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Towards a Big Data Framework for the prevention and control of HIV/AIDS, TB and Silicosis in the mining industry

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Abstract

This paper proposes a big data integrated framework to assist with prevention and control of HIV/AIDS, TB and silicosis (HATS) in the mining industry. The linkage between HATS presents a major challenge to the mining industry globally. When the immune system is compromised by HIV/AIDS and silicosis, it makes it easier for tuberculosis to infect the body. In addition, the silica dust which affects the lungs may also cause silicosis and tuberculosis. The objective of this paper is to posit a big data integrated framework to assist in the prevention and control of HATS in the mining industry. Literature was reviewed in order to build a conceptual framework. Although this study is not the first to apply big data in healthcare, to the researcher's knowledge, it is the first to apply big data in understanding the linkage between HATS in the mining industry. The literature review indicates only a few studies using big data in healthcare with no research found on big data and HATS. It therefore makes a contribution to existing body of literature on the control of HATS. The proposed big data framework has the potential of addressing the needs of predictive epidemiology which is important in forecasting and disease control in the mining industry. The paper therefore lays a foundation for the use of viable systems model and big data to address the challenges of HATS in the mining industry. As part of future work, the framework will be validated using sequential explanatory mixed methods case study approach in mining organizations.

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1. Introduction

The mining sector is the industry most affected by the epidemics of HIV/AIDS and tuberculosis in Southern Africa [1]. The existence of very high risks HIV/AIDS and tuberculosis in the mining industry has been acknowledged since the 1980s, but little is being done to address the situation [1]. They state that the current policies and regulations in the mining industry have had little effect in the prevention and control of the epidemics of HATS. The other challenge is that the prevention and control of each disease though necessary, is insufficient in itself because of the interrelationship of the diseases. Many researchers state that many barriers exist in the way that tuberculosis and HIV/AIDS are perceived [2]. They challenge that failure to successfully integrate HATS control programs has the potential to threaten the viability of both programmes and note that a coordinated approach is needed if the increased incidence of HATS is to be reversed globally in the mining industry. The Millennium Development Goals acknowledge the global challenge of tuberculosis and its association with the HIV/AIDS pandemic. They also highlight the need of a coordinated approach supported at the highest level. In addition, they note that a single strategy has been seen to be limited to succeed in addressing the complex challenges of HATS epidemic. In Africa TB control remains weak and gains can still be made through strengthening of basic disease controls [2].

Corbett et al. [3] note that HIV/AIDS and Silicosis have severe effects on tuberculosis risk to mine workers due to their multiplicative interactions. The prevalence of silicosis in the mines leads to more mine workers being affected by tuberculosis. The mining industry has a higher risk of tuberculosis due to factors such as silica dust, crowded living conditions and HIV/AIDS infection [3]. In South Africa, historically the tuberculosis incidence rates in the gold mines have been always higher than the national average [2]. The higher TB incidence rates in the mines have been attributed to higher rates of exposure to silica dust and silicosis (silicosis increases risk of tuberculosis by up to 3 times), the HIV/AIDS epidemic (HIV/AIDS increases risk of tuberculosis by up to ten times) and the environmental factors associated with the mines [2]. This paper is organized as follows: Introduction, Brief Literature, Proposed Framework, Discussion and Conclusions. The next section presents the Literature Review on Epidemiology Approach, Systems Approach and Viable Systems Model, Big Data.

2. Literature Review

According to Murray et al. [4] the South African gold mines have the highest recorded rates of tuberculosis worldwide. They point out that the social circumstances in the mines contribute to serious interrelated epidemics of silicosis, tuberculosis and HIV infections. They add that the environmental factors such as single sex accommodation, overcrowding and silica dust exposure are conducive for the increase prevalence of HATS in the mining industry. They state that it is important to note that silicosis substantially increases the risk of TB to the same level of HIV/AIDS infection. Recent studies have also shown that silica exposure is associated with tuberculosis [4]. teWaterNaude et al. [5] note that the existing South African occupational exposure limit (OEL) of $0.1 mg/m^3$ of silica may not be protective for silicosis and suggest that the occupational exposure limit needs to be lowered to $0.025 mg/m^3$. Several researchers have found an association between increased severe silicosis and higher TB incidence in the gold mines in South Africa [3]. Other researchers found that silica dust exposure on its own increases tuberculosis risk and that this risk persists even after silica dust exposure ends. These findings have profound implications on occupational health policies in the mining industry [3].

2.1 Epidemiology Approaches to Tuberculosis

According to Roy and Chauhan [6] there are three epidemiology approaches to tuberculosis which are: analytic epidemiology (dealing with risks factors associated with the agent), descriptive approach (dealing with prevalence and incidence of tuberculosis infection) and lastly the predictive approach (dealing with the forecasting of the tubercular epidemic). They state that the epidemiology is important for the implementation of national tuberculosis control programmes. They add that in order to understand the epidemiological basis of tuberculosis control, there is a need to understand the dynamics of the disease and major determinants of epidemiology of tuberculosis. They proposed a four step model (exposure, infection, disease and death) for understanding epidemiology tuberculosis control. For this reason there is a need for establishing better systems for prevention, early diagnosis and treatment of HATS for miners, ex-miners and their families. Predictive epidemiology helps with developing system for effective control of diseases such as TB, silicosis and HIV/AIDS in the mines [6].

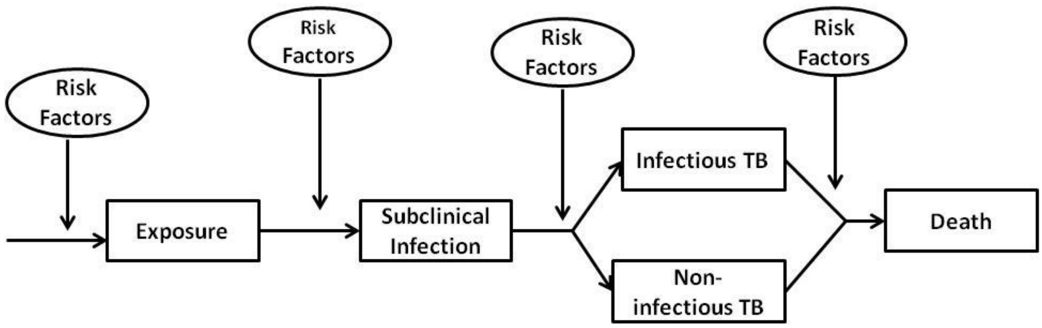

Figure 1. A model for tuberculosis epidemiology (Source: Roy et al, [6])

According to the model Figure 1, an exposure to an infection case is necessary to acquire the tuberculosis infection. The understanding of risk factors that lead to infection is dealt with by analytical epidemiology. The distribution and frequency of the disease in a given community is dealt with by the descriptive approach. Finally the forecasting and modeling of the epidemic based on observation from the past is dealt with by the predictive epidemiology. The insight from understanding risk factors of a given community is important to develop effective tools to prevent and control tuberculosis [6]. They state that predictive and descriptive epidemiology is essential for efficient and effective tuberculosis control programmes.

According to Khoury and Wagener [7] the prevention of common diseases relies on identifying risk factors and implementing intervention in high-risk groups. They add that the classical epidemiological paradigm of searching for "risk factors" and intervening in high-risk groups has enjoyed much success in controlling and preventing many infectious diseases. Boonstra and Broekhuis [8] emphasize that the implementation of an integrated health information systems has the potential for improving the quality and efficiency of health delivery system across the world. Paul et al. [9] state that integrated health information systems have the potential to offer economic benefits through efficiency savings via appropriate data management to identify potential bottlenecks in the provision and administration of care, which can become more predictable. The HATS problem situations are associated with issues that go beyond one discipline and require understanding of the big picture (holistic approach). Midgley [10] urges the use of a systems approach to public health because of the complexity of public health issues and numerous interacting variables. The next section looks at how systems approach can be used as a theoretical lens to understand the complexity of HATS in the mining industry.

2.2 *Systems Approaches*

Decision makers have been urged to become more aware of different strengths and weaknesses of different systems approaches [11]. He advises managers to balance the hard and soft systems approach to achieve efficiency and flexibility in organizations. The system of systems methodologies Figure 2 is based on the assumption that there is a fit between systems approaches and problem contexts [12]. The SOSM logic is that any single type of problem context can be assigned meaningfully to a conforming (dominant) systems approach. Hard systems thinking approaches are suitable for a problem situation that is targeted at improving efficiency and efficacy in a scenario having set goals and objectives [12]. Hard systems thinking assumes that problem situations in organizations can be understood using cause and effect relationships; and relies on such relationships to resolve problem situations. Soft systems thinking approaches assume that knowledge can be obtained from interpreting human thoughts and feelings through debates [12]. Soft systems thinking approaches also assume that problem situations in organizations are subjective since stakeholders have different worldviews.

Participants dimension of contexts (increasing diversity of values)

Systems dimension of contexts (increasing complexity)

	Unitary Hard Systems Approaches	Pluralist Soft Systems Approaches	Coercive Emancipatory Systems Approaches
Simple	Simple-unitary problem contexts •Operations research (OR) •Systems engineering (SE) •Systems analysis (SA)	Simple-pluralist problem contexts •Strategic assumption surfacing and testing (SAST)	Simple-coercive problem contexts •Critical systems heuristics
Complex	Complex-unitary problem contexts •System dynamics •Organizational cybernetics •Complexity theory	Complex-pluralist problem contexts •Interactive planning •Soft system methodology	Complex-coercive problem contexts •Critical systems approaches •Total system intervention

Fig. 2. SOSM Systems Approaches (Adopted from Reynolds et al, [12])

The emancipatory systems thinking assumption is that organizations are full of discrimination and oppression of certain members [12]. The emancipatory systems thinking emphasis is in emancipating and empowering oppressed stakeholders by the existing system. The critical systems thinking assumption is that organizations are too complex to understand using one approach. Critical systems thinking assumes that different approaches (hard, soft and emancipatory) can be used together to complement each other in complex problem situation in organizations. Most problem situations in organizations may not be understood and let alone solved using a single approach [12].

Based on Figure 2, the tuberculosis epidemic is classified as a hard complex-unitary problem context where there are agreements on the existence of a problem and what is required is how to address the problem situation. According to the literature, there is an agreement that tuberculosis is a complex problem mostly in the mining industry because of the environment. The rationale to address the problem situation, therefore, is to use a complex hard systems approach to prevent and control HATS in the mining industry. Hard systems thinking approaches have an emphasis on prediction and control to achieve desired objectives which are outside human observation [11]. This makes it suitable to assist mining organizations with the prevention and control of HATS. The use of cause and effect relationships of hard system thinking helps in the prediction of the prevalence of risk factors to allow effective interventions to the problem situation. Hard systems approach sees the organizational world as having a clearly identifiable purpose made up of systems which can be objectively studied. Applied hard systems approaches (such as organizational cybernetics) encourage multidisciplinary and interdisciplinary approaches to solve complex-unitary problem situations in organizations [11].

Organizational cybernetics which is a hard systems approach is based on the assumption that systems must not be broken down into parts in order to understand them, but require control by monitoring their output and manipulating inputs to achieve desired goals [13, 14]. Organizational cybernetics' philosophy is that complex systems are recursive in nature as higher level form is found in the parts which are viable on their own. The viable systems model (VSM) is part of organizational cybernetics, which uses various cybernetics laws and principles to improve organizational performance and is seen as appropriate for the prevention and control of HATS in the mining industry. The viable systems model is based on organizational cybernetics which is an interdisciplinary science which was transferred to the domain of management [13, 14]. Since viable systems model (VSM) is based on structuralist epistemology, it has been successful in the design of adaptive and goal seeking entities. VSM can be used to design or diagnose an organization to be sustainable in the environment [13].

VSM emphasizes greater autonomy of operations and systematic cohesion to achieve goals. The viable systems model as a model has been credited for being able to steer and provide insights to social systems based on its structuralist epistemology and explanatory power [14]. The viable systems model can be of help to organizations in developing a shared understanding of risk factors associated with HATS. The viable systems model has been attributed with enhancing empowerment and autonomy of parts through decentralization and change of structure. Based on Figure 3 below, the VSM is made up of five elements, System 1 (Implementation), System 2 (Coordination), System 3 (Operational Control) System 4 (Development) and System 5 (Policy). The different functions represented by the five elements need to be performed adequately for the overall system to remain viable.

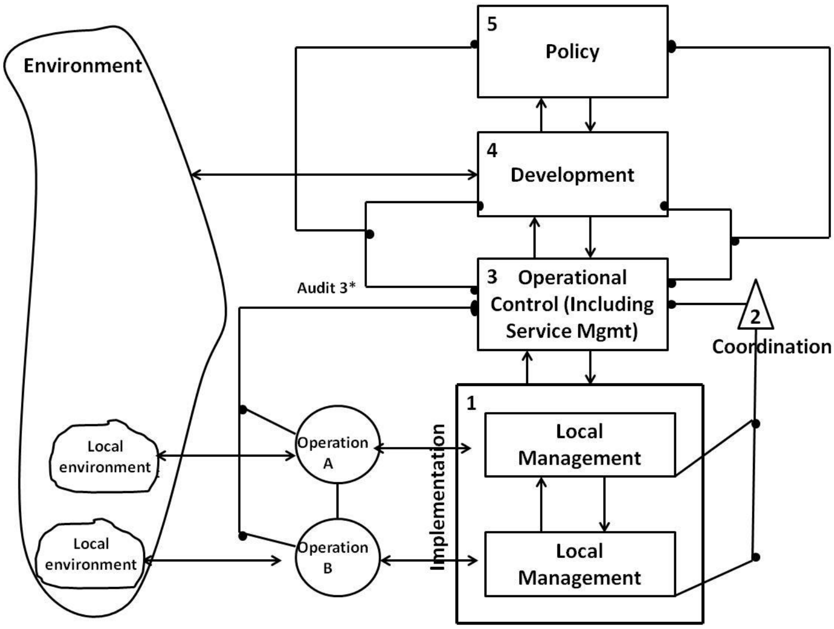

Fig. 3. The Viable System Model (Adapted from Jackson, [14])

Based on Figure 3, System 1 (Implementation) consists of various parts that carry out related tasks to achieve the purpose of the system. System 1 is viable on its own and responds to environmental changes according to its priorities. The goals and objectives of system 1 are set at System 5, refined into targets and report back performance to System 3. System 2 provides the coordination and audit function. System 2 is responsible for coordinating and ensuring that rules and regulations are obeyed. System 3* of System 3 is responsible for the auditing role to ensure that targets (System 3), rules and regulations (System 2) are obeyed. System 3 is responsible for operational control which includes performance monitoring and maintenance.

System 4 is responsible for development and decision making based on the information from System 3 and changes from the external environment. System 4 captures all the internal and external information to the organization for decision making purposes. The information in System 4 is important for predictions to be made about the future state of the system. The information is communicated to System 3 for quick interventions and System 5 for long term planning. System 4's other activities include corporate planning, research and development. System 5 is responsible for formulating policies using information from System 4 and communicating to System 3 for implementation. System 5 helps in balancing the external and internal demands placed on the organization. System 5 is responsible for ensuring that the organization adapts to its environment for its survival. This section presented how the viable systems model can assist in the prevention and control of HATS in the mining industry. In addition the section presented the fit between HATS and viable systems model from a systems approach perspective as a way forward in proposing the framework. The next section presents how big data can assist in the prevention and control of HATS as part of the proposed framework.

2.3 Big Data in Epidemiology

Big data has been defined as the collection of complex data sets difficult to manage and process using traditional applications [15]. Many researchers concur that big data which is in its early days has most of its potential for value creation still unclaimed [16]. Big data rely on large data sets and predictive analysis to produce insight for decision making in the healthcare sector. The power of big data to provide insights to problems in many disciplines has seen major investments and excitement in big data [17]. Whilst many sectors have embraced big data, the health sector is lagging behind on the use of big data [16]. The potential value creation of big data is in aggregating individual data sets into algorithm to provide insights rare with individual data sets. The benefits of big data are its ability to combine small separate data sets to allow correlations useful for decision making in the prevention and control of HATS. The availability of information improves decision making on the prevention and control of HATS in the mining industry. The management of big data is important to improve decision making on the complex multiplicative HATS through predictive modeling, statistics and algorithms. Most researchers concur that big data is the cornerstone of modern epidemiology because of the availability of computational and analytical tools to deal with complex large data sets [15]. A study by Harvard revealed that big data have a potential of realizing $300 billion annual savings in the US health sector [18]. In addition to the associated cost savings, in some cases it is a matter of life and death without big data. The combining of data sets allows an opportunity to learn the relationship between different TB risk factors in the mining industry. Many researchers concur that big data have potential to generate a hypothesis which helps to gain insights on HATS [6]. The lack of data on the impact of various risks (silicosis, HIV infection, malnutrition, diabetes, smoking, crowded living and indoor pollution) poses a challenge to the understanding of TB epidemic in the mining industry. The availability of information helps to narrow the focus on better preventive and control interventions and focus more on high prevalence low risk factors than low prevalence high risk factors (prevention paradox) [15]. The big data therefore have the potential to enable quicker interventions to hot spots through data driven monitoring of HATS in the individual mines. The ability to develop complex big data analytical techniques will enable to understand the cause and effect relationship HATS risk factors in the mining industry. Some of big data capabilities include reporting (What happened?), monitoring (What is happening now?), data mining (Why did it happen?), evaluation (Why did it happen), predictive (What will happen?) [16]. This section presented a brief literature on HATS, Epidemiology approaches; Viable System Model and Big Data on how they can contribute to the prevention and control of HATS. Table 1 below shows literature summary contributions used to propose the new framework presented in the next section. The next section presents the proposed integrated framework constructed based on literature.

Table 1. Literature summary on Approaches

Approaches	Contributions to the framework
Epidemiology Approaches	• Understand risk factors associated with diseases [6] • Understand distribution and frequency of diseases [6] • Understand dynamics of the diseases and major determinants [6] • Develop effective system control of diseases [6] • Predicting and forecasting of diseases [6] • Early diagnosis and treatment of diseases [16]
Viable System Model	• Understand cause and effect relationships of risk factors [12] • Emphasis on prediction and control of risk factors [12,13] • Control by monitoring output and manipulating inputs [12,13] • Encourages multidisciplinary and interdisciplinary approach [11,12] • Design adaptive and goal seeking entities[11,13] • Ensure regulations and rules are obeyed [11,13] • Continuous feedback loop [11,13] • Auditing to correct deviation from targets [11,13]
Big Data	• Allows management of large data sets [16] • Allows predictive modelling and analysis [15] • Allows aggregation of individual data sets [16] • Allows generation of algorithms to give insights [15] • Enables reporting, monitoring, data mining, evaluation and prediction [16] • Generate hypothesis [6] • Computational and analytical ability on large data sets [15]

3. The Proposed Big Data Framework

The previous sections presented a brief literature on HATS, Epidemiology, Viable Systems Model and Big Data in relation to their expected contribution to the proposed framework to assist with the prevention and control of HATS in the mining industry. This section present the proposed framework based on literature. Based on Figure 4 of the proposed framework, System 1 will be responsible for the primary activities of prevention and control of HATS. In this case it will be responsible for collecting data on various TB risk factors in the mines. System 2 will be responsible for ensuring that all stakeholders are involved, standards and procedures are being followed such as those dealing with acceptable silica dust exposure level to workers. In addition to that System 2 will ensure that there is communication between system 3 and system 1 to achieve the expected targets and resolve system conflicts were necessary. It will also helps in sharing common standards to be followed to achieve the objectives of the whole system and empower individual systems.

System 3 of the proposed framework is responsible for ensuring accountability to the mining companies by effective monitoring that standards are being adhered to in the industry. System 3 also ensures that there is collaboration between Department of Mines and mining companies responsible for the prevention and control of HATS. System 4 of the framework is responsible for planning for the future by studying the changing environment of the mining industry. This planning is achieved by getting continuous feedback of the changing environment in order to plan for long term viability. The ongoing continuous feedback from local mines is important for decision making on the prevention and control of HATS.

System 5 of the proposed framework is responsible for national policy making at the highest level with regard to tuberculosis programmes. System 5 has the authority to make decisions on TB programme implementation at the national level. It also serves as the final check for work done by mines and regional offices. Departments of Mines will enable the different mines to continually interact with the regards to the prevention and control of HIV/AIDS, TB and silicosis through regular audits and inspections. Wherever necessary, changes may be required at the mines or at national level in response to environmental changes in the mining industry such as the lowering occupational exposure limits (OEL) as suggested in the literature review section as the current level are considered too high to cause silicosis to the miners.

The big data component of the framework will be responsible for data management at the system 1 level were different TB risk factors will be captured and System 4. The big data component of the framework assists in the storage and generation of information required in the prevention and control HATS in the minig industry. The big data component will be responsible for recording the required data from different TB risk factors and combine the data to provide information with regard to the disease prevalence in the mining industry. The big data component will supply information on HATS prevelance in the mines to the relevant authorities for decision making and intervention strategies.

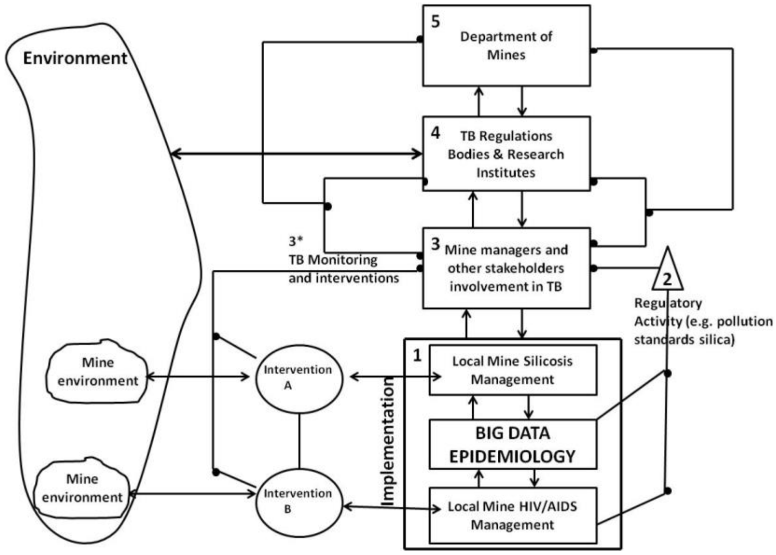

Fig. 4. The Proposed HATS Big Data Conceptual Framework (Adapted from Jackson, [14])

The predictive analysis from big data generates statistical results important to explain the relationship between risk factors in order to optimize the intervention strategies for the prevention and control of HATS in the mining industry. The big data predictive analysis of statitical results assists in improving to forecast HATS prevalence. In addition, silica dust exposure can be measured and controlled to reduce the prevelance of silicosis in the mines. The recording of the silica dust exposure is important to make sure that mines are compling with the agreed occupational exposure limits. The big data component addresses the concern that occupational exposures and survelliance systems in South Africa are weak with no proper predictive systems for decision making. Furthermore, it addresses the need for an integrated approach for the prevention and control of HATS [4]. The big data component will enable communication of epidemic prevelance trends to various stakeholders indicated in section 2.3. The success of the proposed framework will depend on the collection of massive data from different TB risk factors for accurate predictions to be used by policymakers to prevent and control of HATS. Reports generated from the proposed framework will be useful for reporting on the Millenium Development Goals on teburculosis.

The study will adopt a mixed methods sequential explanatory case study approach to validate the proposed integrated framework. The main advantage of the case study is its ability to mix qualitative and quantitative methods [19]. The case study adds completeness as it allows both quantitative and qualitative paradigms. The first quantitative phase will use questionnaires to collected data from participants on their perception of the proposed framework for the prevention and control of HATS. The second qualitative phase will use observation, documents review and semi-structured interviews as follow up to get answers to inconclusive quantitative responses [19]. After the interviews, the proposed framework will be refined to incorporate the input from the participants in order to produce a final framework. The companies will be selected from the gold mining companies in South Africa which have the highest prevalence of silica which causes silicosis. This will be also important to assess the control measure in place to reduce the exposure to silica of employees in the selected mines. Lastly, a final improved framework will be refined to incorporate results from the quantitative and qualitative phases.

4. Discussion and conclusion

The proposed integrated framework is expected to provide information for predicting and controlling HATS in the mining industry. Data from various TB risk factors will be integrated into a single database to provide statistical data that can be used for the prevention and control HATS in the mining industry. Most of the TB risk factors necessary for predictive analysis will be captured regularly to provide information for decision making and intervention strategies. The proposed framework will be able to provide data for analytical, descriptive and predictive epidemiology on HATS. The information provided will improve the surveillance of the epidemics in the mining industry. The proposed framework's strength is consolidating different data sets in order to produce information necessary for decision making and prevent managers from being overwhelmed by irrelevant information. The proposed framework is therefore one way towards a holistic and structured approach to understand the complex linkage of HIV/AIDS, tuberculosis and silicosis in mining industry. The limitation of the framework in that it has not been validated which is part of future work. Although the proposed framework has limitations, it may act as a stimulus for further research in the area. The researcher looks forward to refining the proposed integrated framework in further research after validation in mining organizations for improvements. Limitations of the study are that Big Data in healthcare is still relatively a new subject which makes it difficult to find solid articles that provide an overview of the new technology. The challenges of big data are issues of privacy, security, compliance with rules and regulations. Since the study is based on case studies which are based on small samples this may prove difficult to generalize the findings. To deal with these limitations the researcher recommends further research to address some of the shortcomings.

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