Barriers to BDPA applications in Sustainable HSC Practices

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Abstract

Big data and Predictive analytics (BDPA) research in humanitarian supply chain operations has gained popularity for its ability to manage disaster risks. BDPA approach not only aims to predict future events, but also concentrates on current events and further prepare for the future events. However, review of prior studies shows this area is highly diverse and fragmented. Further, BDPA driven approach in HSC operations is complicated due to presence of multiple barriers, whose interrelationships are yet to be documented for purpose of enhancing existing knowledge base. The gaps in existing literature motivated to pursue the current study and aim to identify the leading barriers and further categorize them and finally develop the contextual interrelationships using popular Fuzzy Total Interpretive Structural Modeling (TISM) approach. Fuzzy TISM is a well expressed mental model interpreting both the nodes (indicating 'what') and links (indicating 'how' and 'why') which serves as the basis for theory building process. The TISM model shows that the fifteen barriers have achieved eight levels and decision makers must aim to remove the bottom level barriers for achieving sustainability in humanitarian supply chain operations.

Keywords
Barriers, Big data and Predictive Analytics (BDPA), Fuzzy Total Interpretive Structural Modeling (TISM), Humanitarian Supply Chain (HSC), Sustainability.

1. Introduction
Disasters cause losses of human life, destruction of homes, infrastructure and disruption of normal life (O'Brien et al., 2006). The various strategies in risk management may include reducing exposure to disasters; increase resilience to changing climatic risks; transformation; reducing vulnerabilities; prepare, respond and recover; and transfer and share risks. Interestingly, BDPA in humanitarian supply chain (HSC) operations has proven to be a useful tool for reducing vulnerabilities in disaster situations (Akter & Wamba, 2017). However, review of prior literature shows this area is diverse and fragmented and BDPA application in the field of HSC operations is under a nascent stage which requires more research focus from future researchers. BDPA can create visibility to actors involved in HSC operations through access to real time information critical for reducing disaster risks. BDPA can be useful for preventing disasters by detecting disasters in advance and the information can be used for shifting the people in the community to safer zones and plan relief aids and logistics in a better fashion (Wang et al. 2016). In a pre or post disaster situation voluminous data is generated from multiple sources such as from web, social networks platforms, multimedia data and GPS data which is difficult to be managed mainly due to lack of updated technology platform for storage, processing and lack of adequate skilled manpower for correct interpretation. Big data is further complicated due to diverse in nature involving multiple sources and multiple formats which requires integration and analysis before the decision making can be done. So, the decision making of disaster management officials and HSC agencies depends on the timing and quality of information (Bag, 2016). Therefore, success of BDPA application in sustainable HSC operations solely depends on the right process of data collection, storage, structuring, processing and analyzing for producing accurate and timely information in managing disasters effectively (Zhang et al., 2012; Hazen et al. 2014). However, multiple challenges involved in BDPA application basically acts as barriers in sustainable HSC operations. Such barriers have been mentioned in few earlier studies but there is lack of research on categorizing and prioritizing the barriers. To bridge gap in the existing literature the current study aims to identify the key barriers and further develop the contextual interrelationships using advanced multi-criteria decision making technique.

The rest of the section is structured as under, as follows. Section 2 presents the review of prior literature followed by section 3 on research methods. The section 4 presents the Fuzzy TISM modelling. The final section covers the conclusion drawn from study followed by unique contribution and future research directions.

2. Literature Review

The aim of conducting the review of prior studies is to understand the progress of BDPA application in the field of HSC and further identify the leading barriers influencing the sustainable outcomes. The review resulted into some interesting observations. It was found that much progress has happened in the field of commercial supply chains considering BDPA applications. BDPA has been found to be effective in enhancing the operational and strategic capability of organizations, thus impacting positively on the financial performance (Hazen et al., 2016). This is due to the fact the BDPA can increase information transparency which results into better quality of decision making (Janssen et al., 2017). BDPA application in commercial supply chains can be enhanced through collaboration and improving relationships with suppliers (Bag, 2017). However, there are some basic differences between commercial supply chains and HSC which disables us from using the same theory (BDPA application in SCM) in HSC operations.
Humanitarian supply chains (HSC) are diverse in nature as compared to the commercial supply chains in many aspects. The basic attributes of HSC are unpredictability of demand, sudden demands of high volume for wide range of items, specialised logistics channel requirements, high level of uncertainty and high stakes associated with sufficient and well-timed delivery of supplies (van der Laan et al., 2016). HSC is further complicated due to involvement of dissimilar kind of actors in the decision making process (Day et al., 2012).

3. Methodology

In this section, research team discuss the research methodology and data collection strategy adopted for this study. To answer the research questions we found fuzzy interpretive structural modelling technique suitable in all aspects. This technique offers greater flexibility compared to ISM and TISM and at the same time eliminates the limitations offered by ISM. Fuzzy TISM is an advanced technique which is used by past researchers in theory building. Fuzzy TISM is a well articulated mental model interpreting both the nodes (signifying 'what') and links (signifying 'how' and 'why'). The mental model of the group are not well structured and loosely defined which serves as the basis for theory building process (Sushil, 2016). To gather data for building fuzzy TISM model, research team initially approached an HSC expert who is an ex-military (South African special forces) and was actively involved in disaster relief operations during South Africa floods in 2011 and 2013 South Sudan crisis. Through a brainstorming session for two hours, research team could establish the contextual relationship among the selected barriers. Based on request, this HSC expert gave contact details of four more HSC experts who are currently working with The Food and Agriculture Organization in South Africa; The South African Red Cross Society; United Nations Educational, Scientific and Cultural Organization and Southern Africa Trust. Research team made appointments and through similar brain storming sessions, data is collected from these four experts as well. Therefore, in total research team developed five SSIM matrices based on inputs from five HSC experts. Next, popular fuzzy TISM modelling technique is applied to develop the contextual interrelationships among the selected barriers. As explained previously, this technique eradicates the limitations of simple interpretive structural modelling. Moreover, fuzzy TISM provides greater flexibility in terms of understanding the level of strength among the selected criteria (Khatwani et al., 2015). The steps of fuzzy TISM are adopted from Khatwani et al., 2015.

4. Fuzzy TISM

This step presents the fuzzy TISM modelling. Table 1 presents the leading barriers which were indentified from review of existing literature and further refined through discussion with HSC experts.

4.1. Defining the Barriers

Table 1 Barriers to Big data usage in Sustainable Humanitarian Operations

Categories	Barriers	Definition
Informational Refers to big data generation in real time which can be used in	Multiple sources of data (Alharthi et al., 2017)	Big data is generated from multiple sources such as websites, social networks platforms, multimedia data and GPS data which make it difficult to be managed by data analysts and HSC agencies.

sustainable humanitarian operations to build resilience	Multiple formats of data (Alharthi et al., 2017)	The big data collection and organizing involves multiple formats which makes it too much complicated for data processing and interpretation.
Human Refers to data scientists involved in big data analysis and interpretation	Lack of skills for proper data processing and correct interpretation (Alharthi et al., 2017)	BDPA calls for special skills and knowledge which is important for analysis and correct information generation. However, these skills and knowledge are lacking in African context and is thus considered a barrier to BDPA application in HSC operations.
	Insufficient training and education (Sarkis et al., 2012)	There is lack of proper training and education on BDPA which results in poor performance among data analysts. Continuous education is important for upgrading knowledge in this dynamic environment.
Technological Refers to technology and systems necessary for exploiting big data in sustainable humanitarian operations	Complexity (Alharthi et al., 2017)	Technological complexity is a barrier to BDPA application in sustainable HSC operations. It increases system related complicatedness.
	Fear of new technology (Alharthi et al., 2017)	BDPA application involves complex technology which naturally raises fear on the mind of employees for lack of proper knowledge.
	Infrastructure un-readiness (Alharthi et al., 2017)	Poor infrastructure is one of the barriers to BDPA application in sustainable HSC operations. Both physical systems and software are important for smoothly running the BDPA programs.
Organizational Refers to agencies involved in sustainable humanitarian operations	Traditional mindset of existing employees (Alharthi et al., 2017)	Traditional thinking act as a barrier to BDPA application in HSC operations and it is important to change the mindset of employees working in HSC agencies for accepting the changes.
	Traditional organizational culture across the entire organization (Alharthi et al., 2017)	Cultural changes in the organization will help in developing an environment for better application of BDPA in HSC operations.
	Low focus on new employee development (Alharthi et al., 2017)	Developing BDPA skill sets among new employees is essential for long term sustainability in HSC operations.
	Lack of focus in instilling new management practices (Alharthi et al., 2017)	World class practices helps in better management of BDPA in the organization.
Social (implications for communities)	Low level of critical infrastructure resilience (Papadopoulos et al., 2017b)	Low level of resilience leads to disruption of normal life in the society.
	Poor quality of information sharing (Papadopoulos et al., 2017b)	This acts as a barrier to sustainable HSC operations which lead to untimely and poor decision making.
Economic (financial implications)	Low level of Public-private partnership (Papadopoulos et al., 2017b)	This acts as one the barriers to BDPA application in sustainable HSC operations. Attracting more public-private partnerships will change the current scenario and will enable sustainability.
	Short funding (Jahre & Heigh, 2008)	This is one the reason for poor BDPA infrastructure and lack of proper system across the HSC network. Managing resources efficiently in HSC is the key to success in disaster relief operations.

4.2 Findings

The data analysis using fuzzy TISM is presented in the annexure (Table 2 to Table 22). Based on the analysis the final TISM Digraph is developed and further presented in figure 1 below.

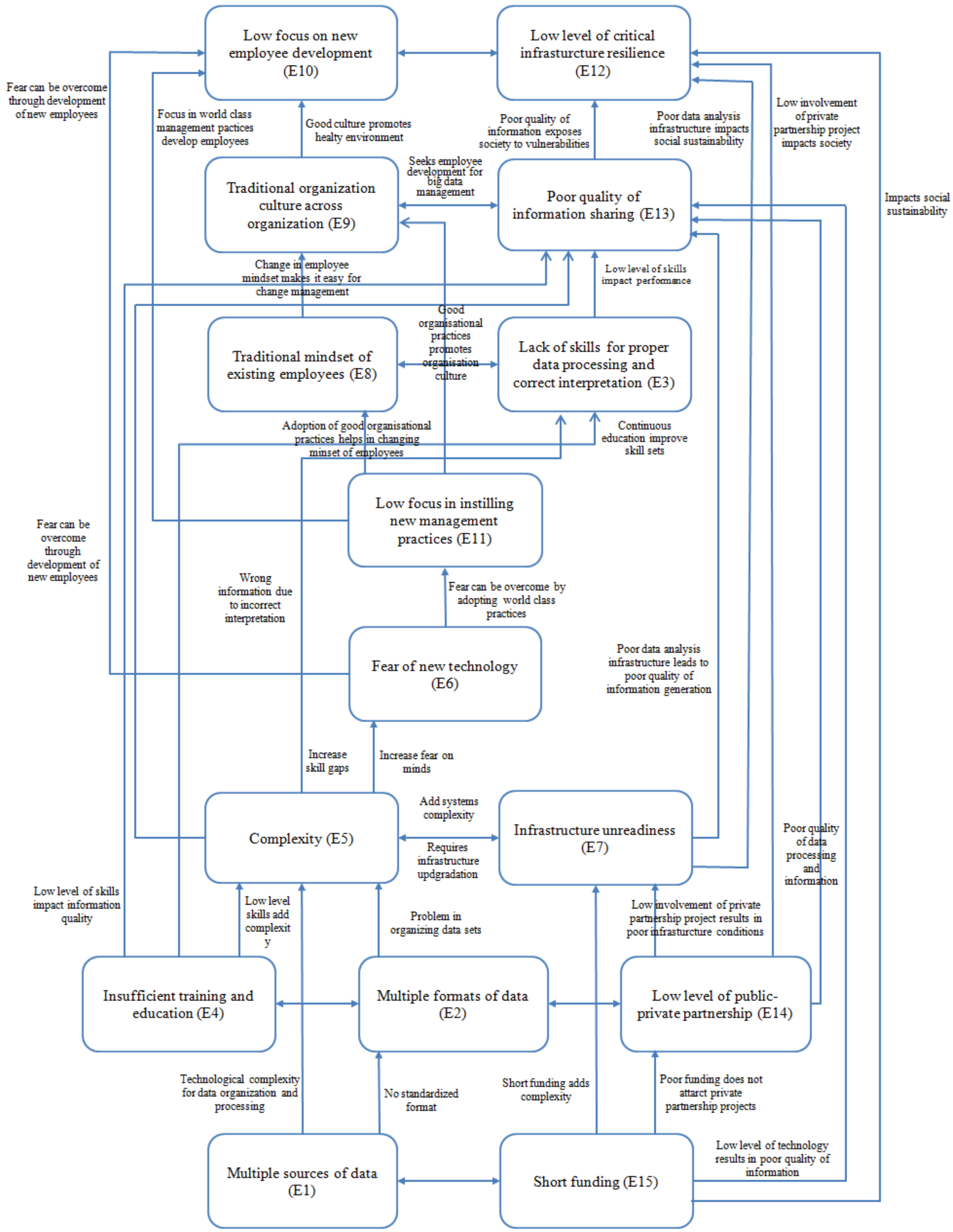

Fig 1. Defuzzified TISM Digraph (Source: Author own compilation)

Conclusion and Recommendations

The study aims to identify the contextual interrelationships among barriers to Big Data and Predictive Analytics (BDPA) application in sustainable humanitarian supply chain (HSC) operations. Through review of prior studies fifteen barriers are identified that is further modelled. The level partitioning yielded eight levels and it is found that developing a new employee and low level of critical infrastructure resilience are the top level barriers whereas the bottom level barriers include multiple sources of data and short funding. Managers should aim to remove the bottom level barriers so as to eliminate the other associated barriers. The strength of fuzzy TISM is that it enables a decision maker to understand the strength of influence of each barrier over other barriers thus making it easy for decision making under humanitarian operations. An interesting finding which emerges from the final model is that multiple sources of big data create a major problem in data collection, sorting and analysis due to involvement of multiple formats. Secondly, short funding also makes it difficult to run the HSC operations smoothly and fail to attract PPP projects which otherwise may benefit in getting the infrastructure ready for using complex technology required in BDPA processing and analysis. Moreover, due to lack of inadequate BDPA training and education among actors involved in HSC operations actually creates fear in the minds which is also a blockage in successful implementation of BDPA in HSC operations. Also such fears can block instilling new management practices in agencies involved in HSC operations. Management of both private agencies, government organizations and NGOs' should emphasize in changing the mindset of workforce through bringing change in the culture in the organization and focus in developing BDPA skills and knowledge creation in all new employees. It is found that infrastructure un-readiness in the under developed countries leads to serious complications such lack of BDPA processing and incorrect interpretation. Thus it results into poor quality of information sharing among disaster prone community. It is one of the reasons as well for low level of critical infrastructure resilience in African countries. The study corroborates with previous studies such as Maghsoudi & Pazirandeh (2016) which suggested that visibility and resource sharing is important for HSC sustainability which is only possible through implementation of BDPA. The key takeaways for managers are firstly, to prepare the groundwork such as standardizing a system for collecting big data and attract more funding sources so as to operate humanitarian operations sustainably. Developing the infrastructure for BDPA in African countries and focusing on BDPA knowledge management will play a crucial role in the success of modern HSC operations.

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Annexure

Table 2 Linguistic scales for the influence Source: Khatwani et al., (2015)

Linguistic terms	Linguistic values
Very high influence (VH)	(0.75,1.0,1.0)
High influence (H)	(0.5,0.75,1.0)
Low influence (L)	(0.25,0.5,0.75)
Very low influence (VL)	(0,0.25,0.5)
No influence (No)	(0,0,0.25)

Table 3 SSIM matrix of expert 1

Barriers	E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2
E1	O(No)	O(No)	V(VL)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	V(H)	O(No)	O(No)	V(VH)
E2	O(No)	O(No)	V(L)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	V(H)	O(No)	O(No)	
E3	O(No)	O(No)	V(H)	O(No)	O(No)	V(H)	O(No)	O(No)	O(No)	A(L)	A(H)	A(VH)		
E4	O(No)	O(No)	V(H)	O(No)	O(No)	O(No)	O(No)	O(No)	V(L)	V(L)	V(H)			
E5	O(No)	V(VL)	V(H)	V(L)	O(No)	O(No)	O(No)	O(No)	X(H)	V(H)				
E6	O(No)	V(L)	O(No)	O(No)	V(H)	V(H)	O(No)	O(No)	O(No)					
E7	A(VH)	A(VH)	V(VH)	V(H)	O(No)	O(No)	O(No)	O(No)						
E8	O(No)	O(No)	O(No)	O(No)	A(VH)	O(No)	V(VH)							
E9	O(No)	O(No)	O(No)	O(No)	A(VH)	V(H)								
E10	O(No)	O(No)	O(No)	O(No)	A(H)									
E11	O(No)	O(No)	O(No)	O(No)										
E12	A(VH)	A(VH)	A(H)											
E13	A(VH)	A(H)												
E14	A(VH)													

Table 4 SSIM matrix of expert 2

Barriers	E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2
E1	O(No)	O(No)	V(VL)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	V(H)	O(No)	O(No)	V(VH)
E2	O(No)	O(No)	V(L)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	V(H)	O(No)	O(No)	
E3	O(No)	O(No)	V(H)	O(No)	O(No)	V(H)	O(No)	O(No)	O(No)	A(L)	A(H)	A(VH)		
E4	O(No)	O(No)	V(H)	O(No)	O(No)	O(No)	O(No)	O(No)	V(L)	V(L)	V(H)			
E5	O(No)	V(VL)	V(H)	V(VL)	O(No)	O(No)	O(No)	O(No)	X(H)	V(H)				
E6	O(No)	V(L)	O(No)	O(No)	V(H)	V(H)	O(No)	O(No)	O(No)					
E7	A(VH)	A(H)	V(VH)	V(H)	O(No)	O(No)	O(No)	O(No)						
E8	O(No)	O(No)	O(No)	O(No)	A(VH)	O(No)	V(VH)							
E9	O(No)	O(No)	O(No)	O(No)	A(VH)	V(H)								
E10	O(No)	O(No)	O(No)	O(No)	A(H)									
E11	O(No)	O(No)	O(No)	O(No)										
E12	A(VH)	A(VH)	A(H)											
E13	A(VH)	A(H)												
E14	A(VH)													

Table 5 SSIM matrix of expert 3

Barriers	E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2
E1	O(No)	O(No)	V(VL)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	V(H)	O(No)	O(No)	V(VH)
E2	O(No)	O(No)	V(L)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	V(H)	O(No)	O(No)	
E3	O(No)	O(No)	V(H)	O(No)	O(No)	V(H)	O(No)	O(No)	O(No)	A(L)	A(H)	A(VH)		
E4	O(No)	O(No)	V(H)	O(No)	O(No)	O(No)	O(No)	O(No)	V(L)	V(L)	V(H)			
E5	O(No)	V(VL)	V(H)	V(L)	O(No)	O(No)	O(No)	O(No)	X(H)	V(H)				
E6	O(No)	V(L)	O(No)	O(No)	V(H)	V(H)	O(No)	O(No)	O(No)					
E7	A(H)	A(VH)	V(VH)	V(H)	O(No)	O(No)	O(No)	O(No)						
E8	O(No)	O(No)	O(No)	O(No)	A(VH)	O(No)	V(VH)							
E9	O(No)	O(No)	O(No)	O(No)	A(VH)	V(H)								
E10	O(No)	O(No)	O(No)	O(No)	A(H)									
E11	O(No)	O(No)	O(No)	O(No)										
E12	A(VH)	A(VH)	A(H)											
E13	A(VH)	A(H)												
E14	A(VH)													

Table 6 SSIM matrix of expert 4

Barriers	E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2
E1	O(No)	O(No)	V(VL)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	V(H)	O(No)	O(No)	V(VH)
E2	O(No)	O(No)	V(L)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	V(H)	O(No)	O(No)	
E3	O(No)	O(No)	V(H)	O(No)	O(No)	V(H)	O(No)	O(No)	O(No)	A(L)	A(H)	A(VH)		
E4	O(No)	O(No)	V(H)	O(No)	O(No)	O(No)	O(No)	O(No)	V(L)	V(L)	V(H)			
E5	O(No)	V(VL)	V(H)	V(L)	O(No)	O(No)	O(No)	O(No)	X(H)	V(H)				
E6	O(No)	V(L)	O(No)	O(No)	V(H)	V(H)	O(No)	O(No)	O(No)					
E7	A(VH)	A(VH)	V(VH)	V(H)	O(No)	O(No)	O(No)	O(No)						
E8	O(No)	O(No)	O(No)	O(No)	A(VH)	O(No)	V(VH)							
E9	O(No)	O(No)	O(No)	O(No)	A(VH)	V(H)								
E10	O(No)	O(No)	O(No)	O(No)	A(H)									
E11	O(No)	O(No)	O(No)	O(No)										
E12	A(VH)	A(VH)	A(H)											
E13	A(VH)	A(H)												
E14	A(VH)													

Table 7 SSIM matrix of expert 5

Barriers	E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2
E1	O(No)	O(No)	V(VL)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	V(H)	O(No)	O(No)	V(VH)
E2	O(No)	O(No)	V(L)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	V(H)	O(No)	O(No)	
E3	O(No)	O(No)	V(H)	O(No)	O(No)	V(H)	O(No)	O(No)	O(No)	A(L)	A(H)	A(H)		
E4	O(No)	O(No)	V(H)	O(No)	O(No)	O(No)	O(No)	O(No)	V(L)	V(L)	V(H)			
E5	O(No)	V(VL)	V(H)	V(L)	O(No)	O(No)	O(No)	O(No)	X(H)	V(H)				
E6	O(No)	V(L)	O(No)	O(No)	V(H)	V(H)	O(No)	O(No)	O(No)					
E7	A(H)	A(VH)	V(H)	V(H)	O(No)	O(No)	O(No)	O(No)						
E8	O(No)	O(No)	O(No)	O(No)	A(VH)	O(No)	V(VH)							
E9	O(No)	O(No)	O(No)	O(No)	A(VH)	V(H)								
E10	O(No)	O(No)	O(No)	O(No)	A(H)									
E11	O(No)	O(No)	O(No)	O(No)										
E12	A(VH)	A(VH)	A(H)											
E13	A(VH)	A(H)												
E14	A(VH)													

Table 8 Aggregated SSIM matrix

Barriers	E15	E14	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2
E1	O(No)	O(No)	V(VL)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	V(H)	O(No)	O(No)	V(VH)
E2	O(No)	O(No)	V(L)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	O(No)	V(H)	O(No)	O(No)	
E3	O(No)	O(No)	V(H)	O(No)	O(No)	V(H)	O(No)	O(No)	O(No)	A(L)	A(H)	A(VH)		
E4	O(No)	O(No)	V(H)	O(No)	O(No)	O(No)	O(No)	O(No)	V(L)	V(L)	V(H)			
E5	O(No)	V(VL)	V(H)	V(L)	O(No)	O(No)	O(No)	O(No)	X(H)	V(H)				
E6	O(No)	V(L)	O(No)	O(No)	V(H)	V(H)	O(No)	O(No)	O(No)					
E7	A(VH)	A(VH)	V(VH)	V(H)	O(No)	O(No)	O(No)	O(No)						
E8	O(No)	O(No)	O(No)	O(No)	A(VH)	O(No)	V(VH)							
E9	O(No)	O(No)	O(No)	O(No)	A(VH)	V(H)								
E10	O(No)	O(No)	O(No)	O(No)	A(H)									
E11	O(No)	O(No)	O(No)	O(No)										
E12	A(VH)	A(VH)	A(H)											
E13	A(VH)	A(H)												
E14	A(VH)													

Table 9 Fuzzy reachability matrix based on aggregated fuzzy SSIM matrix

Barriers	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
E1		VH	No	No	H	No	No	No	No	No	No	No	VL	No	No
E2	No		No	No	H	No	No	No	No	No	No	No	L	No	No
E3	No	No		No	No	No	No	No	No	H	No	No	H	No	No
E4	No	No	VH		H	L	L	No	No	No	No	No	H	No	No
E5	No	No	H	No		H	H	No	No	No	No	L	H	VL	No
E6	No	No	L	No	No		No	No	No	H	H	No	No	L	No
E7	No	No	No	No	H	No		No	No	No	No	H	VH	No	No
E8	No	No	No	No	No	No	No		VH	No	No	No	No	No	No
E9	No	No	No	No	No	No	No	No		H	No	No	No	No	No
E10	No	No	No	No	No	No	No	No	No		No	No	No	No	No
E11	No	No	No	No	No	No	No	VH	VH	H		No	No	No	No
E12	No	No	No	No	No	No	No	No	No	No	No		No	No	No
E13	No	No	No	No	No	No	No	No	No	No	No	H		No	No
E14	No	No	No	No	No	No	VH	No	No	No	No	VH	H		No
E15	No	No	No	No	No	No	VH	No	No	No	No	VH	VH	VH	

Table 10 Final fuzzy reachability matrix ~ Z of 5 experts with fuzzy and crisp values of driving power and dependence of criteria

Bar rier s	E1	E2	E3	E4	E5	E6	E7	E8	E9	E1 0	E11	E12	E13	E14	E1 5	Driv ing pow er	C ri s p v a l u e
E1	(1, 1, 1)	(0. 75, 1,1)	(0,0 ,0.2 5)	(0, 0, 0.	(0. 5,0 .75 ,1)	(0,0, 0.25)	(0,0, 0.25)	(0, 0,0. 25)	(0, 0, 0.	(0, 0,0 .25)	(0,0 ,0.2 5)	(0,0 ,0.2 5)	(0,0. 25,0 .5)	(0,0 ,0.2 5)	(0, 0, 0.	(2.2 5,3, 6.25)	3 . 4 4

				25)					25)						25)		
E2	(0,0,0.25)	(1,1,1)	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)	(0,0,0.25)	(0,0,0.25)	(1.75,2.25,5.75)	2.66
E3	(0,0,0.25)	(0,0,0.25)	(1,1,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(2,2.5,6)	2.88
E4	(0,0,0.25)	(0,0,0.25)	(0.75,1,1)	(1,1,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(3.25,4.5,7.75)	4.77
E5	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(1,1,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0,0.25,0.5)	(0,0,0.25)	(3.25,4.75,8.25)	4.91
E6	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)	(0,0,0.25)	(0,0,0.25)	(1,1,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)	(0,0,0.25)	(2.5,3.5,7)	3.82
E7	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(1,1,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0.75,1,1)	(0,0,0.25)	(0,0,0.25)	(2.75,3.5,6.75)	3.90
E8	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(1,1,1)	(0.75,1,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(1.75,2,5.25)	2.45
E9	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(1,1,1)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(1.5,1.75,5.25)	2.95
E10	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(1,1,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(1,1,4.50)	1.56
E11	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.75,1,1)	(0.75,1,1)	(0.5,0.75,1)	(1,1,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(3,3.75,6.75)	2.27
E12	(0,0,0.	(0,0,0.25)	(0,0,0.25)	(0,0,0.	(0,0	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.	(0,0	(0,0,0.25)	(1,1,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.	(1,1,4.5)	1.

	25)			25)	.25)				25)	.25)					25)		54
E13	(0, 0, 0.25)	(0, 0,0.25)	(0,0,0.25)	(0, 0, 0.25)	(0, 0,0.25)	(0,0, 0.25)	(0,0, 0.25)	(0, 0,0.25)	(0, 0, 0.25)	(0, 0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(1,1, 1)	(0,0,0.25)	(0, 0, 0.25)	(1.5, 1.75,5.25)	2.23
E14	(0, 0, 0.25)	(0, 0,0.25)	(0,0,0.25)	(0, 0, 0.25)	(0, 0,0.25)	(0,0, 0.25)	(0.75,1, 1)	(0, 0,0.25)	(0, 0, 0.25)	(0, 0,0.25)	(0,0,0.25)	(0.75,1, 1)	(0.5, 0.75,1)	(1,1,1)	(0, 0, 0.25)	(3,3.75,6.75)	4.09
E15	(0, 0, 0.25)	(0, 0,0.25)	(0,0,0.25)	(0, 0, 0.25)	(0, 0,0.25)	(0,0, 0.25)	(0.75,1, 1)	(0, 0,0.25)	(0, 0, 0.25)	(0, 0,0.25)	(0,0,0.25)	(0.75,1, 1)	(0.75,1, 1)	(0.75,1, 1)	(1, 1, 1)	(4,5, 7.5)	4.19
Dependence power	(1, 1, 4.5)	(1.75, 2,5.25)	(2.5,3.25,6.5)	(1, 1, 4.5)	(3, 4,7.5)	(1.75,2.25,5.75)	(3.25,4.25,7.25)	(1.75, 2,5.25)	(2.5, 3, 6)	(3, 4,7.5)	(1.5,1.75,5.25)	(3.75,5, 8)	(4.75,6.75,9.75)	(2,2.75, 6)	(1, 1, 4.50)		
Crisp value	1.53	2.48	3.70	1.53	4.44	2.75	4.60	1.07	3.36	4.41	2.69	5.15	6.60	3.13	3.39		

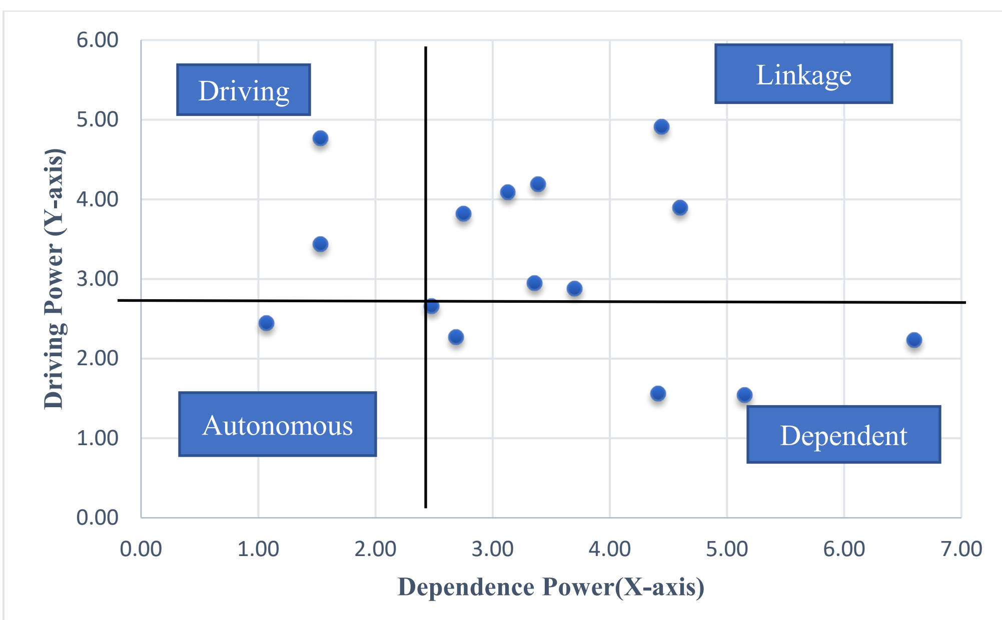

Fig 2 Driving power and Dependence Matrix (MICMAC) based on fuzzy reachability matrix of Table 10 (Source: Author own compilation)

Table 11 Categorizing barriers based on fig 1

No	Barriers	Dependence Power (X)	Driving Power (Y)	Sector	Category
E1	Multiple sources of data	1.53	3.44	IV	Driving
E2	Multiple formats of data	2.48	2.66	III	Linkage
E3	Lack of skills for proper data processing and correct interpretation	3.70	2.88	III	Linkage
E4	Insufficient training and education	1.53	4.77	IV	Driving
E5	Complexity	4.44	4.91	III	Linkage
E6	Fear of new technology	2.75	3.82	III	Linkage
E7	Infrastructure un-readiness	4.60	3.90	III	Linkage
E8	Traditional mindset of existing employees	1.07	2.45	I	Autonomous
E9	Traditional organizational culture across the entire organization	3.36	2.95	III	Linkage
E10	Low focus on new employee development	4.41	1.56	II	Dependent
E11	Lack of focus in instilling new management practices	2.69	2.27	II	Dependent
E12	Low level of critical infrastructure resilience	5.15	1.54	II	Dependent
E13	Poor quality of information sharing	6.60	2.23	II	Dependent
E14	Low level of Public-private partnership	3.13	4.09	III	Linkage
E15	Short funding	3.39	4.19	III	Linkage

Table 12 Defuzzified reachability matrix with fuzzy linguistic terms

Barriers	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	Driving power
E1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	3
E2	0	1	1*	0	1	1*	1*	0	0	0	0	0	1*	0	0	6
E3	0	0	1	0	0	0	0	0	0	1	0	1*	1	0	0	4
E4	0	0	1	1	1	1*	1*	0	0	1*	0	1*	1	0	0	8
E5	0	0	1	0	1	1	1	0	0	1*	1*	1*	1	0	0	8
E6	0	0	0	0	0	1	0	1*	1*	1	1	0	0	0	0	5
E7	0	0	1*	0	1	1*	1	0	0	0	0	1	1	0	0	6
E8	0	0	0	0	0	0	0	1	1	1*	0	0	0	0	0	3
E9	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	2
E10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
E11	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	4
E12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
E13	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2
E14	0	0	0	0	1*	0	1	0	0	0	0	1	1	1	0	5
E15	0	0	0	0	1*	0	1	0	0	0	0	1	1	1	1	6
Dependence power	1	2	5	1	7	5	6	3	4	8	3	8	8	2	1	

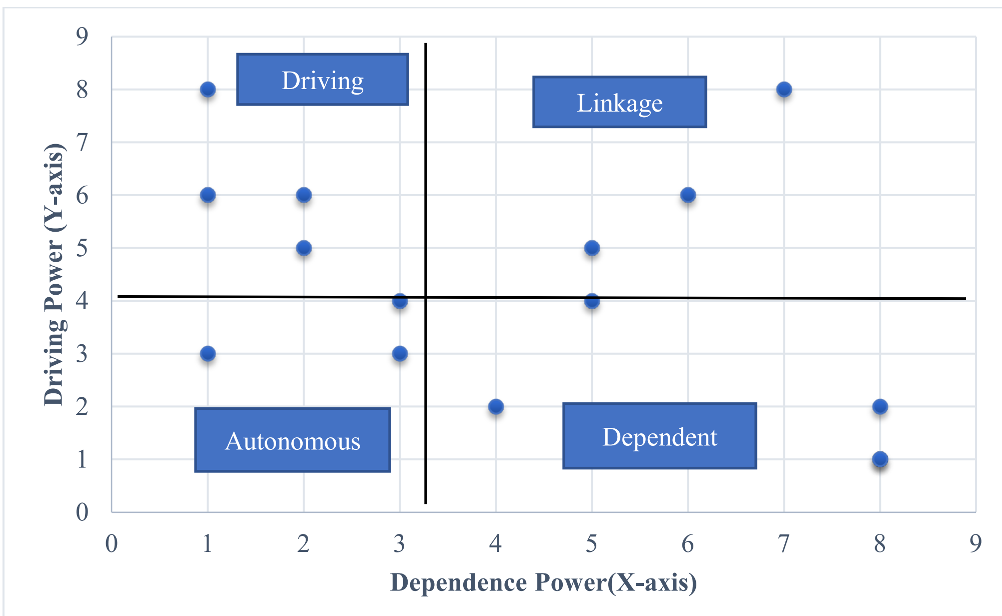

Fig 3. Driving power and Dependence Matrix (MICMAC) based on defuzzified reachability matrix of Table 12
(Source: Author own compilation)

Table 13 Categorizing barriers based on fig 2

No	Barriers	Dependence Power (X)	Driving Power (Y)	Sector	Category
E1	Multiple sources of data	1	3	I	Autonomous
E2	Multiple formats of data	2	6	IV	Driving

E3	Lack of skills for proper data processing and correct interpretation	5	4	III	Linkage
E4	Insufficient training and education	1	8	IV	Driving
E5	Complexity	7	8	III	Linkage
E6	Fear of new technology	5	5	III	Linkage
E7	Infrastructure un-readiness	6	6	III	Linkage
E8	Traditional mindset of existing employees	3	3	I	Autonomous
E9	Traditional organizational culture across the entire organization	4	2	II	Dependent
E10	Low focus on new employee development	8	1	II	Dependent
E11	Lack of focus in instilling new management practices	3	4	IV	Driving
E12	Low level of critical infrastructure resilience	8	1	II	Dependent
E13	Poor quality of information sharing	8	2	II	Dependent
E14	Low level of Public-private partnership	2	5	IV	Driving
E15	Short funding	1	6	IV	Driving

Table 14 First Iteration of final fuzzy reachability matrix partition

Barriers	Reachability set	Antecedent set	Intersection set	Level
1	1,2,5	1	1	
2	2,3,5,6,7,13	1,2	2	
3	3,10,12,13	2,3,4,5,7	3	
4	3,4,5,6,7,10,12,13	4	4	
5	3,5,6,7,10,11,12,13	1,2,4,5,7,14,15	5,7	
6	6,8,9,10,11	2,4,5,6,7	6	
7	3,5,6,7,12,13	2,4,5,7,14,15	5,7	
8	8,9,10	6,8,11	8	
9	9,10	6,8,9,11	9	
10	10	3,4,5,6,8,9,10,11	10	I
11	8,9,10,11	5,6,11	11	
12	12	3,4,5,7,12,13,14,15	12	I
13	12,13	2,3,4,5,7,13,14,15	13	
14	5,7,12,13,14	14,15	14	
15	5,7,12,13,14,15	15	15	

Table 15 Second Iteration of final fuzzy reachability matrix partition

Barriers	Reachability set	Antecedent set	Intersection set	Level
1	1,2,5	1	1	
2	2,3,5,6,7,13	1,2	2	
3	3,13	2,3,4,5,7	3	
4	3,4,5,6,7,13	4	4	

5	3,5,6,7,11,13	1,2,4,5,7,14,15	5,7	
6	6,8,9,11	2,4,5,6,7	6	
7	3,5,6,7,13	2,4,5,7,14,15	5,7	
8	8,9	6,8,11	8	
9	9	6,8,9,11	9	II
11	8,9,11	5,6,11	11	
13	13	2,3,4,5,7,13,14,15	13	II
14	5,7,13,14	14,15	14	
15	5,7,13,14,15	15	15	

Table 16 Third Iteration of final fuzzy reachability matrix partition

Barriers	Reachability set	Antecedent set	Intersection set	Level
1	1,2,5	1	1	
2	2,3,5,6,7	1,2	2	
3	3	2,3,4,5,7	3	III
4	3,4,5,6,7	4	4	
5	3,5,6,7,11	1,2,4,5,7,14,15	5,7	
6	6,8,11	2,4,5,6,7	6	
7	3,5,6,7	2,4,5,7,14,15	5,7	
8	8	6,8,11	8	III
11	8,11	5,6,11	11	
14	5,7,14	14,15	14	
15	5,7,14,15	15	15	

Table 17 Fourth Iteration of final fuzzy reachability matrix partition

Barriers	Reachability set	Antecedent set	Intersection set	Level
1	1,2,5	1	1	
2	2,5,6,7	1,2	2	
4	4,5,6,7	4	4	
5	5,6,7,11	1,2,4,5,7,14,15	5,7	
6	6,11	2,4,5,6,7	6	
7	5,6,7	2,4,5,7,14,15	5,7	
11	11	5,6,11	11	IV
14	5,7,14	14,15	14	
15	5,7,14,15	15	15	

Table 18 Fifth Iteration of final fuzzy reachability matrix partition

Barriers	Reachability set	Antecedent set	Intersection set	Level
1	1,2,5	1	1	
2	2,5,6,7	1,2	2	
4	4,5,6,7	4	4	

5	5,6,7	1,2,4,5,7,14,15	5,7	
6	6	2,4,5,6,7	6	V
7	5,6,7	2,4,5,7,14,15	5,7	
14	5,7,14	14,15	14	
15	5,7,14,15	15	15	

Table 19 Sixth Iteration of final fuzzy reachability matrix partition

Barriers	Reachability set	Antecedent set	Intersection set	Level
1	1,2,5	1	1	
2	2,5,7	1,2	2	
4	4,5,7	4	4	
5	5,7	1,2,4,5,7,14,15	5,7	VI
7	5,7	2,4,5,7,14,15	5,7	VI
14	5,7,14	14,15	14	
15	5,7,14,15	15	15	

Table 20 Seventh Iteration of final fuzzy reachability matrix partition

Barriers	Reachability set	Antecedent set	Intersection set	Level
1	1,2	1	1	
2	2	1,2	2	VII
4	4	4	4	VII
14	14	14,15	14	VII
15	14,15	15	15	

Table 21 Eight Iteration of final fuzzy reachability matrix partition

Barriers	Reachability set	Antecedent set	Intersection set	Level
1	1	1	1	VIII
15	15	15	15	VIII

Table 22 Level Partition

No	Barriers	Level
E1	Multiple sources of data	VIII
E2	Multiple formats of data	VII
E3	Lack of skills for proper data processing and correct interpretation	III
E4	Insufficient training and education	VII
E5	Complexity	VI
E6	Fear of new technology	V
E7	Infrastructure un-readiness	VI
E8	Traditional mindset of existing employees	III
E9	Traditional organizational culture across the entire organization	II
E10	Low focus on new employee development	I
E11	Lack of focus in instilling new management practices	IV

E12	Low level of critical infrastructure resilience	I
E13	Poor quality of information sharing	II
E14	Low level of Public-private partnership	VII
E15	Short funding	VIII

Biographies

Arnesh Telukdarie holds a Doctorate in Chemical Engineering from the Durban University of Technology, South Africa. Prof. Telukdarie is currently an associate professor in the School of Engineering Management at the University of Johannesburg and a Professional Consulting Engineer. Prof. Telukdarie has over 20 years of industrial experience, research interest includes Manufacturing and Corporate Systems.

Surajit Bag is currently pursuing higher research studies under University of Johannesburg in the area of Engineering Management. He has attended several National and International level conferences. His articles are in the spotlight with 381 citations, h-index 11 and i10-index 11 (Source: Google scholar). He is an Editorial board member of International Journal of Applied Logistics, IRJ Science and Amity Journal of Operations Management. He is also serving as the International Advisory Board Member of International Journal of Social Ecology and Sustainable Development.