AGENT-BASED MODEL OF SAND SUPPLY GOVERNANCE EMPLOYING BLOCKCHAIN TECHNOLOGY

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ABSTRACT

Sand is a key ingredient for many industries, including concrete, glass, and electronics. Sand extraction is now exceeding fossil fuels and biomass. The absence of data on aggregates sand mining makes assessments difficult and has contributed to the lack of awareness about this issue. A sand governance business framework is developed applying the blockchain technology as the main goal of this study to regulate the sand extraction and trade. Blockchain technology provides a distributed concurrency monitoring system for the supply management. Agent-Based Modeling and Simulation (ABMS) as an effective bottom-up tool is applied to demonstrate the application of the model. The sand providers and users are modeled as a collection of autonomous decision-making entities called agents. The agents interact with each other, the regulators participate in making decisions on the basis of a set of rules that are defined within the blockchain network.

Keywords: Sand Governance, Blockchain Technology, Agent Based Modeling, Supply Management

1 INTRODUCTION

There is a growing demand for sand and gravel, particularly in the developing countries where rapid economic development influenced growth in the construction industry (de Leeuw et al., 2010). With the increase in construction activities, the demand for river sand has increased exponentially, causing the depletion and exploitation of natural sand resources thus resulting in adverse effects on the environment, such as sliding of river shores and lowering water table (Agrawal, Wanjari, & Naresh, 2017). 1.6 billion tons of cement production annually accounts for consuming 10 to 11 billion tons of sand, gravel and crushed rock per year (Mehta, 2001). As a result of the globalization of sand mining, some countries are concerned about the environmental impacts such as China, Ghana, and India. Consequently, sand mining should be considered as an aspect of global environmental change (de Leeuw et al., 2010).

Sand and gravel are now the most-extracted materials in the world, even exceeding fossil fuels and biomass in terms of weight (Torres, Brandt, Lear, & Liu, 2017). Sand is a key ingredient for concrete, roads, glass, and electronics. Massive amounts of sand are mined for land reclamation projects, shale gas extraction, and beach re-nourishment programs (Torres et al., 2017). There is a growing demand for sand and gravel in the rapid economic development (de Leeuw et al., 2010). While scientists are making a great effort to quantify how infrastructure systems such as roads and buildings affect the habitats that surround them, the impacts of extracting construction minerals such as sand to build those structures have been overlooked. Most studies focused on extraction and impacts on specific sites, not in a wider context. As a major ingredient for a variety of products and an integrated part of the supply chain of numerous industries, sand has been decomposed into many sectors based on the intended applications (Mansour, 2015). The apparent consumption of industrial sand and gravel of the United States, the world's leading producer and consumer of industrial sand and gravel, was 89.4 million tons in 2016 (Ober, 2017). It is difficult to collect definitive data on silica sand and gravel production in most nations because of the wide range of terminology and specifications found among different countries. The United States remained a major exporter of silica sand and gravel, shipping it to almost every region of the world (Ober, 2017). It is expected to experience an increased demand for products that sand forms a major input, as a major component in the supply chain for a variety of industries (Mansour, 2015). The supply chain is a complex adaptive system and features a dynamics, uncertainty and partial information sharing (Long & Zhang, 2014). To overcome the shortcomings of the analytical methods, simulation has been widely used in supply chain evaluation as a decision-making tool (Long & Zhang, 2014). Since supply chains are inclined to be decentralized system, blockchain technology appears to be practical to support the supply chain system.

Sand governance is a very wide concept; the focus of this study is only sand supply management. This study aims to provide a framework, applying the blockchain technology to improve the sand supply and reduce the illegal mining, therefore having less impact on the environment. The rest of the paper is organized as follows. Section 2 presents a series of related studies of the applied tools. Section 3 proposes the methodology. Section 4 provides the results of the proposed framework modeling, and simulations. Section 5 contains the discussion and the limitation of the proposed model. The paper is concludes in section 6.

2 LITRATURE REVIEW

There is a growing demand for sand and gravel in the rapid economic development (de Leeuw et al., 2010). Based on the study by Thornton et al. (2006) sand mining was one of the main causes of erosion rates in bays' shoreline. Jonah, Agbo, Agbeti, Adjei-Boateng, and Shimba (2015) assessed the ecological impacts of beach sand mining on three beaches of Ghana over a four-month period. Lai et al. (2014) demonstrated extensive sand mining, which resulted in the wider and deeper outflow channel of a lake in China, caused the decline in the lake levels. Mascarenhas and Jayakumar (2008) describe with evidence that dunes play a defensive role in the wake of tsunami along the coast, and can rescue habitations and humankind. The lakes sand mining increase the risk of flooding and decreasing the flood storage capacity (de Leeuw et al., 2010). Based on the literature, the main concerns of sand mining that required more consideration are as follow:

- The lack of adequate information regarding the negative effects and costs of sand mining with weak governance and uncontrolled corruption are facilitating illegal sand mining
- The absence of global monitoring of the extraction contributes to the gap in knowledge, which turns into a lack of action.

- The impacts of sand mining on ecosystem, wildlife, marine, landscape, infrastructure are critical in many areas

The proposed framework aims to cover the main concerns of the current sand governance system with applying ABM and blockchain technology.

2.1 Agent Based Modeling (ABM)

An agent is a computer system situated in a certain kind of environment and is capable of autonomous action to meet its designed objectives. Moreover, a multi-agent system is a loosely coupled network of software agents that interact to solve problems that are beyond the individual capacities or knowledge of each problem solver (Kavak, Padilla, Lynch, & Diallo, 2018). Agent Based approach is general and powerful because it enables to capture complex structures and dynamics. The other important advantage is that it provides for construction of models in the absence of the knowledge about the global interdependencies (Lynch, Kavak, Gore, & Vernon-Bido). The dynamics of the system arises from the interaction of agents whereby the behavior of the agent is determined by its cognitive structure (Schieritz & Grobler, 2003). The ABM techniques can simulate the effect of the mining on the land change. ABM facilitates the incorporation of subsets of different ancillary data and discrete variables. In addition, the ubiquity of the agents' results in a larger vision of what the agents represent and offer better assessment based on empirical findings.

NetLogo is used as the ABM tool for this study. NetLogo is a multi-agent programmable modeling software program (Wilensky, 1999) that can be used to study the interaction between multiple heterogeneous agents and the phenomena that emerge as a result of their interaction over time (Lu, Cheung, Li, & Hsu, 2016). NetLogo has been applied in several studies in supply chain management for modeling and simulation. Ponte, Sierra, de la Fuente, and Lozano (2017) carried out an experiment via NetLogo to simulate the interaction between inventory models depending on the demand. Long and Zhang (2014) used NetLogo to model and simulate an integrated framework of supply chains.

This study proposes a new framework to monitor the sand resource supply by using the blockchain technology. The system is modeled employing Netlogo and the results of the simulations facilitate the decision-making on the mining operation and monitor the supply chain management.

2.2 Blockchain Technology

The basic idea of blockchain technology is allowing the actors in a system which are called nodes, to transact digital assets using a peer-to-peer network that stores these transactions in a distributed way across the network (Ølnes, Ubacht, & Janssen, 2017). The blockchain is a mere data structure with distributed multiversion concurrency control (Mattila, 2016). The distributed system scheme is depicted in Figure 1. Blockchain technology enables the development of a new sand governance system with participatory decision-making and decentralized relevant organizations that can operate over a network of computers without any human intervention (Wright & De Filippi, 2015). Smart contracts can be applied to set up autonomous digital entities to manage the sand resource and help societies to become more sustainable (Chapron, 2017). Certain basic technologies that are required for any governance system are first a way of both recordings a set of rules, second a way for people to interact with the rules, and third a way to enforce the rules. The blockchain is ideal for recording information that can be later verified as authoritative, and offers a novel way of accomplishing the three basic functions of governance. Blockchain would enable end users to verify exactly how, where and by whom the product they intend to purchase has been assembled and made, thereby denying a market for illegal and counterfeit products (Apte & Petrovsky, 2016). Recently, several studies have focused on the applicability of blockchain in different aspects of the supply chain management. Tian (2016) studies the utilization and development of blockchain technology in agri-food supply chain. The integration of supply chain through the blockchain technology to achieve disruptive transformation in digital supply chain management and networks is explained in the research by Korpela, Hallikas, and Dahlberg (2017). Kshetri (2018) examines how blockchain is likely to affect key supply chains management objectives such as cost, quality, speed, dependability, risk reduction, sustainability, and flexibility by presenting early evidence linking the use of blockchain in supply chain activities to increase transparency and accountability. However, the application of blockchain technology on enhancing the decision-making process for the supply-demand planning is not considered, hence this study applied blockchain technology for this concern. If there is a critical situation of sand mining in an area, for instance, the information could be transmitted to the environment agency, so the process can be stopped for a specific duration. Experts of different fields can be used to bridge the gap between limited capacity and the aspiration for the governance. The new artificial intelligence technologies are promoted as a tool improving the evidence base and equity of governance in developing countries. Applying blockchain technology provides new opportunities for enhanced transparency and increased engagement in the environmental management.

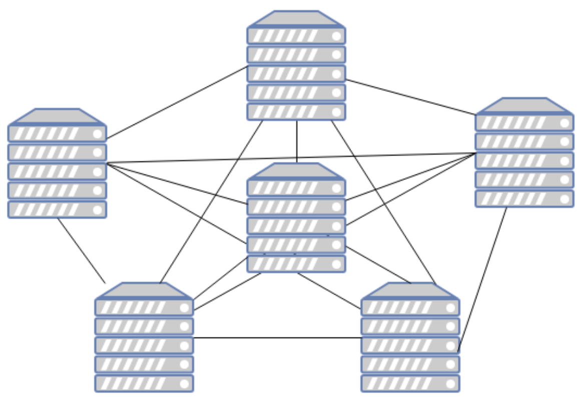

Figure 1: Blockchain Distributed System

The impacts of extracting construction minerals such as sand to build those structures have been overlooked in most studies on the field. In addition, the focus of the studies is on extraction and impacts on specific sites, not in a wider context. Therefore, a comprehensive monitoring system is necessary to manage the supply planning, mining operation, and the trade of the valuable resource of sand. In the proposed agent-based system, the heterogeneous agents work independently or in a cooperative and interactive manner to make decisions and communicate in a decentralized environment through the blockchain network. The supply demand can be simulated to provide an estimation of the results of the real situation which can help the decision makers. The blockchain technology is used to track the trade through the complex supply chain from mining operation of the sand resource to consumers. Since the transactions would be through the blockchain platform, the cost per transaction decreases and the security is enhanced.

3 METHODOLOGY

The methodology contains the first phase of analyzing all the information within a blockchain network. All relative parties can provide their analysis and suggestions for decision-making of the sand mining operation for the area under their supervision. The transactions of sand trades are applied through the blockchain platform, hence, would be verified by all the parties and the risk of smuggling and illegal sand mining as the critical problem mentioned can be decreased. The second phase is providing a blockchain governance framework for regulators to take the necessary actions based on the information provided in the previous phase. The proposed framework is illustrated in Figure 2.

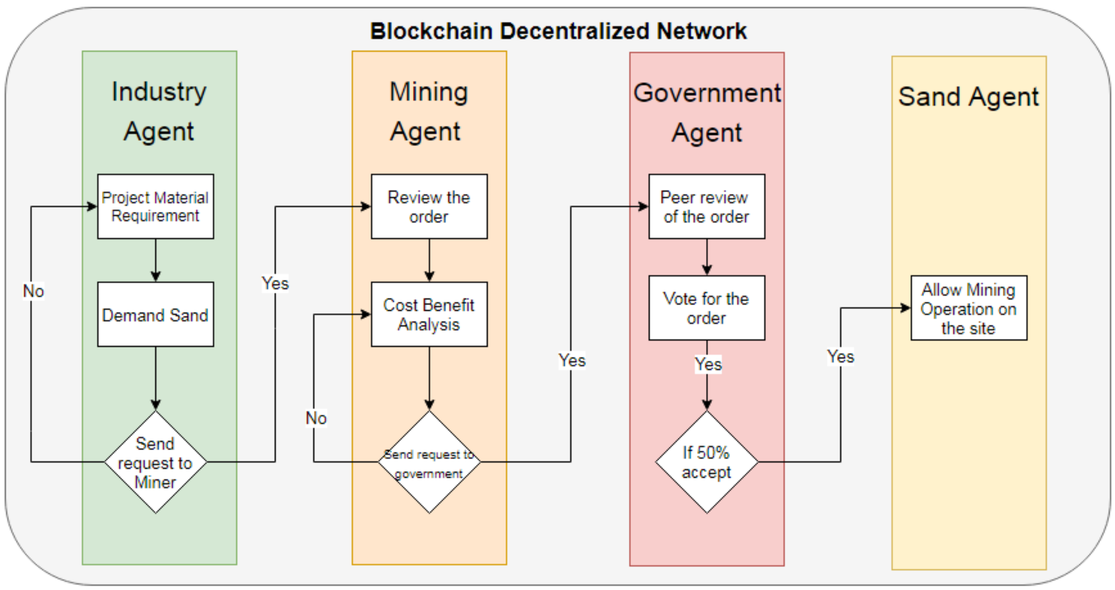

Figure 2: Sand Governance Blockchain Framework

The agents determined for this study are the sand resources as the supply agent, the government is the other agent which has the authority to prohibit the sand mining operation in the area. However, the government decisions can be subject to unforeseen factors. Thus, in the proposed framework the agent is modified by adding related experts of the field including the environmental expert who can study and analyze the risks of mining on the sand resource, monitor the impacts of mining on the land. The government agent is a network linked to each other to make the decision. The mining operation would be contingent on the government network decision. The industry agent is defined as the industry or business demand the sand supply. The miner agent tries to make interaction with the sand resource to get the permission for mining the resource, should provide a logical statement of the mining for the network approval. Therefore, the application will only be approved based on environmental circumstances, economic rationale, and the internal policies while all the involved parties within the government decision council accept the trade.

The properties that can help the decision makers to analyze the circumstances are described in equations (1) and (2). Where (d) is the demand parameter requested by the industry agent, (t) is the duration require by the mining agency to the operation, (a) is the safe availability volume of sand in the resource to be mined on that certain time, and (r) is the condition based on the reason provided by the miner and would

$$\text{Permission} = \left(\left(a - (d * t)\right) * r\right) \tag{1}$$

be 1 only if is for industrial purpose and zero for other purposes. The permission parameter is a function of the equation (1):

Equation (2) is the decision of the government. If the equation (1) is a positive number then the decision would be approving the mining request.

$$\mathrm{Y} = \begin{cases} 0 & \text{otherwise} \\ 1 & \text{if Permission} > 0 \end{cases} \tag{2}$$

In addition, in this framework, a fine is allocated for the illegal mining operations. The fine deposit would be defined by the local council and the price of the volume mined would be added to that for the miner and can be seen in Table 2. The main properties of the two systems operation are compared in Table 1.

Table 1: Two systems comparison Parameters

System	Mining Rate	Profit	Fine	Monitoring
Current Supply	Based on demand	Miner profit = (Market price – mining cost)	0	Local Regulators
Block Chain supply network	Based on the resource circumstances	Miner profit = Market price – [(mining cost + sand mining price) + fine]	$\left(\delta * \left(\frac{\text{price}}{\text{unit}} * demand\right)\right) + \text{fine deposit}$	Decision council
* δ is defined by the local decision council				

The agents represent real world parties that cooperate to reach the desired objectives. Each agent attempts to maximize its utility while cooperating with other agents to achieve their goals. In this framework, the domain agents include both monitoring agents and the demand agents. One of the main properties of the agents defined in this study is that they are essentially decentralized since they are communicating in the blockchain platform. Every link between demand agents and monitoring agent can be interpreted as a potential supplier-customer relationship. The relationship will be active during the simulation run if there is a trade agreement. Some of the agents' characteristics are predetermined, for instance, agents have given order policies. Other characteristics evolve over the course of the simulation, for example, the volume that is exchanged between two particular agents (Schieritz & Grobler, 2003).

The environment defined for this model is a decentralized network which all agents communicate and cooperate through the blockchain platform. All demanding agents advertise their abilities, knowledge in the acquaintance database. The monitoring agents do the transaction by sending messages to the decentralized network. The monitoring agents are autonomous in making decisions by considering all the rules defined for the system through coordination of the decision team within the network.

Through applying blockchain technology, instead of having a central authority that maintains the database and guards its authenticity, a copy of the entire database is distributed to every involved participant to maintain independently. The copyholders follow the predetermined rules and compare their versions together through a continuous process of voting. The most voted version of the network is accepted.

4 RESULTS

For this study three different scenarios were defined and simulated for both the current and the proposed systems, the details are shown in Table 3. In the current system, the sand is mined by the miners for the contracts with the industries and businesses demanding the sand supply. In the proposed system, the sand is monitored by the government and each demand request needs the decision council approval for the operation. The illegal mining operation would be more costly for the miners.

Table 2: Simulation Parameters Values

Parameter	Value
Market Sand Price / unit	$\$ 10\ x$
Sand Price/ unit for mining	$\$ 5\ x$
Fine deposit	$A = 200x$
δ for the area	$B = 0.5\ x$
Mining Rate / hour	$10\ unit/day$
Safe capacity for mining	$C = 300\ x$
Sand Mining Cost /unit	$\$\ x$

The attributes in this framework are quantitative and arbitrary numbers are used for the values since there is no real data for this system. The proportions for the values are grounded on the current market condition. Based on the defined equations in the methodology and values of Table 2, the results of the comparisons on the simulated cases are shown in Table 3.

As the results are shown in Table 3, the cost of illegal mining for the miners is even higher that the profit compared to the current system. This monitoring system can reduce the illegal mining as well as providing benefits for the resource in order to implement sustainability programs. The graphs shown in Figure 3 and 4 illustrate the impact of uncontrolled mining operation on the resource.

Table 3: Simulation Results

Case	Demand	System	Permission	Profit	Fine	Monitoring
Case One: Mining for the cement company demand	100 Unit	Current	NA	$\$ 900\ x$	0	No monitoring
		Block Chain supply network	YES	$\$ 400\ x$	0	Decision council approved the case
Case Two: Mining for Exporting to	200 Unit	Current	NA	$\$ 1800\ x$	0	No monitoring
		Block Chain supply	NO	$\$ -400\ x$	$\$ 1200\ x$	Decision council rejected the request

Island A		network				due to the reason
Case Three: Mining for the glass company demand	50 Unit	Current	NA	$ 400 x	0	No monitoring
		Block Chain supply network	NO	$ − 250 x	$ 450 x	Decision council rejected the request due to the concerns about the sand availability and the environmental impacts

5 DISCUSSION

The comparisons of the properties of both situations simulated illustrate the great benefits of having the blockchain technology for governing the sand resources which can have less impact on the environment. Moreover, the sustainability of the sand supply chain can be improved. In the current supply system, there is no monitoring system on the sand mining operation as well as the environmental impact on the surrounded area. The proposed framework contains a government agent that reviews and monitors the operation over the resource and prohibit the mining operation in risky conditions.

There are some limitations for implementing this methodology as well. Since the blockchain technology has been recently considered to be applied in different fields, the negative aspects are not studied very much. However, for the implementation of such projects, blockchain experts are required to first develop the system. On the other hand, regulations are required to be in place at the first stage and cooperation of the local government is necessary for developing the system.

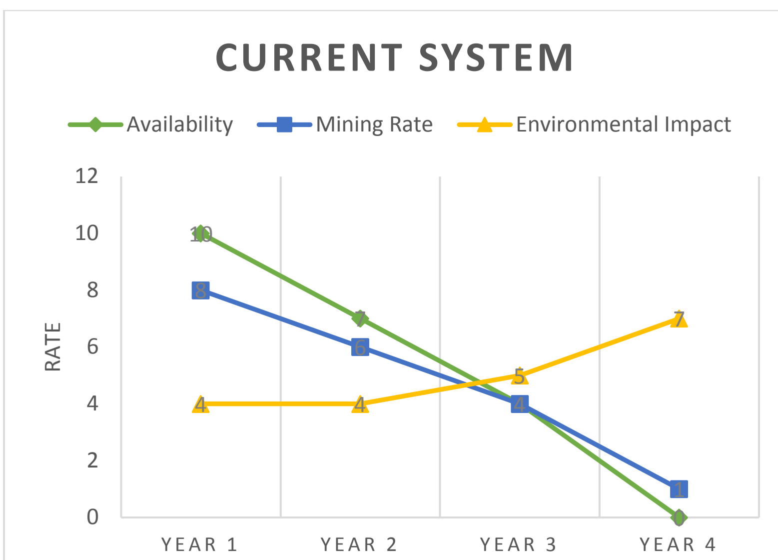

Figure 3: Current System Rates in Time

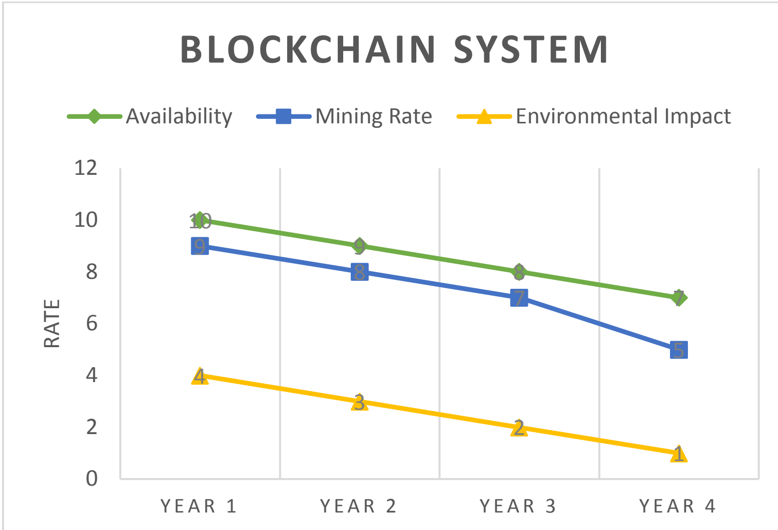

Figure 4: Blockchain System Rates in Time

6 CONCLUSION

It is time to treat sand like a key resource, on a par with clean air, biodiversity, and other natural endowments that nations seek to manage for the future. Therefore, there is a need to develop a framework for sand governance, along with global and regional sand budgets. This methodology can eliminate the illegal sand mining by monitoring the sand trades through the blockchain technology. Moreover, the impacts on the environment can be reduced by taking immediate actions for the critical regions which the applied methodology identifies. In addition, it can arm regulators with policy-making of natural resources treatments. Applying the decentralized blockchain system and using influential parties through the ABMS generates major effects from a discrete decision to the cooperative outcome.

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