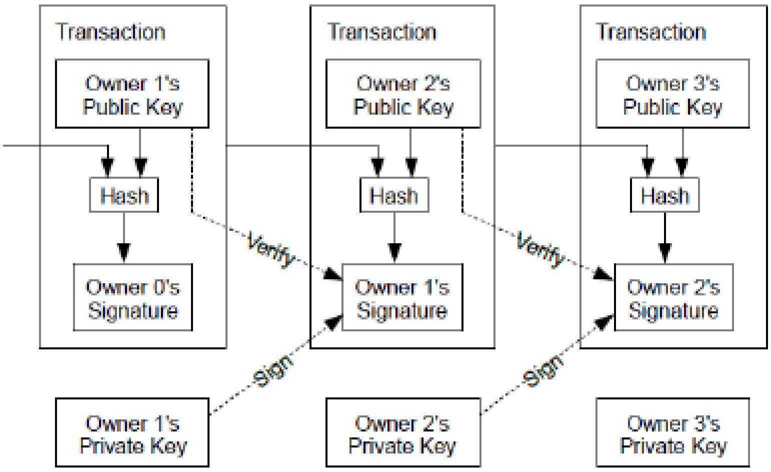
Graph 2. Components of the Block



Source: Nakamoto, 2008

When the blocks are examined structurally, it is observed that they consist of two components. The first one is the data in the block and the other is the block header. The block header consists of three elements. These are the summary (hash value) of the block, the merkle root value of the data in the block, and the timestamp.

Graph 3. How Transfers Work in Blockchain



Source: Nakamoto, 2008

In order to form a valid block, the first requirement is to solve a puzzle. The goal here is to get a certain approximate value instead of finding the exact equivalent of a summary function. When one of the participants participating in solving the puzzle finds this value, the block studied is associated with the previous valid block and propagated over the network. Then all parties in the network add the new block to their local databases and synchronize (Garay et al., 2015). The process of adding new blocks to the blockchain is called mining. Participants who carry out this process are, therefore, called miners. Miners are essential for keeping track of the blockchain and transfer operations (Beck, 2018). In order for the transfer transactions to take place, it must be clear who the parties are. However, in order to ensure their confidentiality, the parties do not have to provide their personal information. For this purpose, private keys are used to address the parties (Möser et al., 2016).

Blockchain Mining

When a blockchain is analyzed in terms of the data it carries, it is seen that it does not actually reveal a new structure. In addition, keeping the data in blocks and transferring it through chains is not new. The feature that distinguishes blockchain from previously used data retention and transfer systems comes from the operating principle of blockchain and the way blocks are created. This difference also reveals the feature that causes blockchain to be called "secure" (Iansiti and Lakhani, 2017).

Miners take on the key role in blockchain, which essentially is a distributed network. Miners are people with a computer system (Zheng et al., 2017). Miners keep the blockchain alive with the work they do and the task they undertake. These people, called miners, can be defined as the building blocks that hold transaction records (Abeyratne and Monfared, 2016). This is because all transaction records are stored in the miners' computer systems (Stein, 2017).

It is the miners, who play a key role in the operating of blockchain, and the competitive state between them that allows blockchain to be considered "secure"(Chang et al., 2017). Miners compete with each other while performing their work on the block (Aste et al., 2017). This competitive environment they are in is like a game and who wins the game is determined by probability (Kiayias, 2016).

If we exemplify the competitive environment with Bitcoin mining, all working miners compete with each other using their computing power. In this race, in the event that one miner's processing power is greater than the other miner's processing power, the miner with higher processing power will be more likely to find blocks to process (Liu et al., 2018). The main reason for this race is the desire to win the "blog" award (Rosenfeld, 2011). The computers used by miners resolve a series of algorithms to produce coins, and the process is known as mining. To solve these algorithms, miners involved in the blockchain look for a new block. The miner who finds a new block earns a certain amount of reward for solving the algorithm of the block he is working on. Similarly, miners mediate money transfers. They are rewarded for using the computer systems connected to the blockchain in coin transfer. Because of these awards, many people invest to become a Bitcoin miner (Fanning and Centers, 2016).

Mining Algorithms

There are various algorithms that regulate the competition of miners connected to a blockchain in finding blocks (Lei, 2017). The first one is proof-of-work, i.e. the proof-of-work algorithm. Another algorithm is proof-of-asset; there is also the proof-of-stake algorithm. These two algorithms are the two most widely used algorithms on the blockchain. In addition to these, it is possible to talk about different algorithms used in semi-private blockchains.

● <u>Proof-of-work:</u> The basic working principle of this algorithm is based on the processing power of computers connected to the blockchain. The algorithm is shaped depending on the process known as Hashcash. The Hashcash algorithm is an algorithm developed to prevent the spread of spam emails. The summary information of the email is calculated through the hash functions and the final result of the function is expected to be smaller than a certain value. If the function value obtained is not smaller than the desired value, a number of random changes are made in the email and the process is renewed. This process can be repeated billions of times until the function value is below the desired value. As a result, a number that is difficult to generate but easy to verify is obtained. Such a structure is easy to capture since it contains a specific number if sent as spam. If you want to send spam mail, it is necessary to repeat this process many times and perform a process that will last for days just to send 1,000 emails. But when it comes to individual jobs, this takes only a few seconds. This is an acceptable delay. The party receiving the mail checks this number in the mail it receives. This number is proof of a job done (Mattila, 2016). This situation is called Proof of Work (Tromp, 2015).

Bitcoin is based on a working principle similar to this algorithm used in emails. Miners are gathered in one block first. They then run the block's header through the hash function. The result of the function is desired to be less than a certain value. The function is repeated by randomly changing the number in the block header until the value is smaller than the desired number. The difficulty of this process varies depending on the processing power of the miners. As the the miners' power increases, so the algorithm sets a smaller value as the acceptance limit (Watanabe et al., 2016).

● Proof-of-stake: This algorithm is not based on the processing power of the miners. Miners compete proportionally to the coins they possess. In other words, they are differentiated from the cryptocurrency on the blockchain and accordingly determine the probability of finding a new block (Kiayias, 2017). This algorithm is similar to the interest system used for fiat coins (Bentov et al., 2014).

● Sequential Mining: A more restrictive algorithm is needed in semi-private, non-public blockchains. In this algorithm, people who can be miners are determined in advance. This is, in effect, a form of authorization. In this system, miners are required to create their private keys (private key) and to declare their public keys. Authorized miners are identified to the software through their private keys (Crosby, 2016). Mining is carried out sequentially. All miners who are authorized in this algorithm have the same probability of finding blocks. Generally, the mining of two blocks consecutively by the same miner is restricted by the system. It is important for miners to protect their private keys since the algorithm is based on authorization to mine. In the event that an authorized key is lost or shared by the owner, the new person who owns that key also has the privilege to be a miner. This algorithm is not suitable for long-term blockchains. It should be preferred for short-term blockchains that are formed with a specific purpose. There is almost zero competition in the system. However, since the miners are competing among themselves in real life, a competitive environment is created in this system as well.

Blockchain mining has been covered extensively in the literature with the mining strategy dimension. In 2016, Göbel et al. studied the dynamics of unclaimed blocks by using Markov models (Göbel et al., 2016). Nojoumian et al. (2018) proposed a new reputation-based framework for proof of work, in which miners are not only encouraged to do honest mining but also to engage in any malicious activity against other mining pools (Nojoumian et al, 2018). Also in 2018, Liu et al. studied the dynamics of choosing a mining pool in a blockchain network where mining pools can choose arbitrary block mining strategies (Liu et al., 2018). Quin et al. examined the pool selection problem as it is a risky decision for miners (Quin et al., 2018). In addition to these studies, in the literature, there is no study on equipment selection in blockchain mining. In the study titled "A Static Theory of

Promises" written by Jan A. Bergstra and Mark Burgess in 2008, Bitcoin mining, the devices used, and the concept of difficulty were discussed, though not in detail (Bergstra and Burgess, 2008).

3. Cryptocurrencies

Today, the usage areas of physical money are gradually decreasing, and this traditional structure is being replaced by digitalization. It is possible to say that digital currency is the first example of cryptocurrency. Digital currencies can be electronically stored and electronically moved (Griffith, 2014a). Digital money is actually a representation of the printed money in the bank. The first known digital currency, DigiCash, was developed by David Chaum in 1989 and is a centrally managed cryptographic electronic payment system (Griffith, 2014b).

Virtual currencies are a form of digital currencies, but unlike them, they are not based on a physical entity such as representing physical currencies in the bank. Virtual currencies were defined by the European Central Bank as "non-regulated/unregulated digital money that is generally controlled by its developers, adopted, and used by limited virtual group members" (European Central Bank, 2012). A new definition was introduced to virtual money by the European Banking Authority in 2014. This definition states: "It is a digital representation of value that is neither issued by a central bank or public authority, nor necessarily attached to a fiat currency (legal tender) but is used by natural or legal persons as a means of exchange and can be transferred, stored, or traded electronically" (European Central Bank, 2014). In 2015, the European Central Bank revised its definition of virtual money. Accordingly, the current definition of virtual money is expressed as "a digital representation of a value that can be used in some cases instead of money, although it is not issued by any central bank, credit institution, or e-money institution" (European Central Bank, 2015).

Cryptocurrency, on the other hand, differs from digital money and virtual money by definition. Cryptocurrencies use the science of encryption (Gandal and Halaburda, 2014). Cryptocurrencies provide the means for additional money supply. In addition, they have the quality of being digital values that can carry out secure transactions. Cryptocurrencies are an alternative to physical money. They also include the features of digital and virtual currencies that have emerged with the digitalized world (Dniprov el al., 2019). They do not possess a central structure. They are not regulated or controlled by a central authority. They differ from traditional money systems in terms of money supply. Their supply is made public in the amounts determined during the establishment phase. There is no need for national central banks to issue additional money for their issuance. Nobody can interfere in their production or ownership. The amount of money in circulation and the algorithm of supply have been completely set since the formation of the relevant cryptocurrency (Graydon, 2014). Another distinctive feature of cryptocurrencies is that there is no need for a third intermediary outside those parties conducting the money transfer. In traditional systems, security is provided by the institution or agency that is mediating the money transfer. In cryptocurrencies, the system itself undertakes this work. With physical money, there is an authority in charge of issuance. Cryptocurrencies do not need the support of such an authority due to their decentralized nature. This support is discharged through the system on which cryptocurrencies are built and through the system users.

The first known cryptocurrency is Bitcoin. Bitcoin was introduced by the person or people known by the pseudonym Satoshi Nakamoto in 2009. Bitcoin has no physical counterpart. It exists only in computer code. It is open-source in structure. It allows transactions to be carried out via miners without the need for intermediary institutions. There is no need for a bank or payment system infrastructure for stakeholders to carry out these transactions. All of this is done according to the operating principle of blockchain. Although it is not an intermediary institution, the operations are verified by solving complex algorithms on very powerful computers. Since this private currency is not under the control of any central bank, the money supply is determined by the users along with the money demand (Dinu, 2014).

According to Satoshi Nakamoto, there are some weaknesses in a trust-based system in which online trading depends only on a trusted third party. In the current system, completely irreversible transactions are not possible. In addition, because mediation costs lead to an increase in transaction costs, it limits the minimum transaction volume and does not allow smaller transactions to be made. A certain amount of fraud can be considered inevitable, and the inherent cost and payment uncertainties can be resolved face-to-face using physical money. However, there is no system that makes it possible to pay through a communication channel without a trusted third party. At this point, what is needed for direct transactions between the parties is an electronic payment system that verifies the transaction through encryption rather than trust. Irreversible transactions protect the seller from fraud, while the safety mechanism secures the buyer. Satoshi Nakamoto proposed using distributed servers that prove, based on accounts, the chronological order of transactions between the parties to ensure transaction security without a third party and to find a solution to the double-spending problem (Nakamoto, 2008).

Ethereum is an open-source cryptocurrency that uses smart contracts (Lu, 2019). Ethereum, developed by the Swiss-based Ethereum Foundation, is a decentralized platform that operates “Smart Contracts” and uses its own Turing-Complete programming language. On this platform, applications operate as programmed without any interruption, strict control, fraud, or third-party intervention. These applications run on Blockchain, which has an extremely strong global infrastructure that displaces a value and represents the ownership of an asset. In this way, markets are created, records of debt and commitments are maintained, and funds can be transferred without the risk of an intermediary or opposing party. Ethereum, officially released in 2015, is popular with many developers and corporate actors (Hileman and Rauchs, 2017).

There are many studies in the literature about cryptocurrencies. Dong and Dong (2014) looked at Bitcoin's functions as currency and financial asset. In their study, daily data between 2011 and 2013 were used and triple arbitrage between Bitcoin and the world's leading currencies (Euro, Sterling, Yuan, Yen, etc.) was examined. The results show that Bitcoin liquidity is low and indicate that the risk premium as a financial asset is high. (Dong and Dong, 2015). Guo and Liang (2016) see blockchain technology as a promising technological innovation for the banking industry. (Guo and Liang, 2016). Yechen, Dickinson, and Jianjun (2017) investigated the effects of Consumer Price Index, US Dollar Index, Dow Jones Industry Index, Fed Policy Interest Rate, and gold prices on Bitcoin price using monthly data between 2011 and 2016. It was concluded that gold prices have a very limited effect on Bitcoin price and, therefore, Bitcoin cannot be used as a hedging tool against gold prices (Zhu, 2017). Schweizer et al. (2017) in their study on the use of Blockchain technology as a crowdfunding platform stated that this new technology presents an opportunity to fix some of the problems faced by the social business enterprises that have emerged as an alternative to traditional business enterprises. (Schweizer, 2017). Estrada (2017) investigated the relationship between Bitcoin and S&P 500, VIX, and Google Trends. At this point, while S&P 500 cannot explain the volatility in Bitcoin prices, it seems that Bitcoin price volatility has explanatory power over S&P 500. In the relationship between Bitcoin price volatility and VIX, it turns out that both variables affect each other (Estrada, 2017).

4. Methodology

Best And Worst Method (Bwm)

This section of the article describes the BWM steps that can be used to achieve the weights of the criteria (Rezaei, 2015).

Step 1: A series of decision-making criteria are determined. In this step, obtained by seeking expert opinion or by literature review, given that {c1; c2;…;cn}the n criterion was determined.

Step 2: The best (most desirable, most important) and worst (least desirable, least important) criteria are determined. In this step, decision-makers who seek expert opinion are used to determine the best and worst criteria.

Step 3: It is the stage where binary comparison matrices are created according to the best and worst criteria as predicted by BWM. The decision-maker uses a scale ranging from 1 to 9 at this stage. Ultimately, the AB vector is created which includes the comparison known as Best to Others.

$$A_B = (a_{B1}, a_{B2}, \dots a_{Bn}) \quad (1)$$

Here, a_{Bj}, indicates the choice of best criterion B compared to criterion j. Comparing a criterion to itself gives us $A_{BB} = 1$.

Step 4: Similar to the Best to Others vector created in Step 3, this creates a Worst to Others vector. In this step, the effects of other factors on the criterion called the least desired, the worst, or the least important by the decision-maker on the other factors are evaluated on a shifting scale ranging between 1 and 9. The phase results in the following vector: A_W.

$$A_w = (a_{1w}, a_{2w}, \dots, a_{nw})^T \tag{2}$$

Step 5: This is where the most appropriate weight for each criterion being (w^*_1; w^*_2; ...; w^*_n) is determined. The expression ξ^* indicates consistency. The greater the value in the expression ξ^*, the less reliable the comparisons are. The main purpose of this stage is to create maximum absolute differences and to determine the optimal weights as a result. The optimum weight for these factors for each w_b/w_j and w_j/w_w pair respectively is $w_b/w_j=a_{bJ}$ and $w_j/w_w=a_{jw}$. The aim here is to minimize the maximum absolute differences as seen in the following constraints.

$$min\, \max_j \left\{ \left| \frac{w_B}{w_j} - a_{Bi} \right|, \left| \frac{w_j}{W_w} - a_{jw} \right| \right\} \tag{3}$$

$$\sum_j w_j = 1 \tag{4}$$

$$w_j \geq 0, \text{ for all } j\text{'s} \tag{5}$$

The resulting linear programming model is as follows:

$$min \xi \tag{6}$$

$$\left| \frac{w_B}{w_j} - a_{Bj} \right| \leq \xi, \text{ for all } j\text{'s} \tag{7}$$

$$\left| \frac{w_j}{w_w} - a_{jw} \right| \leq \xi, \text{ for all } j\text{'s} \tag{8}$$

$$\sum_j w_j = 1 \tag{9}$$

$$w_j \geq 0, \text{ for all } j\text{'s} \tag{10}$$

Assigned to the criteria after the model is solved, the weights (w^*_1; w^*_2; ...; w^*_n) and ξ rate are obtained. Given that for minimal consistency $a_{Bj}= a_{jW}=a_{BW}$:

$$(a_{BW} - \xi) \times (a_{BW} - \xi) = (a_{BW} + \xi) \qquad (11)$$

$$\xi^2 - (1 + 2a_{BW})\xi + (a_{BW^2} - a_{Bw}) = 0 \qquad (12)$$

Table 1. Consistency Index

a_{BW}	1	2	3	4	5	6	7	8	9
Consistency Index (max ξ)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Source: Rezaei, 2015

For different $a_{BW} \in [1,2,3,.....,9]$ values, when the solution is made, the maximum values are ξ. Using the given ξ values and the consistency index values (*CI*), the consistency rate (*CR*) is calculated as follows:

$$CR = \frac{\xi}{CI} \qquad (13)$$

TOPSIS Method

The first studies on the TOPSIS method were done in 1981 by Hwang and Yoon (Chen and Tsao, 2008). It was developed by Chen and Hwang in 1992 taking these studies as a reference (Chen and Hwang, 1992). The TOPSIS method can be expressed as a geometric system consisting of "n" pieces, that is, criteria and "m" alternatives. It is based on the concept that the alternative is found in the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution when looking for the answer to the multiple-criteria decision-making problem consisting of the negative ideal solutions resulting from the combination of the worst values and the positive ideal solutions resulting from the combination of the best values (Chen and Tzeng, 2004).

Stages of the TOPSIS Method

The application stages of the TOPSIS method are discussed in detail below (Shih et al., 2007):

Step 1: The first stage involves the creation of the decision-making matrix. The points in the line section of the decision-making matrix (i), i = 1,2,…, m express the alternatives in order of superiority, while the points in the column section (j), j = 1,2,…, n show the criteria to be used in making a decision. The matrix D is the data matrix created by the decision-maker and is shown as follows.

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$$\text{Di j} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (14)$$

Step 2: The decision matrix created at this stage is normalized. Normalization is performed by taking the square root of the sum of the squares of the elements in the column where each value is located in the decision-making matrix and dividing the values in the column by this value.

$$\text{Rij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad i=1,2,\ldots,m;\ j=1,2,\ldots,n \quad (15)$$

R matrix can be shown as follows:

$$\text{Ri j} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad (16)$$

Step 3: At this stage, a weighted normalized decision-making matrix is obtained. First, the weight values for the evaluation criteria (wi) are determined. The totals of the weight values of the criteria are equal to 1.

$$\sum_{i=1}^{n} w_i = 1 \quad (17)$$

Afterward, by multiplying every column in the R matrix by its related wi value, the Y weighted normalized matrix is obtained. The Y matrix can be shown as follows:

$$\text{Yij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_n r_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_n r_{mn} \end{bmatrix} \quad (18)$$

Step 4: Positive (A*) and negative (A-) solutions are created. Using the weighted normalized matrix (Y) to create the ideal solution set, for maximization the greatest column values are selected while for minimization the smallest column values are selected. A positive ideal solution is obtained using the following formulation:

$$A^* = \{(max_i y_{ij} | j \in J), (min_i y_{ij} | j \in J')\} \quad (19)$$

The set to be calculated using the above formula can be expressed as;

$$A^* = \{y1^*, y2^*, ..., yn^*\}. \quad (20)$$

Using the weighted normalized matrix (Y) to create the ideal negative solution set, for maximization the smallest column values are selected while for minimization the greatest column values are selected. A negative ideal solution is obtained using the following formulation:

$$A^- = \{(min_i y_{ij} | j \in J), (max_i y_{ij} | j \in J')\} \quad (21)$$

The set to be calculated with the above formulation can be expressed as A- = {y1-,y2-,...,yn-}. In both formulations, J shows benefit (maximization), while J' shows loss (minimization). The number of criteria in both the positive and negative ideal solution comes from the m element.

<u>Step 5:</u> The distance of alternatives to the positive ideal and negative ideal solutions is calculated. In the TOPSIS method, the distance of the criteria for each alternative from the positive ideal solution and the negative ideal solution set is calculated using the Euclidian distance approach. The distance values obtained with this approach are known as the Positive Ideal solution (Si *) and the Negative Ideal solution distance (Si-). The formulation used in calculating the distance to the positive ideal solution (Si *) is as follows:

$$Si^* = \sqrt{\sum_{j=1}^{n} (y_{ij} - y_j^*)^2} \quad i=1.2,\ldots,m \quad (22)$$

In calculating the distance to the Negative Ideal solution (SI-) the following formulation is used:

$$Si^- = \sqrt{\sum_{j=1}^{n} (y_{ij} - y_j^-)^2} \quad j=1.2,\ldots,m \quad (23)$$

The distances to be calculated here are as much as the compared alternatives (SI*, SI-).

<u>Step 6:</u> The values for relative proximity to the ideal solution are calculated. In calculating the relative proximity of the alternatives to the ideal solution (CI*) both positive and negative ideal separation measurements are used. The criterion evaluated here is obtained by proportioning the distance from the negative ideal solution to the sum of the positive ideal solution distance and the negative ideal

International Journal of Contemporary Economics and Administrative Sciences
ISSN: 1925 – 4423
Volume: XI, Issue: I, Year: 2021, pp. 134-159

solution distance. The formulation of the relative proximity value to the ideal solution is as follows:

$$Ci^{*}= \frac{S_i^-}{S_i^- + S_i^*} \quad (24)$$

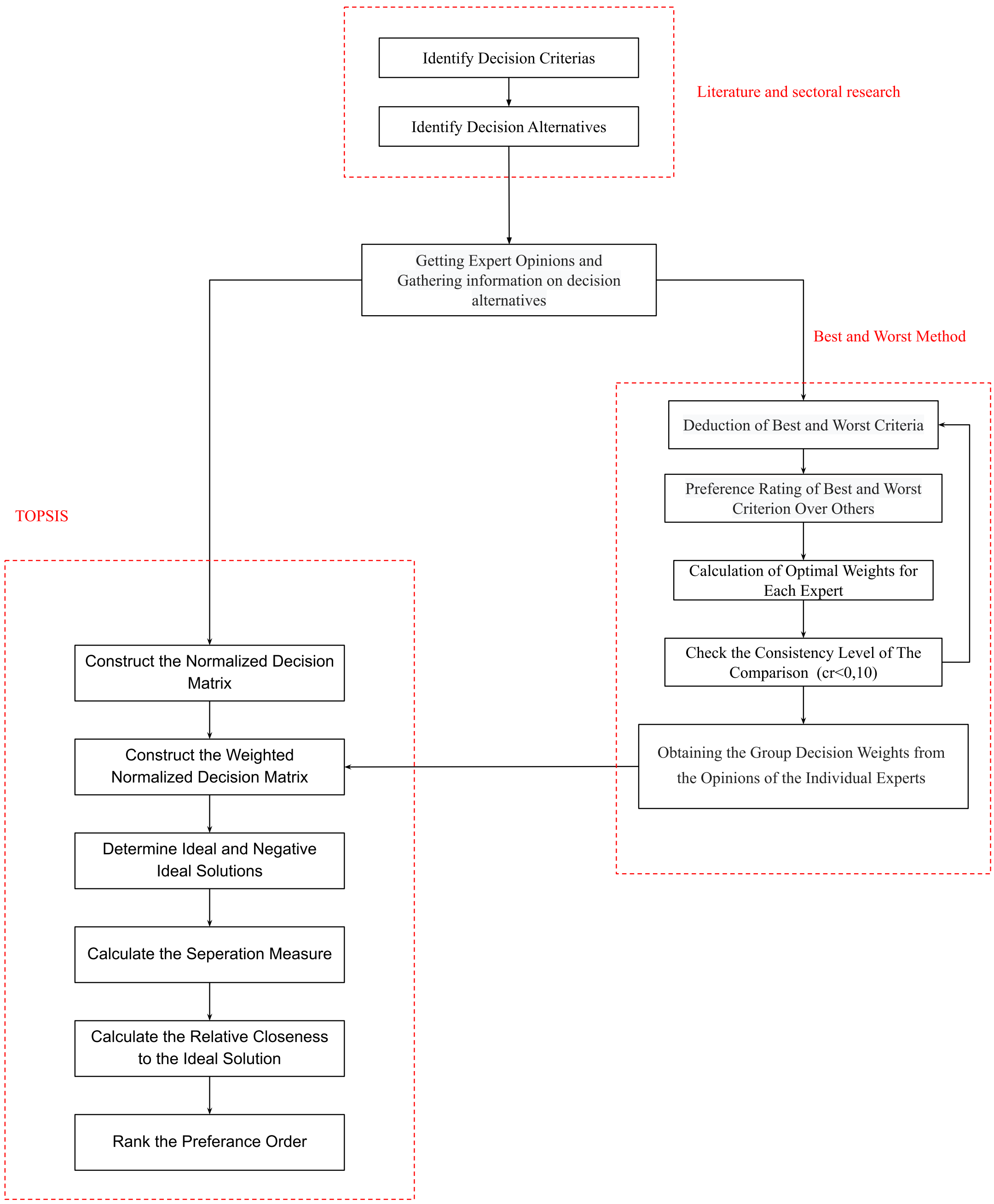
The obtained Ci* value ranges from 0 to 1 (0≤ Ci*≤1). If the Ci* value is 1 (Ci*= 1), we can say that the relevant alternative is at the positive ideal solution point, and if the Ci* value is 0 (CI*=0), we can say that the alternative is at the negative ideal solution point.

5. Application

Miners included in the blockchain with computer networks make significant gains by using the incentive system, but on the other hand the high expenses that miners have to bear make the choice of mining equipment a decision problem. The choice of the most optimal GPU in cryptocurrency mining is very important for the efficiency and profitability of the mining operations to be performed. This selection is made intuitively by miners. Since this decision-making problem depends on multiple criteria such as hashrate, price, and power consumption, etc.; it should be handled using Multiple-Criteria Decision-Making Methods. In this study, 19 GPUs available on the market in January 2020 are selected as decision-making alternatives. This study uses six criteria. They are: hashrate, GPU price, GPU RAM capacity, power consumption, number of power sockets on the GPU, and GPU ease of use.

In the study, a relatively new method, BWM, and the TOPSIS method based on the closest distance from the ideal solution. The BWM method has superiority over the other MCDM methods based on other expert opinions on consistency in terms of enabling binary comparison by identifying the best and worst criteria. The TOPSIS method was used to rank decision-making alternatives. The method allows different decision-making criteria that do not use the same scale to be used together. In addition, objective and subjective criteria can be included simultaneously. Given these advantages, a BWM-TOPSIS hybrid method was applied. Since a hybrid method is used in which two different multi-criteria decision making methods are handled together, the framework of the application is shown in the Graph 4. The application is made using Excel Solver.

Graph 4. Framework of The Application



Source: Authors' calculations

International Journal of Contemporary Economics and Administrative Sciences
ISSN: 1925 – 4423
Volume: XI, Issue: I, Year: 2021, pp. 134-159

Determining Criteral Weights By The Bwm Method

Since it is necessary for determining relative importance levels, criteria weights should be calculated. When using MCDM methods, it is important to seek the opinion of qualified expertes' opinions for the reliability of the results (Vafaeipour et al., 2014). When the literature is examined, it is seen that there is no strict rule regarding the number of experts to be consulted in multi-criteria decision making methods. The general view is that it should be determined according to the nature of the decision problem and the number of experts available. In many studies, it is seen that three experts, one academic and two sectoral, were consulted. (Štirbanović et al., 2019; Noor-E-Alam et al., 2011; Chowdhury et al., 2010; Qi, 2010; Kung et al., 2011) In this study, the opinions of three experts, one academic and two sectoral, were asked and criterion weights were determined according to this group decision.

In the study, the BWM method was used to select the appropriate equipment for mining Ethereum-based cryptocurrencies. In the application, the decision-makers were asked to determine the best and worst criteria and to create Best to Others and Worst to Others vectors. The criterion weights shows in Table 2 were obtained by taking the arithmetic average of the weights obtained according to the comparisons made by the decision-makers.

Table 2. Criteria weights by experts group decision

Weights	Hashrate (Overclocked)	GPU price	GPU RAM capacity	Power Consumption	Number of power sockets on the GPU	GPU ease of use (whether or not it requires modding)
	0.13590389	0.406168	0.103919	0.223765	0.073579	0.056666

Source: Authors' calculations

The avarage consistency ratio in the models used to calculate weights using BWM was calculated as 0,043 , whis is $\xi < 0.10$ (Rezaei, 2016). It is concluded that the binary comparisons made in this regard are consistent in terms of linear BWM.

As can be seen in Table 2, the most important criterion in choosing a GPU is the price, which is a fixed cost for miners, with a weight of 0.406. In the second place, there is power consumption, which has an important place in the variable costs of the miners. The hashrate, which tends to be considered as the most important criterion by miners, is in the 3rd place with a weight of 0.153. In general, it is noteworthy that cost criteria are more important than other criteria.

Determining The Order Of Decision Alternatives By TOPSIS Method

Using the obtained criterion weights and the TOPSIS method, the GPU models to be used in the choice of Ethereum-based GPU were listed. There are 19 decision-making alternatives in the study. At this stage, the characteristics of the GPUs according to the criteria are listed as in Table 3.

Table 3. GPU Models and Criteria Values

Model	Hashrate	Price ($)	Power (Watts)	Ram	Power Sockets	Requires Mod
RX 470	26	150	120	4	1	1
RX480	29.5	188	135	4	1	1
RX570	27.9	179	120	4	1	1
RX580	30.2	190	135	8	1	1
VEGA56	36.5	325	210	8	2	1
VEGA64	40	350	230	8	2	1
RADEON VII	78	1,025	230	16	2	1
GTX 1050TI	13.9	170	70	4	1	2
GTX 1060	22.5	400	90	6	1	2
GTX 1070	30	520	120	8	2	2
GTX 1070TI	30.5	660	130	8	2	2
GTX 1080	34	608	150	8	2	2
GTX 1080TI	49.5	850	190	11	2	2
GTX 1660	20.5	228	90	6	1	2
1660TI	25.7	280	90	6	1	2
RTX 2060	27.6	350	130	6	1	2
RTX 2070	36.9	350	150	8	2	2
RTX 2080	36.9	750	190	8	2	2
RTX 2080TI	52.5	1,150	220	11	2	2

Source: Authors' calculations

When Table 3 is examined, it is seen that the GPU with the highest hashrate is RADEON VII. This GPU is followed by RTX 2080 Ti. A subjective decision-maker is likely to focus only on the hashrate and choose one of these two GPUs. A decision-maker that only focuses on the price of the GPU is also expected to choose between the RX470 and GTX1050Ti. However, the price criterion alone is also not sufficient in making this decision. Apart from fixed costs, the most important variable cost for miners is electricity. For this reason, the electricity consumption of the GPUs cannot be ignored in GPU selection decision. DAG (Directed Acylic Graph) is used in Ethereum, Ethereum Classic, Expanse, Ubiq, and all other Ethash

IJCEAS
International Journal of Contemporary Economics and Administrative Sciences
ISSN: 1925 – 4423
Volume: XI, Issue: I, Year: 2021, pp. 134-159

coins using proof of work. DAG is produced in every mining period and tends to grow from period to period. When the GPU's RAM size is smaller than the DAG size, mining is not possible with that GPU. For this reason, the RAM size of the GPU is an important criterion in GPU selection. In systems used for mining, the number of power outputs suitable for the GPU is limited in PSU's (Power Supply Units) that meet the power requirement of the system. Depending on the number of GPU socket outputs on the PSU in the system, the number of power sockets on the GPU can become important in GPU selection. While Nvidia brand GPUs do not require any BIOS modding for mining, AMD brand GPUs do require BIOS modding to work efficiently. Not all miners are able to make BIOS modding. Accordingly, the user-friendliness of the GPU varies according to whether it requires BIOS modding or not. User-friendly GPUs are more preferred by miners; therefore, the GPU modding requirement is selected as a criterion. In Table 3, 1 represents "GPU needs BIOS modding to work efficiently"; 2 represents "GPU does not need BIOS modding to work efficiently." The values shown for AMD brand GPUs in the table are the values obtained after BIOS modding is done. The price data in Table 3 are taken from amazon.com and ebay.com. The hashrate values of the GPUs show the average values of Ethereum miners received in 2019 (The Best GPUs for Mining, 2019). Other technical data for the GPUs in Table 3 are taken from the official websites of GPU manufacturers.

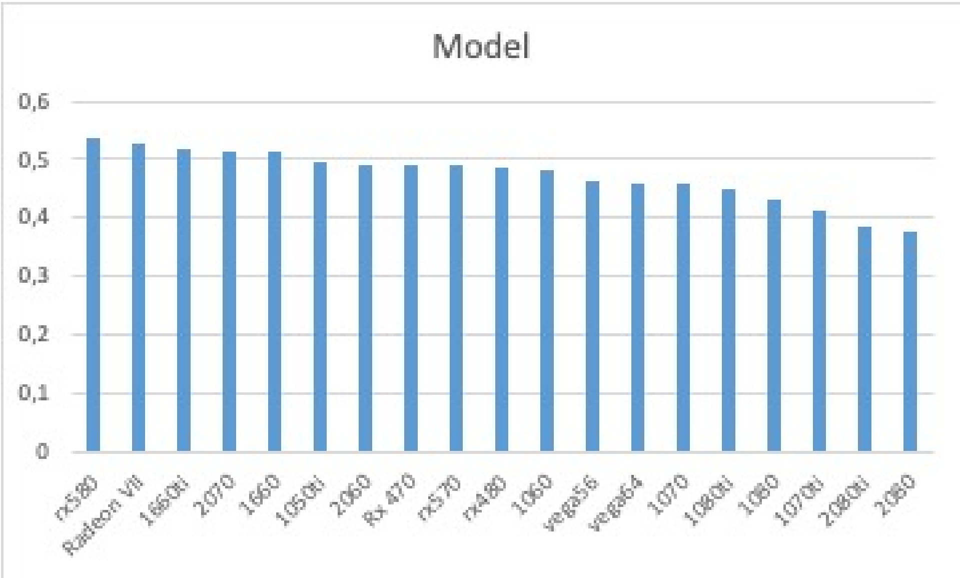
Table 4 GPU Models Rankings

MODEL	S_i^*	S_i^-	$\frac{S_i^-}{S_i^- + S_i^*}$	RANK
RX 470	0,497026	0,478995	0,490763	8
RX480	0,487211	0,461849	0,486638	10
RX570	0,489529	0,470374	0,490023	9
RX580	0,411216	0,476056	0,536539	1
VEGA56	0,454224	0,392801	0,463742	12
VEGA64	0,458532	0,390976	0,460238	13
RADEON VII	0,479503	0,529905	0,524966	2
1050TI	0,527357	0,514182	0,493675	6
1060	0,462424	0,432493	0,483277	11
1070	0,438455	0,371525	0,458684	14
1070TI	0,463231	0,326101	0,413135	17
1080	0,446468	0,336117	0,429496	16
1080TI	0,436633	0,356539	0,44951	14
1660	0,461134	0,486568	0,513419	5
1660TI	0,438579	0,473269	0,519022	3
2060	0,442531	0,429222	0,492367	7
2070	0,399624	0,423194	0,514322	4
2080	0,483504	0,289297	0,374349	19
2080TI	0,540609	0,341439	0,387098	18

Source: Authors' calculations

After TOPSIS method steps were applied, it can be seen that in table 4 the RX580 model is the highest rated GPU and should be chosen by miners. According to the results of the application, the RTX 2080 model GPU received the lowest score.

Graph 5. GPU Model Rankings Using the TOPSIS Method



Source: Authors' calculations

Graph 5 shows the results obtained with the BWM-TOPSIS method. The optimal rankings of graphics card that miners should prefer can be seen above. There is not much difference between the overall scores of the video cards. However, it would be beneficial for Ethereum miners to consider Graph 5 in terms of efficiency.

Conclusion and Recommendations

In this study, operations were made for the selection of GPUs used for mining, which is an important element in the study of Ethereum Blockchain. In order to carry out these operations, the opinions of three experts were sought and six criteria were selected for the selection of GPUs. The weights of these criteria were calculated using BWM using comparative scores from the experts (Hashrate: 0.14; GPU Price: 0.41; GPU RAM Capacity: 0.10; Power Consumption: 0.22; Number of Power Sockets on the GPU: 0. 07; GPU Ease of Use: 0.06). In this case, it is concluded that price is the most important criterion.

GPUs are ranked with the TOPSIS method using the calculated criteria weights and the GPUs' average values. According to the ranking result; the RX 580 is rated as the highest scoring GPU. This is followed respectively by the Radeon

International Journal of Contemporary Economics and Administrative Sciences
ISSN: 1925 – 4423
Volume: XI, Issue: I, Year: 2021, pp. 134-159

VII, GTX 1660Ti, RTX 2070, and GTX 1660 GPUs. The RTX 2080 received the lowest score. Miners are advised to make their GPU selection decisions according to the results of this objective study.

The weights of the criteria obtained as a result of the application may differ from country to country. For example, in a country where electricity charges are very low, power consumption may be less important. In this respect, miners will be able to choose a GPU using this combined method, taking into account the values in their own countries. New graphics cards are being released day by day. In order to keep the results of this study up-to-date, studies including new video card models can be made using the proposed BWM-TOPSIS method. There are many MCDMs in the literature. Studies with the same purpose can be carried out using these methods. A comparison of the results obtained from these methods can be the topic of further study.

REFERENCES

Abeyratne, S. A. and Monfared, R. P. (2016). Blockchain ready manufacturing supply chain using distributed ledger. International Journal of Research in Engineering and Technology, 5(9), pp. 1-10.

Abeyratne, S. A. and Monfared, R. P. (2016). Blockchain ready manufacturing supply chain using distributed ledger. International Journal of Research in Engineering and Technology, 5(9), pp. 1-10.

Altman, E., Reiffers, A., Menasche, D. S., Datar, M., Dhamal, S. and Touati, C. (2019). Mining competition in a multi-cryptocurrency ecosystem at the network edge: A congestion game approach. ACM SIGMETRICS Performance Evaluation Review, 46(3), pp. 114-117.

Anderson, R. (1996, October). The eternity service. In Proceedings of PRAGOCRYPT (Vol. 96, pp. 242-252).

Aras, S. T. and Kulkarni, V. (2017). Blockchain and its applications–a detailed survey. International Journal of Computer Applications, 180(3), pp. 29-35.

Aste, T., Tasca, P. and Di Matteo, T. (2017). Blockchain technologies: The foreseeable impact on society and industry. computer, 50(9), pp. 18-28.

Avunduk, H. and Hakan, A. Ş. A. N. (2018). Blok zinciri (blockchain) teknolojisi ve işletme uygulamaları: Genel bir değerlendirme. Dokuz Eylül Üniversitesi İktisadi İdari Bilimler Fakültesi Dergisi, 33(1), pp. 369-384.

Beck, R. (2018). Beyond bitcoin: The rise of blockchain world. Computer, 51(2), pp. 54-58.

Bentov, I., Lee, C., Mizrahi, A. and Rosenfeld, M. (2014). Proof of activity: Extending bitcoin's proof of work via proof of stake [extended abstract] y. ACM SIGMETRICS Performance Evaluation Review, 42(3), pp. 34-37.

Berg, C. (2017). What diplomacy in the ancient near east can tell us about blockchain technology. Berg, C, 55-64.

Bergstra, J. A. and Burgess, M. (2008). A static theory of promises. arXiv preprint arXiv:0810.3294.

C. Graydon. (2014). What is an Altcoin?, https://www.ccn.com/altcoin, (accessed 18 January 2019)

Çarkacıoğlu, A. (2016). Kripto-Para Bitcoin. Sermaye piyasası kurulu araştırma dairesi araştırma raporu.

Chang, P. Y., Hwang, M. S. and Yang, C. C. (2017, August). A blockchain-based traceable certification system. In International Conference on Security with Intelligent Computing and Big-data Services (pp. 363-369). Springer, Cham.

Chaum, D. (1983). Blind signatures for untraceable payments. In Advances in cryptology (pp. 199-203). Springer, Boston, MA.

Chen, M. F. and Tzeng, G. H. (2004). Combining grey relation and TOPSIS concepts for selecting an expatriate host country. Mathematical and computer modelling, 40(13), pp. 1473-1490.

Chen, S. J. and Hwang, C. L. (1992). Fuzzy multiple attribute decision making methods. Fuzzy multiple attribute decision making, pp. 289-486.

Chen, T. Y. and Tsao, C. Y. (2008). The interval-valued fuzzy TOPSIS method and experimental analysis. Fuzzy sets and systems, 159(11), pp. 1410-1428.

Chowdhury, A., Jha, M. K. and Chowdary, V. M. (2010). Delineation of groundwater recharge zones and identification of artificial recharge sites in West Medinipur district, West Bengal, using RS, GIS and MCDM techniques. Environmental Earth Sciences, 59(6), pp. 1209-1222.

CoinMarketCap, General Graphics. https://coinmarketcap.com/charts/ (accessed 12 December 2019)

CoinMarketCap, Top 100 Cryptocurrencies by Market Value. https://coinmarketcap.com (accessed 12 December 2019)

Crosby, M., Pattanayak, P., Verma, S. and Kalyanaraman, V. (2016). Blockchain technology: Beyond bitcoin. Applied Innovation, 2(6-10), pp. 71.

Dinu, A. (2014). The Scarcity of Money: The Case of Cryptocurrencies. Unpublished Master’s Thesis.

Dniprov, O., Chyzhmar, Y., Fomenko, A., Shablystyi, V. and Sydorov, O. (2019). Legal status of cryptocurrency as electronic money. Journal of Legal, Ethical and Regulatory Issues, pp. 22, 1-6.

Dong, H. and Dong, W. (2015). Bitcoin: Exchange rate parity, risk premium, and arbitrage stickiness.

Easley, D., O'Hara, M. and Basu, S. (2019). From mining to markets: The evolution of bitcoin transaction fees. Journal of Financial Economics, 134(1), pp. 91-109

Estrada, J. C. S. (2017). Analyzing bitcoin price volatility. University of California, Berkeley.

European Banking Authority, (4. July 2014), "EBA Opinion on virtual currencies(PDF)", Frankfurt am Main: European Central Bank, pp. 1-46.

European Central Bank, (Feburary 2015), “Virtual Currency Schemes – a further analysis (PDF)”, Frankfurt am Main: European Central Bank, pp. 1-37

European Central Bank, (October 2012), "1.Virtual Currency Schemes (PDF).", Frankfurt am Main:European Central Bank, Frankfurt am Main: European Central Bank, pp. 1-55.

Fanning, K. and Centers, D. P. (2016). Blockchain and its coming impact on financial services. Journal of Corporate Accounting & Finance, 27(5), pp. 53-57.
Fanning, K. and Centers, D. P. (2016). Blockchain and its coming impact on financial services. Journal of Corporate Accounting & Finance, 27(5), pp. 53-57.
Gandal, N. and Halaburda, H. (2014). Competition in the cryptocurrency market.

Garay, J., Kiayias, A. and Leonardos, N. (2015, April). The bitcoin backbone protocol: Analysis and applications. In Annual international conference on the theory and applications of cryptographic techniques (pp. 281-310). Springer, Berlin, Heidelberg.

Göbel, J., Keeler, H. P., Krzesinski, A. E. and Taylor, P. G. (2016). Bitcoin blockchain dynamics: The selfish-mine strategy in the presence of propagation delay. Performance Evaluation, pp. 104, 23-41.

Griffith, K. (2014). A quick history of cryptocurrencies BBTC-Before Bitcoin. Bitcoin Magazine, pp. 16.

Griffith, K. (2014). Digital vs. Virtual Currencies. Bitcoin Magazine, pp. 22.

Guo, Y. and Liang, C. (2016). Blockchain application and outlook in the banking industry. Financial Innovation, 2(1), pp. 1-12.

Haber, S. and Stornetta, W. S. (1990, August). How to time-stamp a digital document. In Conference on the Theory and Application of Cryptography (pp. 437-455). Springer, Berlin, Heidelberg.

Hileman, G. and Rauchs, M. (2017). 2017 global blockchain benchmarking study. Available at SSRN 3040224.

Iansiti, M. and Lakhani, K. R. (2017). Harvard Business Review, 95(1), 118-127.

Kiayias, A., Koutsoupias, E., Kyropoulou, M. and Tselekounis, Y. (2016, July). Blockchain mining games. In Proceedings of the 2016 ACM Conference on Economics and Computation (pp. 365-382).

Kiayias, A., Russell, A., David, B. and Oliynykov, R. (2017, August). Ouroboros: A provably secure proof-of-stake blockchain protocol. In Annual International Cryptology Conference (pp. 357-388). Springer, Cham.

Kung, J. Y., Chuang, T. N. and Ky, C. M. (2011, June). A fuzzy MCDM method to select the best company based on financial report analysis. In 2011 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE 2011) (pp. 2013-2017). IEEE.

Lei, A., Cruickshank, H., Cao, Y., Asuquo, P., Ogah, C. P. A. and Sun, Z. (2017). Blockchain-based dynamic key management for heterogeneous intelligent transportation systems. IEEE Internet of Things Journal, 4(6), pp. 1832-1843.

Lin, I. C. and Liao, T. C. (2017). A survey of blockchain security issues and challenges. IJ Network Security, 19(5), pp. 653-659.

Liu, X., Wang, W., Niyato, D., Zhao, N. and Wang, P. (2018). Evolutionary game for mining pool selection in blockchain networks. IEEE Wireless Communications Letters, 7(5), pp. 760-763.

Lu, Y. (2019). The blockchain: State-of-the-art and research challenges. Journal of Industrial Information Integration, 15, 80-90.

Mattila, J. (2016). The blockchain phenomenon. Berkeley Roundtable of the International Economy, 16.

Möser, M., Eyal, I. and Sirer, E. G. (2016, February). Bitcoin covenants. In International conference on financial cryptography and data security (pp. 126-141). Springer, Berlin, Heidelberg.

Nakamoto, S. (2019). Bitcoin: A peer-to-peer electronic cash system. Manubot.

Neyer, G. and Geva, B. (2017). Blockchain and payment systems: What are the benefits and costs?. Journal of Payments Strategy & Systems, 11(3), pp. 215-225.

Nguyen, Q. K. (2016, November). Blockchain-a financial technology for future sustainable development. In 2016 3rd International conference on green technology and sustainable development (GTSD) (pp. 51-54). IEEE.

Nojoumian, M., Golchubian, A., Njilla, L., Kwiat, K. and Kamhoua, C. (2018, July). Incentivizing blockchain miners to avoid dishonest mining strategies by a reputation-based paradigm. In Science and Information Conference (pp. 1118-1134). Springer, Cham.

Noor-E-Alam, M., Lipi, T. F., Hasin, M. A. A. and Ullah, A. S. (2011). Algorithms for fuzzy multi expert multi criteria decision making (ME-MCDM). Knowledge-Based Systems, 24(3), pp. 367-377.

Pilkington, M. (2016). Blockchain technology: principles and applications. In Research handbook on digital transformations. Edward Elgar Publishing.

Qi, J. (2010, August). Machine tool selection model based on fuzzy MCDM approach. In 2010 International Conference on Intelligent Control and Information Processing (pp. 282-285). IEEE.

Qin, R., Yuan, Y. and Wang, F. Y. (2018). Research on the selection strategies of blockchain mining pools. IEEE Transactions on Computational Social Systems, 5(3), pp. 748-757.

Qin, R., Yuan, Y., Wang, S. and Wang, F. Y. (2018, June). Economic issues in bitcoin mining and blockchain research. In 2018 IEEE Intelligent Vehicles Symposium (IV) (pp. 268-273). IEEE.

Rezaei, J. (2015). Best-worst multi-criteria decision-making method. Omega, 53, pp. 49-57.

Rezaei, J. (2016). Best-worst multi-criteria decision-making method: Some properties and a linear model. Omega, 64, pp. 126-130.

Rifi, N., Agoulmine, N., Chendeb Taher, N. and Rachkidi, E. (2018). Blockchain technology: is it a good candidate for securing iot sensitive medical data?. Wireless Communications and Mobile Computing, 2018.

Rosenfeld, M. (2011). Analysis of bitcoin pooled mining reward systems. arXiv preprint arXiv:1112.4980.

Rotman, S. (2014). Bitcoin versus electronic money.

Sayeed, S. and Marco-Gisbert, H. (2019). Assessing blockchain consensus and security mechanisms against the 51% attack. Applied Sciences, 9(9), 1788.

Schneier, B. and Kelsey, J. (1998, January). Cryptographic support for secure logs on untrusted machines. In USENIX Security Symposium (Vol. 98, pp. 53-62).

Schweizer, A., Schlatt, V., Urbach, N. and Fridgen, G. (2017, December). Unchaining Social Businesses-Blockchain as the Basic Technology of a Crowdlending Platform. In ICIS.

Shih, H. S., Shyur, H. J. and Lee, E. S. (2007). An extension of TOPSIS for group decision making. Mathematical and computer modelling, 45(7-8), pp. 801-813.

Stein, T. (2017). Supply chain with blockchain—showcase RFID. Accessed on, 8(10), pp. 2018.

Štirbanović, Z., Stanujkić, D., Miljanović, I. and Milanović, D. (2019). Application of MCDM methods for flotation machine selection. Minerals Engineering, 137, pp. 140-146.

The Best GPUs for Mining. https://2miners.com/blog/the-best-gpus-for-mining-in-2019/ (accessed 15 December 2019)

Tromp, J. (2015, January). Cuckoo cycle: a memory bound graph-theoretic proof-of-work. In International Conference on Financial Cryptography and Data Security (pp. 49-62). Springer, Berlin, Heidelberg.

Tu, K. V. and Meredith, M. W. (2015). Rethinking virtual currency regulation in the Bitcoin age. Wash. L. Rev., 90, pp. 271.

Vafaeipour, M., Zolfani, S. H., Varzandeh, M. H. M., Derakhti, A. and Eshkalag, M. K. (2014). Assessment of regions priority for implementation of solar projects in Iran: New application of a hybrid multi-criteria decision making approach. Energy Conversion and Management, 86, pp. 653-663.

Viriyasitavat, W. and Hoonsopon, D. (2019). Blockchain characteristics and consensus in modern business processes. Journal of Industrial Information Integration, 13, pp. 32-39.

Watanabe, H., Fujimura, S., Nakadaira, A., Miyazaki, Y., Akutsu, A. and Kishigami, J. (2016, January). Blockchain contract: Securing a blockchain applied to smart contracts. In 2016 IEEE international conference on consumer electronics (ICCE) (pp. 467-468). IEEE.

Weldon, M. N. and Epstein, R. (2018). Beyond Bitcoin: leveraging blockchain to benefit business and society. Transactions: Tenn. J. Bus. L., 20, pp. 837.

Zheng, Z., Xie, S., Dai, H., Chen, X. and Wang, H. (2017, June). An overview of blockchain technology: Architecture, consensus, and future trends. In 2017 IEEE international congress on big data (BigData congress) (pp. 557-564). IEEE.

Zhu, Y., Dickinson, D. and Li, J. (2017). Analysis on the influence factors of Bitcoin's price based on VEC model. Financial Innovation, 3(1), pp. 1-13.