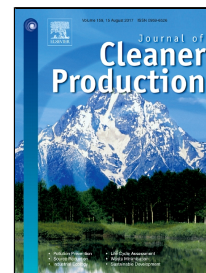


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**An Implementation Path for Green Information Technology Systems in the Ghanaian  
Mining Industry**

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## **An Implementation Path for Green Information Technology Systems in the Ghanaian Mining industry**

### **ABSTRACT**

The mining and extractive industry's operations have significant harmful environmental consequences. Mining companies have started adopting green supply chain management (GSCM) practices which include green information technology systems (GITS) to help provide economic benefits while seeking minimal environmental damage. These mining organizations face significant hurdles related to introducing and implementing various GSCM practices which can address some of the environmental burdens. This study addresses this issue by adopting a GSCM practices framework and applying a novel decision support method that integrates grey numbers with DEMATEL and the NK model for evaluating and developing an implementation path model. Using a multiple case field study with input from managers of the Ghanaian gold mining industry, the adopted GSCM practices framework and methodology is applied. The results provide an evaluation and development path model to guide these organizations and managers for GSCM planning and investment decisions. The path results show that these organizations should first develop SSP (Strategic Supplier Partnership) with their suppliers for implementing GITS (Green Information Technology and Systems) and other GSCM practices. These results provide some exploratory insight and guidelines for managers and policy-makers who seek to integrate green initiatives. This study also sets the

stage for further investigation of organizational greening in developing countries and the mining industry.

**Keywords:** *Green Information Technology Systems; Green Organizational Practices; Grey Theory; DEMATEL; NK Model; Mining Industry; Ghana*

## 1. INTRODUCTION

Mining operations have been important economic activities in both developed and developing nations for centuries (Hilson, 2000, 2012). However, the extraction and consumption of nature's resources have contributed to serious environmental consequences and underlying economic implications (Jia et al., 2015; Kusi-Sarpong et al., 2015). Improving natural resources mining operations and corporate environmental sustainability performance in the mining industry is increasingly becoming an important organizational strategy (Kusi-Sarpong et al., 2016a; Eccles et al., 2014; Ihlen & Roper, 2014; Ryoo & Koo, 2013; Molla, 2013)

However, implementing these mining operations, in the mining industry, require and rely heavily on information technology and systems (ITS) (Ageron et al., 2012; Ryoo & Koo, 2013; Corbett, 2013). Not only is ITS's usage important for communicating, controlling and managing sustainability issues within organizational operations and the supply chain, but is also an important focus of environmental footprints and for environmentally sustainable practices (Uddin & Rahman, 2012; Sarkis et al., 2013). Green ITS has the capacity not only to help minimize energy

consumption of organizations and mines (Kusi-Sarpong et al., 2016b; Chilamkurti et al., 2009), but also support in mitigating the overall environmental impact significantly (Ryoo & Koo, 2013; Bhadauria et al., 2014).

GSCM investment and implementation decisions should not only focus on selecting appropriate GSCM practices but also require the understanding of the interactions among the GSCM practices. Part of this understanding of interactions includes identifying a sequential implementation order to achieve the best environmental performance. The existing literature argues that order of implementation or the joint implementation of practices will have an impact on final performance results (Govindan et al., 2015; Cua et al., 2001). For example, Zhu et al. (2013) posited that internal green supply chain practices should be implemented sequentially before external green supply chain practices.

Green information technology systems (GITS) are an important GSCM practice. There is a big challenge for organizations and supply chains when introducing GITS, when compared to other GSCM practices, since these practices are relatively recent compared to practices such as green product design. In addition there are a number of GITS sub-practices that need to be implemented, and determining the sequence of implementation of these GITS sub-practices is also important.

The interrelationships amongst the GSCM practices and within the five GITS practices are investigated so as to address the GSCM and GITS implementation sequence problem. This investigation of the interrelationships and the construction of an implementation path is a major objective of this study. The general objective is

more specifically focused on the Ghanaian gold mining industry. The implementation path framework can guide organizations or supply chains on how to better introduce GSCM practices, but especially the implementation steps for GITS practices. Another objective and contribution of this study is to introduce a multistage methodology to help develop these paths.

In practical situations when gathering this information, inaccurate measurement and crisp evaluation cannot effectively handle problems involving uncertainty and imprecision inherent in mapping the perceptions of decision-makers. The theory of grey system and grey numbers developed by Deng (1989) has been used to handle imprecise data and vague linguistic expressions and applied to a variety of multiple criteria decision making (MCDM) problems. In this study, grey system theory will be combined with the DEMATEL method and NK model to deal with the uncertainty and imprecision problems in linguistic expressions. The Grey-DEMATEL method is used to extract the mutual relationships of interdependencies within GSCM major practices and the GITS sub-practices, and recognize the performance of these practices. The Grey-NK model is used to construct the path frameworks for the GSCM major practices and GITS sub-practices based on the results of Grey-DEMATEL method. In the final stage of the Grey-NK model, the possible maximum and minimum performances for each GSCM practice and GITS sub-practice configuration can also be obtain. Hence, this grey path framework can be used to not only support a GSCM plan, but also give more objective information as a reference for decision makers.

The contributions of this study include: (1) identifying multiple levels of GSCM practices including GITS practices from a comprehensive literature review; (2) developing a methodology that integrates grey system theory with the DEMATEL method and an NK model, which can evaluate the interrelationships at various analysis levels and construct an implementation path framework among the GSCM practices; and (3) applying this methodology using empirical data for a Ghanaian gold mining industry context.

The rest of the paper is organized as follows. In Section 2, literature review relating to green supply chain management practices is presented. The methodology and application is presented in Section 3 covering the fundamental concepts and background information of the methods to be incorporated into a unified novel method, comprising of grey system theory, DEMATEL and NK fitness landscapes model (NK model), and the integration of these methods to propose a novel Grey-DEMATEL and Grey-NK method to develop a path framework. The section also presents the case application involving multiple-field study with input from managers from some selected large scale Ghanaian gold mining companies.. Section 4 presents the results of the study covering results analysis and comparative analysis of the results. The research and managerial implications are presented in Section 5. Finally, the conclusion composed of the summary of the findings and further research directions are presented in Section 6.

## **2. LITERATURE REVIEW**

### **2.1 Green Supply Chain Management Practices**

The increased interest and concern by mining organizations and industry towards environmental sustainability results from governmental regulations (legislation), industrial standards, aboriginal and community pressures, as well as other institutional pressures (Tang & Zhou, 2012; Agan et al., 2013; Colwell & Joshi, 2013). Responding to these pressures, various efforts and actions have been undertaken to decouple or reduce the environmental influence from supply chains within the mining industry (Gunson et al., 2012; Edraki et al., 2014). There have been a large number of GSCM practices introduced over the years by both industry and academia. GSCM practices range from green purchasing to integrated supply chains flowing from suppliers, to manufacturers, to customers and reverse logistics (Beske et al., 2014; Seuring and Müller, 2008). For example, Green et al. (2012) empirically investigates the impact of various GSCM practices on performance.

Challenges exist for companies on how to manage the many GSCM practices. Some scholars have evaluated the relationship between environmental practices and firm performance, and have helped guide organizations in choosing the right GSCM practices for implementation (Sarkis, 2003). For example, Zhu et al. (2008) proposed a measurement model for GSCM practices implementation. Lin (2013) used fuzzy DEMATEL to examine the influential factors among GSCM practices, performance, and external pressures. Rostamzadeh et al. (2015) developed a quantitative evaluation model to measure the uncertainty of GSCM activities and apply the VIKOR method to solve the green multi-criteria decision making problem. However, these attempts didn't guide organizations on how to implement those practices properly.



Most prescriptive methods are limited when it comes to helping organizations introduce and implement various GSCM practices in a systematic way. Second, these methods are limited to evaluating which practices can jointly be implemented leading to the best performance. Due to the limited resources of organizations, it is necessary to help them introduce GSCM practices in a more systematic way, or select several GSCM practices to jointly implement. The existing literature has proven that the order of implementation or the joint implementation of practices will have an impact on the final performance results (Govindan et al., 2015; Cua et al., 2001). Yet, few, if any, tools and investigations have focused on the order of implementation of overall GSCM practices in a systematic way.

In order to address this issue and help bridge the research gap, this study proposes a MCDM tool that takes into consideration GSCM practices to aid in building a path framework for implementation. DEMATEL and NK models can provide valuable information for the implementation order of GSCM practices and performance. DEMATEL is used to determine the interdependencies among the GSCM practices; whereas the NK model can help construct a path framework through the fitness landscape concept to gain insights on implementation order of GSCM practices (Celo et al., 2015; McKelvey, 1999). The fitness landscape of the NK model will be generated from the DEMATEL interdependencies evaluations. This data represent the performance results corresponding to each GSCM practice combination. The NK model uses search strategies to navigate within the fitness landscape to find positions of greatest performance, and then a path framework would be produced

along the optimal search process result.

In order to determine a path framework, various considerations need to be made such as subjective evaluations, incomplete information, and the uncertainty of GSCM practices performance results. For example, human subjective evaluations are usually unclear and difficult for decision makers to describe by exact numerical values (Bai and Sarkis, 2011). The performance results of GSCM practices also are uncertain, and can be represented by a range of best or worst performance result. Grey system theory can help to cope with these uncertainties (Lin et al., 2008; Deng, 1989). The advantage of hybridizing grey DEMATEL and grey NK model are to be able to further address these uncertainties and fuzzy environment (Bai and Sarkis, 2011). Grey DEMATEL and the grey NK model are used to determine these relationships amongst various GSCM practices, to identify the grey performance outcomes of the combination of practices, and construct a path framework among the GSCM practices (and GITS sub-practices).

This study focuses on GSCM practices in the mining industry. A comprehensive description of these GSCM practices is presented in the next section. Diversity in industrial sectors may cause differences in GSCM practices adoption and implementation (Zhu and Sarkis, 2006); thus these results are limited by study of a single industry in a given location.

## 2.2 Green Supply Chain Management Decision Framework for the Mining Industry

This study adopts a green supply chain decision framework as proposed by Kusi-Sarpong et al. (2015) for the mining industry. The framework consists of six major

practices and thirty sub-practices. The major practices include Green Information Technology and Systems, Strategic Supplier Partnership, Operations and Logistics Integration, Internal Environmental Management, Eco-innovative Practices and End-of-life Practices. The focus of this study is to evaluate the relationship between Green Information Technology and Systems major practices and the other five major practices and also, the relationship amongst the Green Information Technology and Systems (GITS) sub-practices. Also, another objective is to construct the implementation path frameworks of these major GSCM practices and GIT sub-practices. Thus, the major and sub-practices include only the six major practices and the five GITS sub-practices. The five GITS sub-practices include (1) use of energy efficient ITS hardware and data centers; (2) implications of cloud computing; (3) end-of-life, obsolete ITS hardware management; (4) software and information support systems; and (5) purchasing greener ITS equipment and IT eco-labels. An overview of these practice sets and their linkages to the mining industry based on expert feedback, experience, and literature are presented.

### **2.2.1 Green Information Technology and Systems (GITS)**

Information technology and systems (ITS) is a key enabler for adoption and implementation of environmentally sustainable supply chain practices in the mining and other industries (Chan et al., 2012; Bull, 2015). For example, mines use ITS such as enterprise resources planning (ERP) systems to integrate all operational processes and suppliers and to aggregate organizational information for performance measurement and managerial decision making; which influence sustainability oriented

decisions. However, the ITS function, a main enabler for successful program implementation, has been almost completely neglected in environmental sustainability supply chain designs in organizations overall, but especially in the mining industry (Ryoo & Koo, 2013; Siurdyban, 2014).

GITS have started to permeate into most organizational and supply chain business processes, especially from environmental sustainability performance perspective (Sarkis et al, 2013). It has been observed for years that there is both environmental sustainability benefits and disadvantages associated with ITS. GITS is meant to limit the disadvantages while improving the benefits.

Some of the disadvantages of ITS occur from their production and usage. ITS, especially computerized and electronic systems, are responsible for energy use that can cause millions of tons of greenhouse gases every day (Malmodin et al., 2010; Pedram, 2012). Production of ITS requires significant energy and materials resources, and finding greener systems is a major challenge, although eco-labeling has aided in this process. At the other end of the supply chain, end-of-life, of ITS, the issue of electronic waste (e-waste) arises. But, until recently, the IT function, which is view as a way to reduce paper and solid waste for example, has been neglected in environmental assessment programs (Siurdyban, 2014).

Not all organizational environmental issues can be addressed completely with GITS hardware and usage. For example, 'carbon dioxide (CO<sub>2</sub>)' emissions cannot be comprehensively mitigate with only energy efficient ITS's (Amin and Leal Filho, 2014). But, control and software systems can be utilized for energy optimization to

minimize overall energy consumption and ‘carbon dioxide (CO<sub>2</sub>)’ emissions (Williams et al., 2014).

The examples of the pervasiveness of GITS and the greening of organizations have been exemplified by various frameworks. For example, as a software virtualization and control tool, GITS can help information management at multiple organizational levels (executive, managerial, operational) through various information systems (Sarkis et al., 2013). Also, a value chain and functional perspective of information systems, e.g. ranging from design of systems, to inbound logistics and procurement, to production and delivery, can help identify numerous ways these information systems can help to improve organizational and supply chain greening.

Improving the ITS ecological footprint in the mining industry is an emergent concern (Kusi-Sarpong et al., 2015). In addressing environmental impacts resulting from ITS usage by the mines, the pursuit of GITS in the mine-site can prove to be an important organizational option (Chou & Chou, 2012). These GITS can also be expanded to manage supply chain relationships and supporting or improving other eco-sustainability initiatives, some of which are intra-organizational, some that extend organizational boundaries (Ryoo & Koo, 2013; Molla, 2013; Park & Jeong, 2014).

A decision framework to help support management decisions or analysis on GITS can be valuable to management (Wilde et al., 2014; Hertel & Wiesent, 2013). The absence of decision frameworks to support management decisions in various industries is a barrier associated with integrating GITS for industry environmental sustainability initiatives. Organizations and supply chains also face challenges on

when to introduce GITS in relation to other GSCM practices. The mining industry is one that has neglected the IT function and their associated environmental benefits and disadvantages (Cai et al., 2013).

Drawing on the GITS (Green IT and Green IS) literature, important Green ITS sub-practices identified by Kusi-Sarpong et al. (2015) are discussed. These sub-practices set the stage for helping to address the issues of environmental sustainability primarily from ITS usage, and in this study for the mining industry in an emerging economy nation.

**1. Use of energy efficient hardware and data centers (GITS1):** Datacenters are critical ITS and computing resources which include servers and storage systems under centralized management that efficiently support organizations to operate continuously or according to the business needs (Corcoran, 2012; Pedram, 2012). The mining industry relies heavily on centralized ITS to support their nearly continuous operations. This heavy reliance on ITS requires continuous operations of servers or data centers for ensuing data availability, and the storage of huge quantities of data. This approach of utilizing ITS at mine locations even necessitate ideal hardware systems to be powered-on to ensure continuous data availability (Maheshwari et al., 2012). This heavy, continuous and increased ITS usage in mines will also mean that there is increased overall energy consumption, further negatively impacting the overall ecological footprint of mines through indirect carbon emissions (Chowdhury, 2012).

This ITS situation requires mines to holistically shift from the use of the

traditional and directly or indirectly ecological harmful ITS to a more efficient and environmentally friendly ITS. To foster this shift, energy-efficient hardware systems that reduce data centers energy consumption through energy-saving features for greening their ITS is necessary (Bener et al., 2014). There is a secondary financial benefit with lessened energy costs (Ryoo & Koo, 2013; Molla, 2013; Corbett, 2013). Renewable energy sources, a sourcing decision, alongside with energy-efficient data center and hardware should also be considered. Designing data center facilities can also greatly improve energy efficiency, thinking of data centers to include extra-hardware considerations is important. Given mining locations, more efficient facility designs will also play a role in GITS.

**2. Consolidating servers using virtualization software, cloud computing (GITS2):** Cloud computing refers to the consolidation of various software and hardware using virtualization software to offer Utility Computing (Corcoran, 2012; Hsu et al., 2014). Adopting cloud computing promises many benefits including pooled and, shared efficient and effective computing resources provisions amongst multiple organizations or users (Mazhelis & Tyrväinen, 2012). Adding to the localized infrastructure is the computing capacity from a public cloud that facilitates an organization to enhance the use of their ITS infrastructure to reduce ITS cost (Hsu et al., 2014). A more centralized location can also utilize economies of scale in both hardware and energy usage. The lessened systemic hardware usage due to centralization reduces material usage and eventually waste streams.

This approach may be used in parallel with efficient data center design, but more

in an information supply chain perspective which may require a shift from traditional onsite to cloud computing (Williams et al., 2014). The mines can consolidate their servers remotely using virtualization software through a cloud computing agent (Hsieh, 2014). Once on the cloud, each of these virtual servers can run independently on their operating system and applications and perform as if they are standalone servers but only run on limited hardware onsite which saves energy, the cost of having and maintaining a server, and fewer facility and hardware (data center) requirements (Zissis & Lekkas, 2012; Li & Wei, 2014). This situation can still allow the mines to leverage their operational data at the same time significantly reduce their operational cost and energy consumption.

From a software perspective, environmental management system and performance system software that may not have been made easily available can be supported by external agents. For example, if emerging country mining companies do not have expertise associated with some environmental software and systems, outsourcing to cloud computing agents may allow them to build this expertise in cheap and efficient ways. This type of GITS may include life cycle analysis tools, databases for green materials (industrial symbiosis) exchange, green supplier identification and selection software, or forecasting and simulation tools focused on environmental impact assessments.

### **3. Reducing electronic waste associated with obsolete equipment (GITS3):**

The mining industry utilizes significant ITS to support their operations (Kusi-Sarpong et al, 2015). Since IT tools has relatively shorter life cycles, this heavy reliant and



utilization of ITS can result in high obsolescence of IT equipment generating substantial amount of e-waste and hence high ecological impact (Sthiannopkao & Wong, 2013). To minimize the high ecological effect of ITS due to significant quantity of e-waste generation (ITS end of useful life), old IT equipment and systems can be replaced with recyclable composite parts or modular systems (Perry et al., 2012) instead of replacing the whole machine with new ones (Shah Khan et al., 2014). This will significantly reduce the amount of e-waste generated by the mines as relatively fewer components are disposed.

Given that the field case study in this paper is in Ghana, what is obsolete may be equipment whose life is extended. This extension may occur by donating obsolete equipment to local communities and schools. Also, making sure equipment gets disposed in an environmentally sound manner is another important consideration. Reuse, remanufacturing, reclamation, and recycling initiatives are all important aspects of minimizing the hazardous and solid waste footprints of these systems (Hsu et al., 2013a; Krystofik et al., 2015). Having supply chain relationships among organizations that can manage, in an environmentally sound way, the end-of-life e-waste using reverse logistics, disassembly, and asset recovery capabilities is critical (Andiç et al., 2012; Kilic et al., 2015). Having these systems available is part of a circular economy (Ma et al., 2014; Wübbeke & Heroth, 2014; Wu et al., 2014). These circular economy activities, whether they are formal (corporate or government support) or informal (individual scavengers in developing nations), may be something that mining and other companies in developing countries can support.

**4. Collaborative group software and virtual meetings (GITS4):** This dimension of GITS represents computer-mediated remote collaboration systems that use videoconferencing technologies for virtual meetings (Julsrud et al., 2012; Ong et al., 2014). This system makes it possible to bring meeting attendees from around the globe into an environment that feels as if they are in the same room (Julsrud et al., 2012; Denstadli et al., 2013; Wang et al., 2014a). These ITS elements enable faster decision making and minimize use of scarce resources. These ITS embedded with energy-saving features, such as displays and lights that automatically turn-off when not in use can further reduce their environmental burdens (Zhu et al., 2013).

Mining companies are typically located in sensitive areas and far away from customers and suppliers. Thus, ITS greenhouse emissions generated through transportation systems (e.g. vehicles use) can be mitigated through video teleconferencing ITS (Denstadli et al., 2013; Ong et al., 2014). Corporate or senior officers traveling from different places for corporate meetings (and with suppliers or customers) can be avoided by utilizing video teleconferencing ITS that improves the eco-impact of the business operations of mines through the elimination of transportation use (Kusi-Sarpong et al., 2015).

**5. Green Purchasing and Eco-labeled of ITS products (GITS5):** Tackling waste from electronics and ITS production throughout the supply chain can provide one of the greatest contributions to lessening a product or material's environmental burden. To help build up the market for GITS, focusing efforts on green purchasing, especially of eco-labelled ITS products, is essential.

In this regards, mining companies should identify and purchase ITS that carry eco-friendly attributes, which can easily be recognized through reputable eco-labels (Horne, 2009; Park & Jeong, 2014). Since nearly every employee and equipment in the mines use ITS, the adoption and use of eco-labeled ITS products within the mines will inform users of the environmental impacts of the ITS products (Wolfson et al., 2014). This will further encourage users and top management mind-shift in the demand and the adoption of eco-friendly innovative technologies for corporate environmental improvement and commitment (Kesidou & Demirel, 2012).

Difficulties may arise if the home location of mines is in a developing country as the availability and understanding of eco-labels, especially for ITS, may be scarce (Scott and Vigar-Ellis, 2014). Careful monitoring and evaluation will be needed, informing and training procurement managers on these issues and having them adopt green purchasing principles may not be an easy task. The reason for this potential barrier for green purchasing is a lack of such purchasing policies in the mining industry (Mathiyazhagan and Govindan, 2014).

### **2.3 Non-GITS supply and operations chain greening categories**

One of the goals of this paper is to explore the relationship between GITS and other activities or programs that can contribute to the greening of organizations and their supply chains. Five other general GSCM practices from a proposed green supply chain decision framework are also introduced (see Kusi-Sarpong et al. (2015) for a detailed evaluation and support of these elements). The major GSCM practices include building strategic supplier partnerships, operations and logistics integration,

internal environmental management, eco-innovative practices, and end-of-life practices. These programs include both internal and external activities. After a brief overview of each, examples of how GITS and ITS may be related to these general programs is also presented.

### **2.3.1 Strategic Supplier partnership (SSP)**

Strategic supplier partnership is a strategic initiative and development undertaken by partnering organizations, between firms and their suppliers, with common objectives aimed at forging long-term relationship to achieve sustainability goals and building collaborative advantage (Wong et al., 2015; Beske, 2012). Supply chain systems, ITS and GITS included, emphasize the need for inter-organizational dependence to achieve overall supply chain efficiency. This requires partnering organizations to jointly plan and develop greening strategies that will contribute to win-win (joint success) outcomes or situations (Wu et al, 2014). The formation and development of strategic suppliers' partnership can enable partnering organizations to achieve significant cost reduction, improve product and service quality, reduce ecological footprints and achieve overall higher level of sustainable supply chain performance (Eltantawy, 2015). Alignment of IT and GITS is a critical aspect of the relationship between GITS and SSP (Kim et al., 2013; Wang et al., 2014b).

GITS can be utilized in these situations for cooperative approaches building strategic environmental decision making across organizational boundaries. A practical example of integrating environmental management information systems inter-organizationally is ASG AB, an international logistics and transport firm

headquartered in Stockholm, Sweden (Shaft et al., 2001). More recently cloud computing can also play a critical role in this inter-organizational environment.

### **2.3.2 Operations and Logistics Integration (OLI)**

Operations and logistics integration is the seamless integration of organizations internal operational, logistical practices and activities including the flow of material and information and network relationship management (Lotfi et al., 2013; Durugbo, 2014). Seamless integration and effective logistics management can be achieved by harmonizing organizational internal operations and external partners operations utilizing information system such as enterprise resources planning (ERP) systems (Madapusi & D'Souza, 2012). OLI initiatives, as an example, are related to GITS by advancing real-time information sharing and encourage paperless transactions thereby leading to lean operations and green logistics activities (Durugbo, 2014). These are some initiatives that more advanced or large scale mining companies can take advantage to help them improve their operations and environmental performance. Integration may also be extended across the organization where environmental information ranging from green product design to efficient transportation planning to save energy, can be included for easy access.

### **2.3.3 Internal Environmental Management (IEM)**

Internal environmental management is comprised of proactive environmental infrastructural investment decisions and policies within an organization that promote and facilitate the implementation of environmental management practices (Papagiannakis et al., 2014). These environmental management practices are required

to directly or indirectly minimize the organizational ecological impact with relatively cost-effective approach (Mårtensson & Westerberg, 2014). IEM practices whose relationship to GITS may range from making sure that ITS are managed and used in an environmentally sound way based on organizational environmental policies, to manage documents and information related to the environmental management systems using ITS.

#### **2.3.4 Eco-innovative Practices (ECO)**

Eco-innovative practices are novel or modified practices, technologies and products that enable organizations to progressively reduce their environmental risk, pollution and mitigate other negative effect of resources use (Przychodzen & Przychodzen, 2015; Wu et al., 2016a, 2017). Organizations are required to take a broader view when designing and developing their eco-innovative programs to avoid being counter-productive (Cheng et al., 2014). Organizations can utilize eco-innovation strategies to create value that contribute to sustainable development and improve environmental performance effect and minimize cost (Cai and Zhou, 2014).

Eco-innovation support will be heavily reliant on ITS. Designs, data, and previous performance information is necessary to help manage eco-innovations. Alternatively, some of these eco-innovations may focus on developing GITS in organizations. Many of the proposed elements of GITS themselves are eco-innovations. Whether the mining industry has focused on GITS as eco-innovations or have used ITS for eco-innovation management is still a question. The major issue is that overall, a mature industry, mining is technologically conservative (Bartos, 2007),

which probably affects limited eco-innovation activity. Having GITS in the planning and discussion may help with eco-innovative practices.

### **2.3.5 End-of-Life Practices (EOL)**

End-of-life initiatives are strategies implemented by organizations to promote proper disposal and/or to recapture value from products that have reached their end of useful life, minimizing ecological effects (Ziout et al., 2014). These initiatives include ‘open-loop’ products recovery systems where value of EOL products are recaptured outside the product’s own system and ‘closed-loop’ product recovery system where value of EOL products are recaptured within the product’s own system (Allacker et al., 2014).

In the mining industry, their products are materials used in other products and materials. Gold mining, as the specific mining industry in this study, has much end-of-life management focus because of its precious metal characteristic. The concern internally, with products used by mining would range from vehicles and equipment used for mining, in addition to the ITS in use by mining organizations. Managing the EOL of their materials used for processing and operations is a critical area they can influence broader product-stewardship activities.

Given these GITS and other green organizational practices, the study now investigates the relationships amongst these practices and their relative importance to the large scale gold mining industry in Ghana.

The six major GSCM practices (factors) and thirty sub-factors are summarized in Table 1. Sub-factors with an asterisk are those utilized in this study.

[Insert Table 1 about here]

### 3.0 METHODOLOGY AND APPLICATION

In this section, the fundamental concepts and background of grey system theory, DEMATEL and NK fitness landscapes model (NK model) are presented. The study begins with grey system theory, which sets the evaluation approach that will be used for intangible and uncertain measures and metrics to handle vague linguistic expressions. A review of DEMATEL method which is capable of evaluating the interdependencies between the GSCM practices and identifies the performance outcomes of these practices is then presented. This is followed by a review of NK fitness landscapes model (NK model) which can help develop a path framework (implementation sequence) for those GSCM practices. Finally, the study integrates these three methods to propose a novel methodology which will be used in GSCM practices evaluation and develop a path framework in the Ghana gold mining industry.

#### 3.1 Methods

##### 3.1.1 Grey System Theory

Grey system theory is an approach for analysis and modeling of systems with insufficient and incomplete information, and which may exhibit random uncertainty (Deng, 1989). Grey related decision-making which is an important part of grey decision theory has a wide range of applications in many fields, such as supply chain management, economics, agriculture, and medicine, becomes the research focus (Bai and Sarkis, 2010a; Bai and Sarkis, 2011).

**Definition 1:** Let  $\otimes x$  be a grey number and it is defined as an interval with known upper and lower bounds but unknown distribution information for  $x$  (Deng, 1989).



That is,  $\otimes x = [\underline{x}, \bar{x}] = [x' \in x \mid \underline{x} \leq x' \leq \bar{x}]$  where  $\underline{x}$  and  $\bar{x}$  are the lower and upper bounds of  $\otimes x$ , respectively.

**Definition 2:** Let  $\otimes x_1 = [\underline{x}_1, \bar{x}_1]$  and  $\otimes x_2 = [\underline{x}_2, \bar{x}_2]$  be two grey numbers. Generally, some basic grey number mathematical operations are represented by the following relationships (expressions 1-4):

$$\otimes x_1 + \otimes x_2 = [\underline{x}_1 + \underline{x}_2, \bar{x}_1 + \bar{x}_2] \quad (1)$$

$$\otimes x_1 - \otimes x_2 = [\underline{x}_1 - \bar{x}_2, \bar{x}_1 - \underline{x}_2] \quad (2)$$

$$\otimes x_1 \times \otimes x_2 = [\min(\underline{x}_1 \underline{x}_2, \underline{x}_1 \bar{x}_2, \bar{x}_1 \underline{x}_2, \bar{x}_1 \bar{x}_2), \max(\underline{x}_1 \underline{x}_2, \underline{x}_1 \bar{x}_2, \bar{x}_1 \underline{x}_2, \bar{x}_1 \bar{x}_2)] \quad (3)$$

$$\otimes x_1 \div \otimes x_2 = [\underline{x}_1, \bar{x}_1] \times [\frac{1}{\underline{x}_2}, \frac{1}{\bar{x}_2}], 0 \notin \otimes x_2 \quad (4)$$

**Definition 3:** Let  $\otimes x_1 = [\underline{x}_1, \bar{x}_1]$  and  $\otimes x_2 = [\underline{x}_2, \bar{x}_2]$  be two grey numbers, with  $l(\otimes x_1) = \bar{x}_1 - \underline{x}_1$ , and  $l(\otimes x_2) = \bar{x}_2 - \underline{x}_2$ . The possibility degree, larger value, of two grey numbers has previously been defined (Nakahara et al. 1992):

$$P(\otimes x_1 \geq \otimes x_2) = \begin{cases} 1 & \underline{x}_1 \geq \bar{x}_2 \\ \frac{\bar{x}_1 - \underline{x}_2}{l(\otimes x_1) + l(\otimes x_2)} & \bar{x}_1 > \underline{x}_2 \wedge \underline{x}_1 < \bar{x}_2 \\ 0 & \bar{x}_1 \leq \underline{x}_2 \end{cases} \quad (5)$$

where  $P(\otimes x_1 \geq \otimes x_2)$  means that the possibility value of grey number  $\otimes x_1$  is bigger than grey number  $\otimes x_2$ , shown as a percentage. Where  $0.5 < P(\otimes x_1 \geq \otimes x_2) \leq 1$  indicates that the grey number  $\otimes x_1$  dominates  $\otimes x_2$ . Denoted  $\otimes x_1 \succ \otimes x_2$ .

These basic operations and possibility degree will be utilized in the specific relationship evaluations to advance the NK model which is further defined later in the application illustration.

### **3.1.2 DEMATEL**

The DEMATEL method, originated from the Geneva Research Centre of the Battelle Memorial Institute, has been used to research on and solve a group of complicated and intertwined problems (Gabus and Fontela, 1973). DEMATEL is a visualization method for building and analyzing a structural model of complicated causal relationships between components. DEMATEL has been successfully utilized in many research areas including business process management, hospitality industry, supplier selection, and green supply chain management (Bai and Sarkis, 2013a; Lin, 2013; Hsu et al., 2013b; Wu et al., 2016b).

To apply DEMATEL, this paper refines the version used by Fontela and Gabus (1976) and proposes the following steps.

- (1) Generating the direct-relation matrix.
- (2) Normalizing the direct-relation matrix.
- (3) Attaining the total-relation matrix.
- (4) Producing a causal/effect diagram.

### **3.1.3 The NK fitness landscapes model**

The NK model (Kauffman, 1993), provides a simple, yet powerful analytical framework to study organizational problem solving using adaptive searches. While

NK was developed to model the evolution of biological systems towards greater fitness, it has recently gained broad acceptance within the organizational research literature (Dosi et al., 2011), but it is still relatively unknown within the supply chain management literature, especially in the field of environmental or green supply chain management (Fan and Lee, 2012).

The NK model has two primary features (Kauffman, 1993). The first feature is a stochastically generated fitness landscape, where “higher peaks” correspond to better solutions or combinations of components. The second feature is the agent(s) that search a given landscape in an effort to improve their “fitness”, or performance. The system uses search strategies to navigate within the fitness landscape to find positions of greatest fitness, in this case the best green performance. These search strategies are heuristics and routines the system uses to configure and reconfigure the components. If a new system fitness value is greater than its current fitness value, the system moves to the new configuration, which is the position on the landscape. In this study, the NK model identifies a best landscape path (Implementation sequence of GSCM practices) for improving organizations performance from amongst various landscape paths.

For the NK model, a complex adaptive system is conceptualized as operating in an environment involving  $N$  components and  $K$  interactions among these components. The parameter  $N$  represents the number of individual components  $c = \{c_i \mid i = 1, 2, \dots, n\}$  in a given system where  $c_i$  can take the value of 0 or 1. The number of possible configurations for a system that comprised of  $N$  components is  $2^N$ . Each configuration is associated with a fitness value, performance, if that particular configuration is implemented. Another parameter  $K$  defines the number of other

components in the system that affect the fitness value of each component. The value of  $K$  can range from 0 to  $N-1$ , which represents the degree of dependence between the components of a system. A fitness value (or performance outcome) depends not only on the choice made concerning that component ( $c_i = 0$  or 1) but also on choices made regarding  $K$  other components that interact with the focal component:  $f_i = f(c_i | K \text{ other } c_j \text{'s})$ . For each possible realization of  $c_i$  and the  $K$  relevant other  $c_j$ 's, fitness value  $f_i$  is a uniformly distributed random variate over the interval (0, 1). The overall fitness value,  $F$ , of the system is the arithmetic mean of the values assigned to each fitness value of the  $N$  components (11):

$$F = \left( \sum_{i=1}^N f(c_i | K \text{ other } c_j \text{'s}) \right) / N \quad (11)$$

Although NK model is a good technique for solving organizational problems, previous studies of NK model in the strategy field are mainly theoretical and comparative of different combinations (Ganco and Hoetker, 2009). To the best of our knowledge, there are few studies that have used NK model as a decision making tool to help organizations in practice decision support. Fitness value is always a uniformly distributed random variate over the interval (0, 1). There is the need to use a method to generate fitness value according to the selected components and the relationships among those components in order to let NK model to be used in different decision contexts. DEMATEL is used to not only extract the mutual relationships of interdependencies within components but also extract the important of each component. In addition, the fitness value of systems is generally given by crisp values. However, in this real world, crisp values are inadequate. Many evaluation criteria by human judgment are surely imperfect and probably uncertain factors; grey

system theory is applied to the DEMATEL method and NK model for solving such a MCDM problem in uncertain environment. Grey DEMATEL method is used to build the effective relationships (Bai and Sarkis, 2013a), considering the fact that human judgment about preferences are often unclear and hard to estimate by exact numerical values. Grey NK fitness landscapes, a new method, can be used to get the effective fitness value with grey number form which could represent the maximum and the minimum fitness values. It can also help construct a path framework through the grey fitness value to gain insights as to how implementation order of GSCM practices for managing green supply chains (Celo et al., 2015; McKelvey, 1999).

#### **3.1.4 The Proposed Grey-DEMATEL and Grey-NK method**

The paper now proposes a novel method based on the above three methods to develop a path framework of components. Grey-DEMATEL is used to build the grey relative relationship model for the components and extract the important of each component. Then, the Grey-NK method is used to construct the path framework for the components.

**Step 1:** Designing a NK system structure.

The general NK model data structure is first defined in this step. This NK model is defined by  $NK = (N, K)$ .  $N$  will represent the number of components (in our case is GSCM practices), and  $K$  will represent the degree of dependence between the components. The interdependencies among components can be captured in an  $N \times N$  influence matrix ( $INF$ ), where  $INF_{ij}$  represents (column) component  $j$  influences the value contribution of (row) component  $i$ . The overall performance results of components combination depends not only on the specific component  $i$ , but also on

how the other components interacting with it ( $K$ ) are resolved. In following Step2 – Step6, DEMATEL will be used to identify the interdependencies amongst the components.

**Step 2:** Establishing the grey direct-relation matrices for each organization.

To measure the grey interdependency relationship between components  $c = \{c_i \mid i = 1, 2, \dots, n\}$ , the grey numbers for five linguistic terms are defined in Table 2.

The grey direct-relation matrices  $M^e = (\otimes m_{ij}^e)_{n \times n}$  are initially populated by having evaluators of each organization  $e$  introduce the grey pairwise influence relationships ( $\otimes m_{ij}^e$ ) between the components in a matrix. All the principal diagonal elements are initially set to a grey value ( $[0,0]$  = no influence).

[TABLES 2 ABOUT HERE]

**Step 3:** Developing the aggregate grey direct-relation matrices.

The direct-relation matrices for the organizations are aggregated into a grey matrix  $M$  by simple average using expression (12):

$$M = \left( \sum_{e=1}^E M^e \right) / E \quad (12)$$

**Step 4:** Normalizing the aggregate grey direct-relation matrices.

On the basis of the aggregate grey direct-relation matrix  $M$ , the normalized grey direct-relation matrix  $N$  can be obtained through expressions (13) and (14).

$$s = \frac{1}{\max_{1 \leq i \leq n} \sum_{j=1}^n \bar{m}_{ij}}, \quad i, j = 1, 2, \dots, n \quad (13)$$

$$N = s \cdot M \Rightarrow \otimes n_{ij} = (s \cdot \underline{m}_{ij}, s \cdot \bar{m}_{ij}) \quad (14)$$

**Step 5:** Determining grey total relation matrices.

The grey total relation matrix ( $T$ ) is determined by expression (15) where  $I$  represents an  $n \times n$  identity matrix.

$$T = (\underline{T}, \bar{T}) = (\underline{N}(I - \underline{N})^{-1}, \bar{N}(I - \bar{N})^{-1}) \quad (15)$$

**Step 6:** Determining the overall grey importance ( $\otimes P_i$ ) of component.

Determine the overall grey importance ( $\otimes P_i$ ) of component  $i$  using expressions (16).

The values  $\otimes P_i$  shows the total net cause and effect index.

$$\otimes P_i = \{\otimes R_j + \otimes D_j \mid i = j\} \quad (16)$$

where  $\otimes R_i = \sum_{j=1}^n \otimes t_{ij} \forall i$  represent the sum of influence by a component  $i$  on other

components, and  $\otimes D_j = \sum_{i=1}^n \otimes t_{ij} \forall j$  represent the sum of direct and indirect influence

that decision component is affect by from the other components.

**Step 7:** Identifying the overall grey fitness value for each component configuration.

**Sub-step1:** Identify the grey fitness value for each component.

Each component can have a fitness value, which can be interpreted as

performance if that component is selected separately, on its own. A fitness value for each component can be determined by the overall grey importance ( $\otimes P_i$ ) of the total relation matrix ( $T$ ).

$$\otimes f_i = \otimes P_i \quad (17)$$

**Sub-step2:** Identify the overall grey fitness value for each components configuration.

This objective now is to find the overall grey fitness value point for the various configuration landscapes. The overall fitness value,  $\otimes F$  (calculated using expressions (18)), of the system is the sum of the values assigned to each fitness value of the component  $c_i$  which are selected ( $c_i=1$ ) and the interdependencies with other component  $c_j$ , that are also selected ( $c_j=1$ ).

$$\otimes F(\{c_i \mid c_i = 1\}) = \sum_{i \in \{i \mid c_i = 1\}} (\otimes f_i + \sum_{j \in \{j \mid c_j = 1, |j| \leq K\}} \otimes t_{ji} * \otimes f_i) \quad i \neq j \quad (18)$$

where  $\{c_i \mid c_i = 1\}$  represent a configuration of components ( $c_i = 1$ ).

**Step 8:** Determining optimal path framework.

The best sequential path in search of better fitness value by the organization will be determined by the following rule:

- (1) The organization starts at all  $c_i = 0$  ( $0, \dots, 0$ ) with a fitness value of 0, which means the organization did not select any component. Initially,  $Atr = \emptyset$  is a sequential path set. In the end,  $Atr$  will be the order of components.



(2) Selected a component  $i$ , which is the max grey fitness value that the organization will get, and let  $c_i = 1$  into  $Atr$  using expressions (19). The possibility degree of two grey fitness values has previously been defined expressions (5).

$$\max(\otimes F(Atr + c_i)) \text{ then } c_i \Rightarrow Atr \quad (19)$$

(3) Keep circulating second step, until all the components are selected into  $Atr$  at all  $c_i = 1 (1, \dots, 1)$ . Then, the order of selected component into  $Atr$  will be seen as a sequential path in search of better fitness value by the organization.

## 3.2 Case Application

### 3.2.1 Environmental Issues and Initiatives within Ghanaian Mining Industry

Environmental sustainable supply chain management performance in the Ghanaian mining industry has come under increasing scrutiny by local communities, the general public, and other stakeholders such as supply chain partners (Peck and Sinding, 2003). Negative environmental impacts from the mining industry's supply chain operations are numerous and include toxic reagent releases, acid drainage, air quality reduction, habitat modification or displacement and pollution (Wasylycia-Leis et al., 2014). As a result, Ghanaian mining companies are under grievous pressure to provide substantial economic benefits with minimal environmental damage. Improving natural resources mining operations and corporate environmental sustainability performance in Ghanaian mining industry is increasingly becoming an important organizational strategy. Therefore, Ghanaian mining companies have started to adopt some environmental sustainable practices in their operations, but the focus of these practices has been internal. Environmental sustainable mining practices

focusing on the supply chains may be an effective approach in response to the pressure exerted by the stakeholders. A possible barrier for improved environmental sustainable performance in Ghanaian mining industry is the lack of understanding and existence of environmental sustainable supply chain management factors (criteria) within this industry. Ghanaian mining organizations can adopt GSCM from a collaborative perspective to help efficiently and effectively build capabilities and improve environmental management to reduce the environmental footprints and improve production to achieve higher economic gains.

Investigating GITS and its relationship to other green organizational practices in Ghana's mining industry is important to both the direct and indirect environmental sustainability improvement. This study on sustainable development issues in the mining sector and Ghanaian mining industry context can help improve the serious negative environmental impacts from supply chain and organizational operations of the mining industry. It also provides researchers and policy makers with an idea of how GITS may be used to contribute to reducing the mining industries environmental impacts.

### **3.2.2 Sample Case Company Characteristics**

Using a purposive sampling approach this investigation is an exploratory multiple-field study involving six large scale multi-national Ghanaian gold mining industrial managers (respondents). The focus was on greening their supply chains. These respondents were involved in a series of stages. First, they were asked to complete a series of matrices as described below in the methodology. Second, some

feedback on general findings from the analysis was also acquired. Table 3 provides an overview of these managers and their mining companies.

[TABLE 3 ABOUT HERE]

### 3.2.3 Proposed Method's Application

An application example of the path framework construction for GSCM practices using the joint Grey-DEMATEL and Grey-NK methodology with inputs from six mining organizations from Ghana is now presented.

**Step 1:** Designing the GSCM system structure.

In our case, the GSCM system, which is a complex adaptive system, is defined in two levels of the NK model by  $NK = (N, SN, K, SK)$ . One main NK model for green strategy will be formed with six GSCM practices ( $N$ ) (e.g., SSP, EOL, ECO, OLI, IEM, GITS) which are summarized in Section 2.3. One sub NK model of GITS with five GITSs ( $SN$ ) will be formed in Section 2.2. The overall GSCM system structure is summarized in Figure 1.

[FIGURE 1 ABOUT HERE]

$K$  and  $SK$  will represent the degree of dependence between the GSCM practices and GSITs. A given complexity measure ( $K = 5$  and  $SK = 4$ ) of the GSCM and GSITs is defined by the amount and patterns of interdependencies among decision variables.

**Step 2:** Establishing the grey direct-relation matrices for each organization.

To measure the interdependency relationship between GSCM practices (or GITSs)

$c = \{c_i \mid i = 1, 2, \dots, n\}$ ,  $E=6$  Ghana mining organizations were asked to make sets of pair-wise comparisons using linguistic terms. Twelve matrices, two corresponding to an organization, were completed. In the empirical cases the GSCM practice grey direct-relation matrices  $M^e = (\otimes m_{ij}^e)_{n \times n}$  are initially populated by each organization  $e$  in a  $6 \times 6$  matrix. Grey sub-direct-relation matrices  $SM^e$  for GITS are populated by each organization  $e$  in a  $5 \times 5$  matrix. A GSCM practice pair-wise influence matrix for one of the organizations is shown in Table 4. For example, in Table 4, according to the respondents from organization 1, GITS has “low influence” on SSP, with a grey value of  $[0.25, 0.5]$ . The GITS pair-wise influence matrices for the same organization are shown in Table 5. For brevity, the remaining matrices for other Ghana organizations are not shown.

[TABLES 4 AND 5 ABOUT HERE]

**Step 3:** Developing the aggregate grey direct-relation matrices.

The GSCM practice direct-relation matrices  $M^e$  and GITS sub-direct-relation matrices  $SM^e$  for the six organizations will be integrated into an aggregate grey GSCM practice direct-relation matrix  $M$  and one aggregate grey GITS direct-relation  $SM$  matrix, which are shown in Tables 6 and 7, respectively.

[TABLES 6 AND 7 ABOUT HERE]

**Step 4:** Normalizing the aggregate grey direct-relation matrices.

In our case, a GSCM practice direct-relation matrix  $M$  and a GITS sub-direct-relation matrix  $SM$  will be normalized to grey matrices  $N$  and  $SN$ , respectively. The

normalized GSCM practice direct-relation matrix  $N$  and a GITS sub-direct-relation matrix  $SN$  are shown in Tables 8 and 9.

[TABLES 8 AND 9 ABOUT HERE]

**Step 5:** Determining grey total relation matrices.

In our case, a grey GSCM practice total relation matrix  $T$  and a grey GITS sub-total matrix  $ST$  will be determined from the normalized matrices  $N$  and  $SN$ , separately. The GSCM practice total relation matrix and a GITS sub-total relation matrices are shown in Tables 10 and 11.

[TABLES 10 AND 11 ABOUT HERE]

**Step 6:** Determining the overall grey importance of GSCM practices or GITSs.

In our case, the overall grey importance  $\otimes P_i$  of GSCM practice or  $\otimes SP_i$  of GITSs are determined for the GSCM practice total relation matrix ( $T$ ) or a GITS relation matrix ( $ST$ ), shown in Tables 10 and 11, respectively.

In the next steps, the Grey-NK model is utilized to simulate a path to get the best performance for the given interdependencies from the grey total relation matrix, also from a given complexity measure ( $K = 5$  and  $SK = 4$ ).

**Step 7:** Identifying the overall grey fitness value for each practice configuration.

Each practice within the GSCM situation has two possible options: to implement or not implement. With this setup, the NK Model can be represented as 6 GSCM practices of system configurations:  $c = \langle c_1, \dots, c_6 \rangle$ . The results have 64 possible

configurations. The sub NK Model can be represented as 5 GSIT configurations which can result in 32 possible configurations. This step in NK model requires two sub steps.

**Sub-step1:** Identify the grey fitness value for only each GSCM practice or GITS.

Each GSCM practice or GITS can have a grey fitness value, which can be interpreted as performance if that practice or GITS implemented separately, on its own. A grey fitness value for each practice can be determined by the overall importance ( $\otimes P_i$  or  $\otimes SP_i$ ) from the total relation matrix ( $T$ ) or from the relation sub-matrices ( $ST$ ).

For example, the GITS has a [0.111,0.2] grey value for performance in Table 10. The grey fitness value of GITS is initially set at [0.111,0.2]. GITS1 has a [0.239,0.467] grey value for GITS level in the relation sub-matrices ( $ST$ ) shown in Table 11. Thus, the fitness value of GITS1 is set to [0.239,0.467].

**Sub-step2:** Identify the overall fitness value for each GSCM practice or GITS configuration.

The overall fitness value,  $F$  (calculated using expressions (18)), of the system is the sum of the values assigned to each fitness value of the practices  $c_i$  which are implemented ( $c_i=1$ ) and the interdependencies with other practices  $c_j$ , that are also implemented ( $c_j=1$ ). For example if GITS is the only general GSCM strategy implemented, then the overall fitness value  $F=[0.111,0.2]$  of the system is equal to the fitness value  $f_1=[0.111,0.2]$  of GITS. If SSP is implemented separately, the system fitness value  $F= [0.237,0.388]$  which is equal to the fitness value  $f_2= [0.237,0.388]$  of SSP. If the joint strategies of GITS and SSP are to be implemented

then interdependent values are to be considered. For example, the value of GITS influence on SSP is  $[0.003, 0.006]$ , which is the value of  $INF_{12}$  from Table 10. The other direction of the interdependency  $INF_{21}=[0.032, 0.048]$ , also from Table 10. The overall fitness value is then equal to  $F = (\sum_{i=1}^N (\otimes f_i + \sum_{j \in \{j | c_j=1, |j| \leq K\}} \otimes t_{ji} * \otimes f_i)) = [0.111, 0.2] + [0.237, 0.388] + [0.111, 0.2] * [0.003, 0.006] + [0.237, 0.388] * [0.032, 0.048] = [0.356, 0.608]$ .

The overall fitness values for the various GSCM practice or GITS configurations are summarized in Tables 12 and 13. With six GSCM practices that take on one of the two values (0 or 1) a total of 64 possible configurations of 0s and 1s are shown in the first six columns ( $c_1 - c_6$ ) in Table 12. With five GITS that takes on one of the two values (0 or 1) a total of 32 possible configurations of 0s and 1s are shown in the first five columns ( $sc_1 - sc_5$ ) in Table 13. The next column shows the overall fitness values for each contribution.

[TABLE 12 and 13 ABOUT HERE]

**Step 8:** Determine optimal path for green supply chain management.

In our case, the organization starts at all  $c_i = 0$  ( $0, \dots, 0$ ) with a fitness value of 0, which organization not selected any GSCM practices or GITSs. Then, the organization searches the better fitness value for getting the best sequential path. First, the organization needs to select a GSCM practice with the biggest fitness value. The fitness value of each GSCM practice can be compared with the separate implementation by the possibility degree which was defined by expressions (5), and can identify the fitness value of SSP as the biggest, because that

$[0.237, 0.388] \succ_{52.1\%} [0.233, 0.379] \succ_{54.7\%} [0.218, 0.366] \succ_{54.5\%} [0.208, 0.352] \succ_{59.2\%} [0.182, 0.324]$   
 $\succ_{92.3\%} [0.111, 0.2]$ . The expression “ $[0.237, 0.388] \succ_{52.1\%} [0.233, 0.379]$ ” represents 52.1% probability that SSP (the fitness value  $[0.237, 0.388]$ ) is better than EOL (the fitness value  $[0.233, 0.379]$ ). Then, the organization should first implement GSCM practice of SSP. Next, the organization needs to select the second GSCM practice with the biggest fitness value. The organization will need to compare the fitness value of two GSCM practices implemented and get the second step of which GSCM practice is to be implemented after SSP. Then, the organization should select and implement the second GSCM practice as EOL according the fitness value in Tables 12. Then, the organization will select the next GSCM practice until all the GSCM practices are selected at all  $c_i = 1 (1, \dots, 1)$ . Then, the sequential path, which show (aggravate and italics) in Tables 12, will be seen as the best implementation strategy of GSCM practice for the organization.

While an exact 3D-visualization of the ‘landscape’ is not possible, from Tables 12 and 13, it combine the values of  $c_1$ ,  $c_2$  and  $c_3$  along an x-axis, of  $c_4$ ,  $c_5$  and  $c_6$  type along a y-axis, and performance along a z-axis. The basic idea of the adaptive walk, in this study and methodology, is to have an organization make adjustments one step at a time as they search for better solutions. Eventually the optimal path leads to a combination (1, 1, 1, 1, 1, 1) of when all GSCM practice are implemented.

Figure 2 shows schematic example of how the organization moves from position 0 to 1 to 2 and finally reaches a peak at position 6. The organization starts at (0, 0, 0, 0, 0, 0) with a performance value of 0. For the first step, a performance value of  $[0.237, 0.388]$  for (0, 1, 0, 0, 0, 0) is the largest, implementing one GSCM practice ( $c_2$



), and sets the path from a new solution position (0, 1, 0, 0, 0, 0) shown as position 1. Next the performance value [0.485,0.801] for (0, 1, 0, 0, 0, 1) is the largest value and it means one more strategy ( $c_6$ ) with a new solution (0, 1, 0, 0, 0, 1) is implemented and shown as position 2. Since the performance value of (0, 1, 0, 0, 1, 1) is higher [0.727,1.226] the organization moves to that position. From there it moves to position 3 by implementing  $c_5$ . Then, the performance value of (0, 1, 0, 1, 1, 1) is higher [0.969,1.673] the organization moves to that position. From there it moves to position 4 by implementing  $c_4$ . Since the performance value of (0, 1, 1, 1, 1, 1) is higher [1.183,2.094] the organization moves to that position. From there it moves to position 5 by implementing  $c_3$ . Then finally to position 6 by implementing strategy  $c_1$  with a performance value of [1.317,2.364]. At position 6, unless the organization has potentially new GSCM practices, the organization maintains that position.

This path, shown in figures 2 is the best implementation path for the organization for GSCM. From the same principle, this study can get the best path of GITS for practices within each GITS, which are shown in Figure 3.

[FIGURE 2 AND 3 ABOUT HERE]

## 4. RESULTS

### 4.1 Results Analysis

The GSCM practices generic path model (Figure 2) for GSCM implementation was established by analyzing the quantitative survey responses using grey-DEMATEL and the grey-NK model.

According to the GSCM practices path results (Figure 2), the case study

organizations should first develop SSP (Strategic Supplier Partnership) with its suppliers. The respondents clearly found this major GSCM practice as an important initial and foundational step for successful GSCM performance. As globalization and outsourcing management, supplier cooperation and continuous improvement have become more critical for organizational and supply chain strategic and long-term core competitive advantage (Bai and Sarkis 2014; Li et al., 2012). An organization's green performance is affected by its suppliers' green performance; therefore building a good strategic supplier partnership is an important strategic decision for GSCM and should be implemented in the primary stage. There are a variety of supply chain practices for building strategic supplier partnership including green supplier selection (Bai and Sarkis, 2010a), green supplier development (Bai and Sarkis, 2010b), and green supplier performance evaluation (Bai and Sarkis, 2014).

The next important practice for managing a green supply chain is for the organizations to implement EOL (End-of-Life Practices). This result may be due to industry characteristics of this application. In the mining industry, their products are materials used in other products and materials. Gold mining, as the specific mining industry in this study, has much end-of-life management focus because of its precious metal characteristic. The rest of the GSCM practices implementation order is ECO (Eco-innovative Practices), IEM (Internal Environmental Management) and OLI (Operations and Logistics Integration). The differences in the performance levels for changing the implementation order of those three GSCM practices are not great. Organizations can decide the specific implementation order according to their situation. In addition, OLI may relate to the third party logistics, so there exists a certain degree of difficulty and uncertainty for the performance level.

Finally, organizations should work on GITS (Green Information Technology and

Systems). The final implementation does not represent that GITS is not important. GITS have started to permeate into most organizational and supply chain business processes, especially from environmental performance perspective (Bai and Sarkis, 2013b). Therefore, these GITS can be seen as support role, such as expand to manage supply chain relationships and support or improve other eco-sustainability initiatives, some of which are intra-organizational, some that extend organizational boundaries (Park & Jeong, 2014). Then, GITS should be implemented at the end to support or improve other GSCM practices.

The application of this methodology introduced GITS as having five potential GITS sub-practices. According to the GITS implementation path results (Figure 3) of GITSs, these organizations should first introduce GITS2 (Consolidating servers using virtualization software, cloud computing). From a software perspective, environmental management system and performance system software that may not have been made easily available can be supported by external agents. Mining companies in emerging countries do not always have expertise associated with environmental software and systems, outsourcing to cloud computing agents may allow them to build this expertise in cheap and efficient ways. Hence, GITS2 is a good start for mining companies in emerging country.

The next important GITS sub-practice to implement for these organizations is GITS4 (Collaborative group software and virtual meetings). Mining companies are typically located in sensitive, isolated, areas and far away from customers and suppliers. Corporate or senior officers traveling from different places for corporate meetings (and with suppliers or customers) can be avoided by utilizing video

teleconferencing ITS that improves the eco-impact of the business operations of mines through the elimination of transportation use (Kusi-Sarpong et al., 2015). Next, in the implementation order of GITS sub-practices is GITS3 (Reducing electronic waste associated with obsolete equipment) and GITS1 (Use of energy efficient hardware and data centers). Finally, it was found that organizations should work on GITS5 (Green Purchasing and Eco-labeled of ITS products). This is because some form of difficulties may arise if the home location of mines is in a developing country as the availability and understanding of eco-labels, especially for ITS, may be scarce (Scott and Vigar-Ellis, 2014).

The study integrates Figure 2 and Figure 3 to construct a general path framework of GSCM for the Ghanaian gold mining industry. The performance landscape is generated for combinations of different GSCM practices or GITSs by the Grey-NK model informed by interdependencies from the Grey-DEMATEL method. The performance value of each GSCM practices or GITSs configuration is show with a grey number in the Table 12 and Table 13, such as  $F = (\underline{F}, \bar{F}) = [0.485, 0.801]$  for GSCM practices configuration (SSP + EOL). The minimum possible value  $\underline{F}$  of  $\otimes F$  represents the possible value of minimum gain for the implementation of this GSCM practice configuration (SSP + EOL). The maximum possible value  $\bar{F}$  of  $\otimes F$  represents the most possible value of maximum gain for the investment of this GSCM practice configuration (SSP + EOL). It doesn't always guarantee the both better value in the minimum possible value  $\underline{F}$  and the maximum possible value  $\bar{F}$  when compare two grey performance value. This brings up the problem that cannot be sorted for grey

number. This study introduces a possibility degree to enhance MCDM at this time and arrive at the dominance possibility for performance of GSCM practice configuration when compared to other GSCM practice configurations.

To understand the performance of GSCM practices and the interdependencies among GSCM practices, let's return to the Grey-DEMATEL results shown in Table 10. GSCM practices can be ranked according to the grey importance level based on the results shown in the Table 10. SSP is the most important when those GSCM practices are separately implemented. Evaluating the important of each GSCM practice and interdependencies among GSCM practices can give organization an intuitive feeling. Organizations can only consider these best GSCM practices if they only implement a single GSCM practice, but this is not suitable for implementing a set of GSCM practices.

## 4.2 Comparative Analysis

For the illustrative case, an integrated evaluation of the six companies is presented. Then, a path model for each company is set up with a comparison of the differences between them.

### 4.2.1 *Developing a path framework for each company's GSCM practices*

The evaluation for each company is now introduced and a path framework for each company's GSCM practices is developed. The result of the implementation sequence as follows:

Organization 1: SSP→EOL→ECO→OLI→IEM→GITS

Organization 2: EOL→SSP→IEM→OLI→GITS→ECO

Organization 3: ECO→GITS→SSP→IEM→EOL→OLI

Organization 4: SSP→IEM→GITS→OLI→EOL→ECO

Organization 5: SSP→EOL→ECO→IEM→OLI→GITS

Organization 6: ECO→IEM→EOL→SSP→GITS→OLI

First, as can be seen from these results, no two companies have the same implementation path. This result illustrates the need to build a different path model according to different business situations. Second, GITS is often placed in the final stage of implementation. It was found that GITS is the last implementation in two companies and the second last implementation in two companies. In a followup on this issue with the respondents, it was found that the business respondents believed that only after the implementation of the relevant green activities, can they more explicitly identify which GITS to implement.

Third, SSP is often placed in the first implementation. It was found that SSP is the first GSCM practice to be implemented for three companies and the second GSCM practice implementation in one company. This shows that the role of suppliers for the organization is essential. Fourth, OLI is often appears as a latter practice, one of the last three, to be implemented for all companies. The above order trends are relatively consistent with the integrated evaluation of the six companies in the illustrative case. This shows that the integrated evaluation results in the illustrative case have a general guiding significance for these six case study Ghanaian gold mining companies.

#### 4.2. 2 *Developing a path framework for each company's GITS sub-practices*

A path implementation framework for each company GITS sub-practice for each

company was also determined. The result of the implementation sequence for each organization is summarized as follows:

Organization 1: GITS4→GITS2→GITS1→GITS5→GITS3

Organization 2: GITS5→GITS4→GITS3→GITS2→GITS1

Organization 3: GITS3→GITS1→GITS2→GITS4→GITS5

Organization 4: GITS2→GITS4→GITS1→GITS3→GITS5

Organization 5: GITS2→GITS4→GITS3→GITS5→GITS1

Organization 6: GITS2→GITS3→GITS4→GITS5→GITS1

As compared to the results above, this path across the companies is more consistent. Half of the companies felt that they should first implement GITS2 and half of the companies see GITS4 as the second GITS sub-practice to implement. Half of the companies see GITS5 as one of the latter practices to implement. Half of the companies also view GITS 1 as the last to GITS sub-practice to implement. The integration of the results from the six organizations helps to construct a unified path model to better guide their GITS sub-practices implementation.

## 5. Research and Managerial Implications

The results presented in this paper have several implications for GSCM practitioners and researchers alike.

Academically, this study advances the green supply management literature in three directions. First, it expands upon the previous approach of only considering operational practices and further develops and introduces green information technology systems (GITS) as an important component of GSCM practices. This

green conceptualization of information technology systems strengthens the theoretical foundation required for evaluation and monitoring of GSCM practices. Second, a view that simultaneously considers the order of implementation and the joint implementation of practices can help organizations effectively manage GSCM practices and make relevant decisions. It also supports green performance evaluation and monitoring for GSCM practices. The performance measurement system should consider the direct relation and the order of the practices. This joint consideration is necessary for organizations with limited resources and a large number of GSCM practices. Third, a theoretical path framework for GSCM practices was developed to support organizations on how to better introduce GSCM practices systematically, especially at which stage to introduce GITS practices. In this particular study, although the results are localized to a given industry in an emerging economy, GITS is identified as the last GSCM practice to be implemented. It supports or supplements other GSCM practices in order to make other GSCM practices better. This research result opens up the door for further research investigation of the relative importance of GITS for organizations seeking to green their supply chains.

The implications for Ghana are discussed second. In Ghana, the implementation of GSCM is still in the very early stages. It is a necessity for organizations to be given intuitive guidance from the theoretical knowledge and evaluation for GSCM (Bai et al., 2016). The approach in this paper can provide some initial guidance on the successful and effective implementation of GSCM practices, especially when considering the relationship among GSCM practices, not just on an individual GSCM practices. The organization can introduce different practices in a sequential process



for the best performance management. Overall speaking, Ghanaian gold mining industry should first build a good strategic supplier partnership as initial step for a successful GSCM, and last implement GITS as support role to support or improve other GSCM practices.

For small and medium sized organizations, may not be able to adopt all the GSCM practices simultaneously; it may have to pick and choose a set of GSCM practices with best strategy to maximize the performance due to resource limitations and other restrictions. The tool and initial study presented here provides appropriate mechanisms for the respondent companies to aid in identifying practices and implementation paths. The incremental implementation path may be the only feasible alternative to build a more complete practice for GSCM. They can also select a combination with limited practices according to their own resource to get the best performance.

There might be more than one path to achieve the goal, and allows some flexibility, especially as the number of alternative practices increases. There are 6 practices, and the number of possible combinations to be estimated would be  $2^6$ . This approach has been supported in the practice literature for green management where the typical argument is to find quick wins with high payback (Flaig, 2005).

Hence, it would be helpful to decision makers to not only delineate the relationship between GSCM practices, but also delineate the relationship among GSCM practices configuration and performance. This study identified the GSCM practices configuration that are most beneficial for performance as well as determining the relationship among GSCM practices that are most useful for

achieving superior performance. A summary of analysis of the results can provide insights into the investment or plan strategies for GSCM practices.

## 6. Conclusions

GSCM practices have recently received considerable attention in GSCM literature. Many organizations consider well-designed and implemented GSCM practice as an important tool for overall supply chain sustainable performance (Wu et al., 2016c). One of the core issues is that given the relative novelty of GSCM practices planning in the supply chain, the process and determination of implementation sequences for a wide variety of GSCM practices is not easy to determine. This study fills a gap in the research by introducing a decision and management support tool to help guide organizations successfully and effectively implement and sequentially introduce different GSCM practices. The nature of GSCM project and practices interdependencies are complex. Understanding these complex relationships is one of the goals and contributions of this study, especially within the context of an emerging economy country, such as Ghana, situation.

Implementing these GSCM practices in the mining industry heavily requires and relies on information technology and systems (ITS). This paper expands upon previous studies that only consider operational green supply chain practices and introduces green information technology systems (GITS) practices as important GSCM practices elements. The green conceptualization of information technology systems strengthens the theoretical foundation required for evaluation and monitoring of GSCM practices. This paper not only investigates the relationship between GITS practice and other GSCM practices, but also provides a methodology to determine best implementation sequences for introducing GITS practices within the GSCM

adoption process.

The GSCM practices implementation and investment decision problem is complex. The GSCM practices were evaluated through a strategic evaluation methodology utilizing a structural analysis tool based on a Grey-DEMATEL and Grey-NK model with managerial input from six Ghanaian gold mining companies. Methodologically this study made a contribution to the NK approach by more thoroughly integrating DEMATEL and grey system theory; which addresses some NK model limitations. DEMATEL helps delineate the interdependencies structure of various GSCM practices. To address uncertainty of human subjective judgments, grey system theory is applied. The methodology is useful for integrating the perceptions and perspectives of various companies and experts.

The case company evaluations results provide some initial insights into the GSCM and GITS practices importance and implementation sequencing. For these case organizations developing SSP with their suppliers is an important initial step for a successful GSCM. The next important GSCM practice is EOL management due to mining industry characteristics, which has significant end-of-life management issues due to precious metal characteristics of its product environment. The remaining GSCM practices implementation order is ECO, IEM, and OLI, with any changes in this elements' sequence having no significant performance effects. The ordering based on performance expectations was somewhat surprising, since GITS seemed to play a supporting role, as the last recommended implementation. This result implies GITS is needed for supporting improvement of other GSCM practices. This implementation order is a theoretical path framework for GSCM practices developed to help organizations on how to better introduce GSCM practices step by step, especially at which step to introduce GITS practices. Evaluation of an actual

implementation process would help confirm these initial planning results.

Clearly, this is only a small example of the technique and various practices and strategies may have different relationships in differing contexts. The Ghana situation, although having great concerns for environmental protection, may have differing priorities than more developed countries. The initial results of the path framework determined in the case study can serve as a reference for other situations and industries.

Establishing a valid and reliable framework for GSCM practices contributes to a better understanding of the nature of GSCM practices. Although there are multiple contributions and utility associated with this study and methodology, limitations do exist. But, these limitations provide a room for an improvement that can provide fodder for further research in this domain.

In terms of broader GSCM issues, this application used just six practices. The technique is malleable and can incorporate more than six practices in a way that particularly suits the different environmental and greening goals of a buyer. For example, GSCM practices can be expanded to incorporate social or sustainable practices that are exogenous and strategically related to the competitive environment. The paper evaluated just the strategic level practices, which can be divided into more detailed sub-practices, such as sub-practices in GITS. This approach can provide more detailed guidance on the effective implementation and operation of sub-practices. Therefore, further research could investigate how to map component strategy level practices to more meaningful sub-practices.

Contextual characteristics are a factor that influence GSCM practices implementation order. However, organizations are not well attuned to which implementation order for GSCM practices is effective under specific contextual

conditions. Some contextual factors such as national policies and regulations, supplier relationships, organizational or industry characteristics, which have been identified as the contingency factors which may affect the effectiveness of a best practice. A flexible path model of GSCM practices to identify the effect of conditional factors on the implementation order of GSCM practices can be developed and studied using the general methodology introduced in this paper.

GSCM practices are not dependent on performance alone, cost can also be involved in GSCM. Integration of these cost dimensions is critical for a comprehensive evaluation. Extending this work to incorporate cost may also be an avenue for further research.

This model remains relatively abstract in nature. First, each GSCM practice can take one of two values 0 or 1, which means each practice within the GSCM has two possible options: implement or not implement. There is no consideration of the implement degree of each GSCM practice, which will impact on the performance value. In the GSCM practice implementation, organization has limited resources or other constraints, and it is necessary to determine the best GSCM practices and investment quantity of each GSCM practices. Therefore, further research could investigate how to select a set of GSCM practices and then allocating the resources investment quantities among them to get the maximum performance outcome.

Even though some limitations and disadvantages do exist within this study, the multi-step methodology provides some useful insight and support for GSCM practices implementation. Advancing knowledge into a path framework of GSCM practices will also advance the understanding and acceptance of green supply chain research and practices. This formal analytical methodology can play an important role in improving GSCM strategy and operations plan. This initial research helps open many

opportunities for further investigation.

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Figure 1: A NK model for green supply chain management

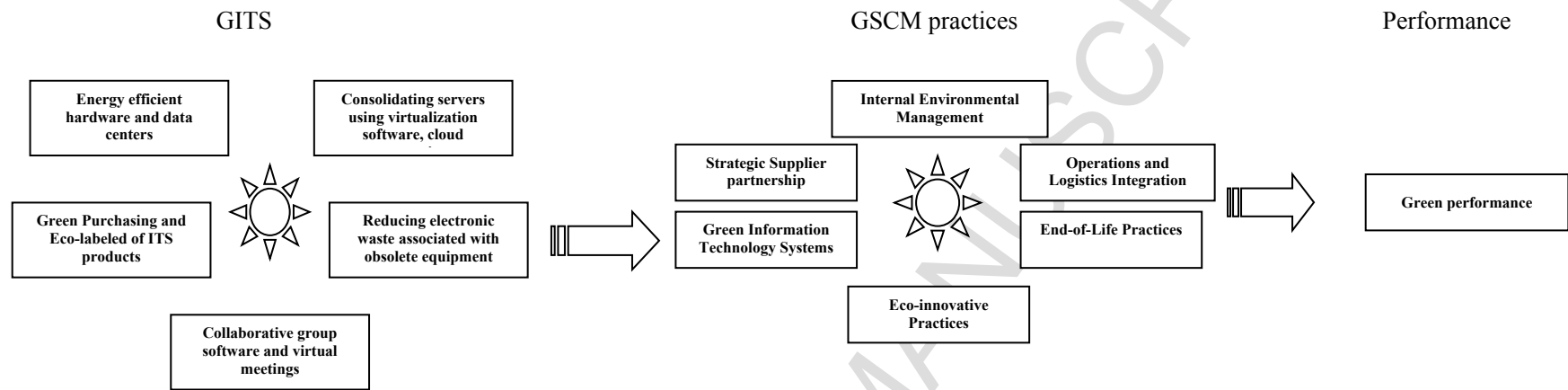


Figure 2: An optimal path of GSCM practices for the 3D-visualization of the 'landscape'

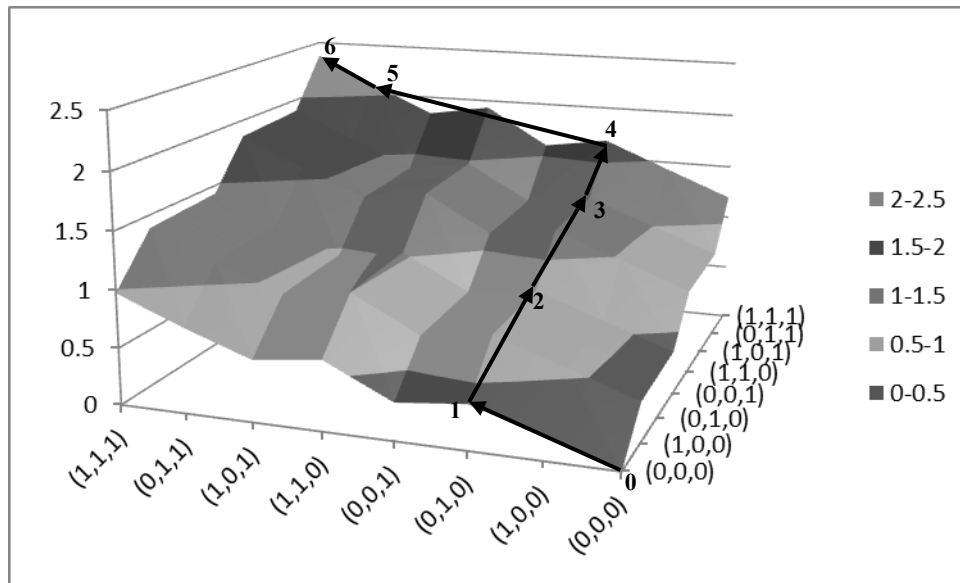


Figure 3: An optimal path of GITS's for the 3D-visualization of the 'landscape'

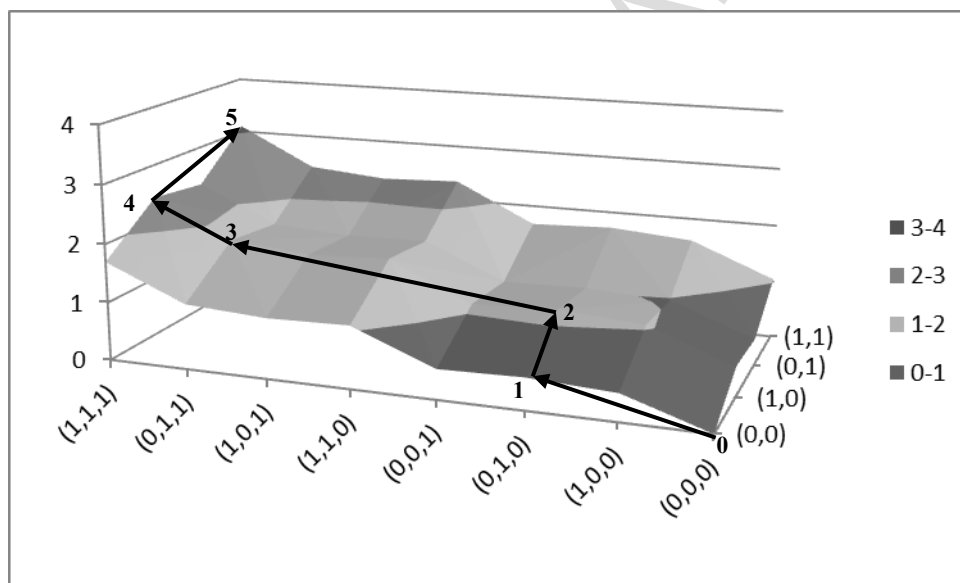
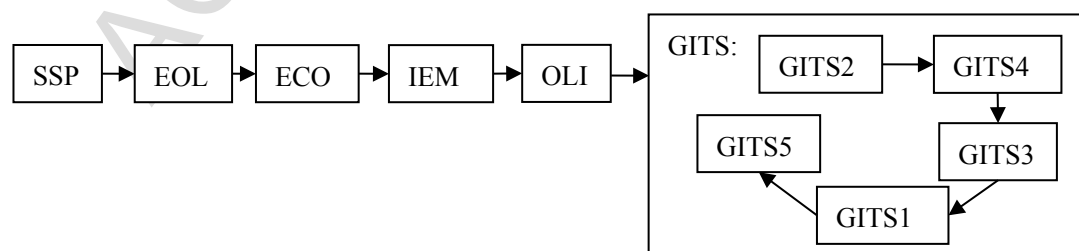


Figure 4: The best optimal path framework of GSCM for Ghanaian mining industry.



**Table 1 GSCM practices (factors) and their sub-factors in the mining industry (\* focused practices)**

No.	GSCM Factors and Sub-factors		Literature
<b>1</b>	<b>Green Information Technology and Systems (GITS) *</b>		
<b>Sub-Factors</b>	<b>GITS1</b>	Use of energy efficient hardware and data centers *	Watson et al., 2008; Jenkin et al., 2011; Chou et al., 2012; Setterstrom, 2008; Sarkis and Zhu, 2008; Wagner et al., 2009; Uddin and Rahman, 2012
	<b>GITS2</b>	Consolidating servers using virtualization software *	
	<b>GITS3</b>	Reducing waste associated with obsolete equipment *	
	<b>GITS4</b>	Collaborative group software and telepresence systems *	
	<b>GITS5</b>	Eco-labeling of IT products *	
<b>2</b>	<b>Strategic Suppliers Partnership (SSP) *</b>		
<b>Sub-Factors</b>	<b>SSP1</b>	Jointly develop environmental management solutions	Vachon et al. 2001; Rao 2002; Geffen and Rothenberg 2000, Simpson and Power, 2005; Simpson et al., 2007
	<b>SSP2</b>	Jointly build programs to reduce or eliminate materials use	
	<b>SSP3</b>	Share environmental management techniques and knowledge	
	<b>SSP4</b>	Collaborate with suppliers to manage reverse flows of materials and packaging	
	<b>SSP5</b>	Communicate goals of sustainability to suppliers	
	<b>SSP6</b>	Monitor environmental compliance status and practices of supplier's operations	
<b>3</b>	<b>Operations and Logistics Integration (OLI) *</b>		
<b>Sub-Factors</b>	<b>OLI1</b>	Lean and green operations	Kleindorfer et al., 2005; Hajmohammed et al., 2013; Vachon, 2007; Wee & Quazi, 2005; Min and Galle, 2001; Carter and Easton, 2011; Zsdisin and Hendrick, 1998
	<b>OLI2</b>	Process redesign to reduce use of scarce or toxic resources and energy consumption	
	<b>OLI3</b>	Community/environmental, employee health and safety concerns	
	<b>OLI4</b>	Internal process integration and production automation	
<b>4</b>	<b>Internal Environmental Management (IEM) *</b>		
<b>Sub-Factors</b>	<b>IEM1</b>	Total quality environment management	Vachon and Klassen, 2008; Min and Galle, 2001; Azevedo et al., 2012; Simpson et al., 2007; Vachon and Klassen, 2006; Baram and Partan, 1990
	<b>IEM2</b>	Environmental compliance monitoring and auditing	
	<b>IEM3</b>	Pollution prevention plans	
	<b>IEM4</b>	Environmental manager and training for employees	
	<b>IEM5</b>	Environmental standards/ISO14001 certification by suppliers	
	<b>IEM6</b>	Employee incentive programs for environmental suggestions	
<b>5</b>	<b>Eco-Innovation practices(ECO) *</b>		
<b>Sub-Factors</b>	<b>ECO1</b>	Substituting toxic inputs with environmentally friendly ones	Carter and Easton, 2011; Vachon, 2013; Azevedo et al., 2012; Paulraj, 2009; Rao & Holt, 2005
	<b>ECO2</b>	Use of fewer inputs to minimize the environmental risks and impacts	
	<b>ECO3</b>	Switching from "dirty" to cleaner technologies	
	<b>ECO4</b>	Internal recycling of inputs, materials and wastes	

<b>6</b>	<b>End-of-Life practices (EOL) *</b>		
<b>Sub-Factors</b>	<b>EOL1</b>	Resale of used parts or components	Stock, 2001; Sarkis, 2003; Rogers and Tibben- Lembke, 2001; Bell et al., 2013
	<b>EOL2</b>	Recondition and refurbishing of used parts or components	
	<b>EOL3</b>	Old/obsolete items being replaced	
	<b>EOL4</b>	Cyanide and arsenic solution recovery and carbon regeneration	
	<b>EOL5</b>	Mining of Tailings	

Source: Kusi-Sarpong et al, 2015

**Table 2** The six mining industry managers and their companies' characteristics

*The six mining industry managers involved in the study*

<b>Manager 1 &amp; Company 1</b>	<b>Manager 4 &amp; Company 4</b>
<b>Position:</b> Supply Manager	<b>Position:</b> Assistant Supply Chain Manager
<b>Role:</b> Management of sourcing/procurement, contract & warehouse	<b>Role:</b> Management of sourcing/procurement, contract & warehouse
<b>Number of Mining Working Years:</b> 19years	<b>Number of Mining Working Years:</b> 10years
<b>Manager 2 &amp; Company 3</b>	<b>Manager 5 &amp; Company 5</b>
<b>Position:</b> Local Supplier & Contractor Development Reg. Manager	<b>Position:</b> Commercial Business Optimization Assistant Manager
<b>Role:</b> Develops & monitors local suppliers and contractors capacity	<b>Role:</b> Commercial (supply, account & admin) business improvement
<b>Number of Mining Working Years:</b> 15years	<b>Number of Mining Working Years:</b> 11years
<b>Manager 3 &amp; Company 2</b>	<b>Manager 6 &amp; Company 6</b>
<b>Position:</b> Environmental Manager	<b>Position:</b> Senior Procurement Manager
<b>Role:</b> Env'tal program implementations and compliance monitoring	<b>Role:</b> Procurement & contract program implementation & training
<b>Number of Mining Working Years:</b> 22years	<b>Number of Mining Working Years:</b> 14years

*The six purposively sampled mining companies interested in greening their operations*

<b>Company 1</b>	<b>Company 4</b>
<b>Size:</b> 2.1million tonnes per year with workforce size of 246	<b>Size:</b> 2.5million tonnes per year with workforce size of 700
<b>Type of Minerals:</b> Gold	<b>Type of Minerals:</b> Gold
<b>Stock listings:</b> TSX(EDV), ASX(EVR) & OTCQX(EDVMF)	<b>Stock listings:</b> ASX/TSX (PRU)
<b>Company 2</b>	<b>Company 5</b>
<b>Size:</b> 13.3 million tonnes per year with workforce size of 3,500	<b>Size:</b> 3.5 million tonnes per year with workforce size of 1670
<b>Type of Minerals:</b> Gold	<b>Type of Minerals:</b> Gold
<b>Stock listings:</b> JSE Ltd, NYSE, NASDAQ DUBAI, NYX & SWX	<b>Stock listings:</b> TSE/NYSE
<b>Company 3</b>	<b>Company 6</b>
<b>Size:</b> 7.5 million tonnes ounces yearly with workforce size of 8539	<b>Size:</b> 2.7 million tonnes per year with workforce size of 700
<b>Type of Minerals:</b> Gold	<b>Type of Minerals:</b> Gold
<b>Stock listings:</b> NYSE (NEM)	<b>Stock listings:</b> TSX (GSC), NYSE (GSS), & GSE (GSR)

**Table 3** The respondents' assessments of linguistic terms and grey number.

<b>Linguistic terms</b>	<b>Grey numbers</b>
No influence(N)	[0,0]
Very low influence(VL)	[0,0.25]
Low influence(L)	[0.25,0.5]
High influence(H)	[0.5,0.75]
Very high influence(VH)	[0.75,1.00]

Table 4 The grey direct-relation matrix for GSCM by organization 1.

Major practices	GITS	SSP	OLI	IEM	ECO	EOL
GITS	[0,0]	[0.25,0.5]	[0,0]	[0,0.25]	[0,0.25]	[0,0]
SSP	[0.5,0.75]	[0,0]	[0.5,0.75]	[0.25,0.5]	[0.5,0.75]	[0.5,0.75]
OLI	[0,0.25]	[0.25,0.5]	[0,0]	[0,0.25]	[0.25,0.5]	[0.25,0.5]
IEM	[0,0.25]	[0.25,0.5]	[0,0]	[0,0]	[0.25,0.5]	[0,0]
ECO	[0,0]	[0.25,0.5]	[0.25,0.5]	[0.5,0.75]	[0,0]	[0.5,0.75]
EOL	[0.25,0.5]	[0.5,0.75]	[0.25,0.5]	[0.5,0.75]	[0.5,0.75]	[0,0]

Table 5 The grey sub-direct-relation matrices for GITS by organization 1.

Major GITSs	GITS1	GITS2	GITS3	GITS4	GITS5
GITS1	[0,0]	[0.5,0.75]	[0.25,0.5]	[0.25,0.5]	[0.25,0.5]
GITS2	[0,0.25]	[0,0]	[0.5,0.75]	[0.5,0.75]	[0.5,0.75]
GITS3	[0.25,0.5]	[0.25,0.5]	[0,0]	[0.5,0.75]	[0.25,0.5]
GITS4	[0.75,1]	[0.5,0.75]	[0.25,0.5]	[0,0]	[0.5,0.75]
GITS5	[0.25,0.5]	[0.25,0.5]	[0,0.25]	[0.25,0.5]	[0,0]

Table 6 The aggregate grey direct-relationship matrix  $M$  for GSCM by all organizations.

Major practices	GITS	SSP	OLI	IEM	ECO	EOL
GITS	[0,0]	[0.5,0.75]	[0.375,0.583]	[0.375,0.625]	[0.333,0.583]	[0.167,0.375]
SSP	[0.583,0.833]	[0,0]	[0.542,0.792]	[0.458,0.708]	[0.542,0.792]	[0.542,0.792]
OLI	[0.417,0.667]	[0.5,0.75]	[0,0]	[0.25,0.5]	[0.292,0.542]	[0.458,0.708]
IEM	[0.375,0.625]	[0.292,0.542]	[0.167,0.375]	[0,0]	[0.458,0.708]	[0.417,0.625]
ECO	[0.375,0.583]	[0.25,0.5]	[0.292,0.542]	[0.625,0.875]	[0,0]	[0.5,0.75]
EOL	[0.167,0.417]	[0.5,0.75]	[0.333,0.583]	[0.667,0.917]	[0.583,0.833]	[0,0]

Table 7 The aggregate grey sub-direct-relation matrix  $SM$  for GITS by all organizations.

Major GITSs	GITS1	GITS2	GITS3	GITS4	GITS5
GITS1	[0,0]	[0.5,0.75]	[0.25,0.5]	[0.25,0.5]	[0.25,0.5]
GITS2	[0,0.25]	[0,0]	[0.5,0.75]	[0.5,0.75]	[0.5,0.75]
GITS3	[0.25,0.5]	[0.25,0.5]	[0,0]	[0.5,0.75]	[0.25,0.5]
GITS4	[0.75,1]	[0.5,0.75]	[0.25,0.5]	[0,0]	[0.5,0.75]
GITS5	[0.25,0.5]	[0.25,0.5]	[0,0.25]	[0.25,0.5]	[0,0]

Table 8 The normalized grey direct-relation matrix ( $N$ ) for GSCM.

Major practices	GITS	SSP	OLI	IEM	ECO	EOL
GITS	[0,0]	[0.003,0.006]	[0,0]	[0,0.003]	[0,0.003]	[0,0]
SSP	[0.03,0.042]	[0,0]	[0.028,0.04]	[0.023,0.036]	[0.028,0.04]	[0.028,0.04]
OLI	[0.021,0.034]	[0.025,0.038]	[0,0]	[0.013,0.025]	[0.015,0.028]	[0.023,0.036]
IEM	[0.019,0.032]	[0.015,0.028]	[0.008,0.019]	[0,0]	[0.023,0.036]	[0.021,0.032]
ECO	[0.019,0.03]	[0.013,0.025]	[0.015,0.028]	[0.032,0.045]	[0,0]	[0.025,0.038]
EOL	[0.008,0.021]	[0.025,0.038]	[0.017,0.03]	[0.034,0.047]	[0.03,0.042]	[0,0]

Table 9 The normalized grey sub-direct-relation matrix ( $SN$ ) for GITS.

Major GITSs	GITS1	GITS2	GITS3	GITS4	GITS5
GITS1	[0,0]	[0.025,0.047]	[0.029,0.051]	[0.025,0.047]	[0.025,0.043]
GITS2	[0.025,0.047]	[0,0]	[0.036,0.058]	[0.051,0.072]	[0.029,0.051]
GITS3	[0.029,0.051]	[0.036,0.054]	[0,0]	[0.018,0.036]	[0.032,0.051]
GITS4	[0.025,0.043]	[0.051,0.072]	[0.04,0.058]	[0,0]	[0.036,0.054]
GITS5	[0.025,0.043]	[0.014,0.032]	[0.032,0.051]	[0.022,0.04]	[0,0]

Table 10 The grey total-relation matrix ( $T$ ) for GSCM.

Major practices	GITS	SSP	OLI	IEM	ECO	EOL	$\otimes P_i$
GITS	[0,0]	[0.003,0.006]	[0,0]	[0,0.003]	[0,0.003]	[0,0]	[0.111,0.2]
SSP	[0.032,0.048]	[0,0]	[0.028,0.04]	[0.023,0.036]	[0.028,0.04]	[0.028,0.04]	[0.237,0.388]
OLI	[0.023,0.039]	[0.025,0.038]	[0,0]	[0.013,0.025]	[0.015,0.028]	[0.023,0.036]	[0.182,0.324]
IEM	[0.02,0.036]	[0.015,0.028]	[0.008,0.019]	[0,0]	[0.023,0.036]	[0.021,0.032]	[0.208,0.352]
ECO	[0.021,0.035]	[0.013,0.025]	[0.015,0.028]	[0.032,0.045]	[0,0]	[0.025,0.038]	[0.219,0.367]
EOL	[0.011,0.027]	[0.025,0.038]	[0.017,0.03]	[0.034,0.047]	[0.03,0.042]	[0,0]	[0.234,0.379]

Table 11 The grey sub-total-relation matrix ( $ST$ ) for GITS.

Major GITSs	GITS1	GITS2	GITS3	GITS4	GITS5	$\otimes SP_i$
GITS1	[0.003,0.01]	[0.028,0.056]	[0.032,0.06]	[0.028,0.056]	[0.028,0.053]	[0.239,0.467]
GITS2	[0.029,0.057]	[0.005,0.014]	[0.04,0.069]	[0.053,0.081]	[0.033,0.062]	[0.304,0.54]
GITS3	[0.031,0.059]	[0.039,0.063]	[0.004,0.012]	[0.022,0.046]	[0.035,0.059]	[0.287,0.509]
GITS4	[0.029,0.054]	[0.054,0.082]	[0.044,0.069]	[0.005,0.014]	[0.04,0.065]	[0.303,0.527]
GITS5	[0.027,0.051]	[0.018,0.042]	[0.035,0.059]	[0.024,0.048]	[0.003,0.01]	[0.247,0.457]

Table 12 The overall fitness values for each GSCM configuration.

GITS( $c_1$ )	SSP( $c_2$ )	OLI( $c_3$ )	IEM( $c_4$ )	ECO( $c_5$ )	EOL( $c_6$ )	Fitness value	GITS( $c_1$ )	SSP( $c_2$ )	OLI( $c_3$ )	IEM( $c_4$ )	ECO( $c_5$ )	EOL( $c_6$ )	Fitness value
0	0	0	0	0	0	[0,0]	0	1	1	1	0	0	[0.653,1.14]
1	0	0	0	0	0	[0.111,0.2]	0	1	1	0	1	0	[0.667,1.16]
0	1	0	0	0	0	[0.237,0.388]	0	1	1	0	0	1	[0.687,1.182]
0	0	1	0	0	0	[0.182,0.324]	0	1	0	1	1	0	[0.696,1.195]
0	0	0	1	0	0	[0.208,0.352]	0	1	0	1	0	1	[0.715,1.208]
0	0	0	0	1	0	[0.219,0.367]	0	1	0	0	1	1	[0.727,1.226]
0	0	0	0	0	1	[0.234,0.379]	0	0	1	1	1	0	[0.632,1.115]
1	1	0	0	0	0	[0.356,0.608]	0	0	1	1	0	1	[0.65,1.132]
1	0	1	0	0	0	[0.297,0.537]	0	0	1	0	1	1	[0.663,1.152]
1	0	0	1	0	0	[0.322,0.565]	0	0	0	1	1	1	[0.699,1.196]
1	0	0	0	1	0	[0.334,0.58]	1	1	1	1	0	0	[0.78,1.386]
1	0	0	0	0	1	[0.347,0.59]	1	1	1	0	1	0	[0.794,1.406]
0	1	1	0	0	0	[0.431,0.743]	1	1	1	0	0	1	[0.812,1.425]
0	1	0	1	0	0	[0.454,0.767]	1	1	0	1	1	0	[0.823,1.441]
0	1	0	0	1	0	[0.466,0.784]	1	1	0	1	0	1	[0.84,1.456]
0	1	0	0	0	1	[0.485,0.801]	1	1	0	0	1	1	[0.852,1.474]
0	0	1	1	0	0	[0.394,0.694]	1	0	1	1	1	0	[0.756,1.354]
0	0	1	0	1	0	[0.407,0.713]	1	0	1	1	0	1	[0.772,1.368]
0	0	1	0	0	1	[0.425,0.73]	1	0	1	0	1	1	[0.785,1.388]
0	0	0	1	1	0	[0.439,0.751]	1	0	0	1	1	1	[0.821,1.433]
0	0	0	1	0	1	[0.454,0.763]	0	1	1	1	1	0	[0.901,1.589]
0	0	0	0	1	1	[0.466,0.78]	0	1	1	1	0	1	[0.922,1.611]
1	1	1	0	0	0	[0.554,0.976]	0	1	1	0	1	1	[0.936,1.633]
1	1	0	1	0	0	[0.577,1.001]	0	1	0	1	1	1	[0.969,1.673]
1	1	0	0	1	0	[0.589,1.017]	0	0	1	1	1	1	[0.901,1.586]
1	1	0	0	0	1	[0.606,1.032]	1	1	1	1	1	0	[1.032,1.849]
1	0	1	1	0	0	[0.513,0.92]	1	1	1	1	0	1	[1.051,1.868]
1	0	1	0	1	0	[0.527,0.939]	1	1	1	0	1	1	[1.066,1.889]
1	0	1	0	0	1	[0.542,0.953]	1	1	0	1	1	1	[1.099,1.93]
1	0	0	1	1	0	[0.558,0.977]	1	0	1	1	1	1	[1.027,1.836]
1	0	0	1	0	1	[0.572,0.987]	0	1	1	1	1	1	[1.183,2.094]
1	0	0	0	1	1	[0.584,1.004]	1	1	1	1	1	1	[1.317,2.364]



Table 13 The overall fitness values for each GITS configuration.

GITS1 ( $SC_1$ )	GITS2 ( $SC_2$ )	GITS3 ( $SC_3$ )	GITS4 ( $SC_4$ )	GITS5 ( $SC_5$ )	Fitness value	GITS1 ( $SC_1$ )	GITS2 ( $SC_2$ )	GITS3 ( $SC_3$ )	GITS4 ( $SC_4$ )	GITS5 ( $SC_5$ )	Fitness value
0	0	0	0	0	[0, 0]	1	1	1	0	0	[0.886, 1.701]
1	0	0	0	0	[0.239, 0.467]	1	1	0	1	0	[0.91, 1.732]
0	1	0	0	0	[0.304, 0.54]	1	1	0	0	1	[0.834, 1.622]
0	0	1	0	0	[0.287, 0.509]	1	0	1	1	0	[0.881, 1.675]
0	0	0	1	0	[0.303, 0.527]	1	0	1	0	1	[0.822, 1.596]
0	0	0	0	1	[0.247, 0.457]	1	0	0	1	1	[0.837, 1.609]
1	1	0	0	0	[0.559, 1.064]	0	1	1	1	0	[0.97, 1.793]
1	0	1	0	0	[0.543, 1.034]	0	1	1	0	1	[0.894, 1.686]
1	0	0	1	0	[0.558, 1.048]	0	1	0	1	1	[0.919, 1.72]
1	0	0	0	1	[0.5, 0.972]	0	0	1	1	1	[0.894, 1.667]
0	1	1	0	0	[0.614, 1.119]	1	1	1	1	0	[1.257, 2.429]
0	1	0	1	0	[0.64, 1.154]	1	1	1	0	1	[1.179, 2.315]
0	1	0	0	1	[0.565, 1.05]	1	1	0	1	1	[1.203, 2.346]
0	0	1	1	0	[0.61, 1.096]	1	0	1	1	1	[1.179, 2.293]
0	0	1	0	1	[0.553, 1.023]	0	1	1	1	1	[1.268, 2.415]
0	0	0	1	1	[0.568, 1.04]	1	1	1	1	1	[1.568, 3.099]