ANALYSIS OF BARRIERS OF E-WASTE MANAGEMENT IN DEVELOPING COUNTRIES APPLYING INTERPRETIVE STRUCTURAL MODELLING

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ABSTRACT

The aim of present study is to identify the significant impediments allied to e-waste management in developing countries. It analyze the linkages among the barriers so that policy makers concentrate on significant parameters to ameliorate the e-waste management system. The interpretive structural modelling (ISM) approach is applied to construct the framework of crucial barriers of e-waste management in developing nations. The elements considered are categorized under barriers. The barriers impede the successful enactment of e-waste management and determined impediments assist the decision maker to ameliorate upon on these barriers. Ten barriers of e-waste were ascertained and kept in four varied ISM framework hierarchy stages. MICMAC test stratified ten barriers into four groups and placed one barrier in autonomous group, four in dependent group and five in independent group to expound the scope of each barrier in the system. In this research only ten barriers have been identified to form ISM framework, but more e-waste barriers can be incorporated to build ISM framework. Further, in this study, the linkages among the determined barriers have not been statistically validated. The study adopts the scientific technique to construct the model of barriers of e-waste. The framework will assist policy maker in policy making and targeting important performance area.

Keywords- E-Waste Management, Interpretive Structural Modelling, Recycling, Barriers, Regulatory Framework

Introduction

Prodigious advancement in communication and information technology culminated in a monumental growth in electronic device application, especiallycomputer and mobile phones etc. Escalating usage of electronic and electrical devices caused notable surge in e-waste globally. The proliferation of manufacturing and application of electronic devices has been mounting over the last two decades (Nnorom, Ohakwe&Osibanjo, 2009). Substantial growth noticed in the past 25 years, the persistent innovation in design and technology is leading to the expeditious obsolescence of many electronic equipments. The shorten product life cycle as a result of constant modifications and updates in software usually do not support older device(Kang &Schoenung, 2004). This precipitate growth of product obsolescence has culminated in one of the rapid swelling waste categories in the planet comprised of different kinds of electronic equipments termed as e-waste. The appellation e-waste considerably buzzing and viewed as the disposed of electronic devices and their constituent at their end of life.

E-waste is explicated as the waste produced from applied electronic items has been dumped by the consumer lacking the intent of reutilize(Kumar, Holuszko& Espinosa, 2017). The presence of hazardous substances in electronic and electrical devices deleteriously influencing human wellbeing and tremendously degradingthe ambience(Babu, Parande& Basha, 2007;Garlapati, 2016; Heeks, Subramanian & Jones, 2015). India presently produces 18 lakh metric tonnes (MT) of electronic waste annually and it is anticipated to rise to 8 million tonnes by 2025 (Chaudhary, Mathiyazhagan&Vrat, 2017). Only 2% of India's whole electronic waste is recycled because of dearth of legislative framework and deficient infrastructure (Economic Times, 2016). India is an emanating nation that possesses 5^{th}rank among the developing nations in the globe and 2^{nd}rank in the Asia producing electronic waste with yearly proliferation of 25% (Nisa, 2014). As per the report of Associated Chambers of Commerce and Industry of India c-Kinetics, India produces 1.85 million tonnes of electronic waste annually.

It represents 4% of worldelectronic waste and 2.5% of world gross domestic products (Business Standard, 2016).Diminishing life cycle of electrical and electronic equipment,diminutive recycling pace, high consumption and illicit transport from developed nations to developing nations (Byster, Westervelt, Gutierrez, Davis, Hussain & Dutta, 2002; Gullett et. al., 2007) are crucial barriers of e-waste management.

This research aims to ascertain the barriers that impede the effective enforcement of e-waste management in the developing nations. The motive of this paper is to impart better knowledge of these barriers just as assist strategy makers explicating the linkages among the barriers and their effect in the enforcement of e-waste management.

Literature Review

It was assessed that by the expiration of 2030, the developed and developing countries will discard 200-300 million and 400-700 million outdated PCs, individually (Sthiannopkao& Wong, 2013).India with a substantial populace of 1.21 billion is tackling precipitate risk due to swelled amount of electronic waste production in the country itself (Mundada, Kumar &Shekdar, 2004). The issues like dearth of services and legislation ofelectronic waste in developing countries have grave apprehensions, results in mismanagement and malpractices and giving rise to defilement atvarious stages (Herat &Agamuthu, 2012; Alghazo et.al., 2019). Numerous researchershave carried out the investigation on the issues of e-waste in the last decades (Borthakur, Govind & Singh, 2019) and some of them concentrate on the problems of electronic waste in developing and developed nations (Sthiannopkao& Wong, 2013), yet the exploration is scant on barriers of electronic waste in developing nations.

Identification of barriers of e-waste management in developing nations

Dearth of knowledge

The fate of e-waste management has exclusively hinged upon perspective of customers, inexhaustible consumption of ICT products, dearth of civic sense will be the concerning factors of efficient e-waste management practices. Paucity of awareness about the disposal of e-waste and lack of awareness regarding the potential risk to health and environment (Arya & Kumar, 2020; Xu,2008; Lau & Wang, 2009). 70% -75% of the consumer are not knowledgeable of perilous effect of e-waste on human wellbeing and environment (Arya, Gupta & Bhardwaj, 2018). Dearth of responsibility of people toward the environment inundates rampant and mishandling of EEE.

Lack of formal recycling

The most menacing issue has been the presence of the informal sector and its avoidance in the current guidelines. The informal sector has not even been recognized for its function, in spite of the fact, it performs a critical function in the administration of this waste category. On another front, the generators, recognized as the major stakeholder in the guidelines, have constantly used the presence of informal sector as a justification for not fulfilling their instruction EPR commitments. A new surfacing environmental threat for 21stcentury is informal recycling of electronic waste products in developing nations. (Osibanjo & Nnorom, 2007).The Retrieval of substances from electronic waste, eco-friendly handling, and disposal of waste depends on the electronic waste policies and system; but over 95% of electronic waste is processed in informal methods and lastly discarded in the unclosed dump yards (Lau & Wang, 2009; Garlapati, 2016; Ravi & Shankar, 2014). Flourishing informal sector become significant obstacle for electronic waste management. Because of inappropriate methods of e-waste recycling leads to environmental degradation and human health risk for workers those are directly engaged in recycling operations (Medina, 2000; Chi, Streicher-Porte, Wang & Reuter, 2011; Williams et.al., 2008). 95% of the electronic waste is being processed by unorganized sector where most of the functioning are carried out with bare hands without using any safety device in India (Veena, 2004). Regardless of government activities, enactment of formal e-waste recycling sector in developing nations confronting numerous obstructions, for example, high cost and supply deficiency, absence of strict legislation, inadequate infrastructure, dearth of hazard awareness, lack of specific training and unavailability of finance (McCann & Wittmann, 2015; Geeraerts, Illes& Schweizer, 2015; Gu, Wu, Xu, Wang &Zuo, 2016).

Lack of consistent definition of e-waste

Perhaps thesignificant gaps are the paucity of a persistent definition of e-waste, which makes it significantly difficultto decisively evaluate the large quantity produced. Not exclusively we are seeing the rise of e-waste quantity, yet the technique of assessing global electronic-waste is also confronting difficulties because of unavailability of explicit e-waste definition (Morris &Metternicht, 2016; Tran, Wang, Dewulf, Huynh &Schaubroeck, 2016).

Dearth of reliable information on e-waste

The biggest challenge in the record keeping is the dearth of collection because of emotional attachment to the devices (Tanskanen, 2012). The scarcity of reliable information, combined with inflated e-waste quantity, leads to uncertain and complex trends of illicit e-waste trading (Bakhiyi, Gravel, Ceballos, Flynn, & Zayed, 2018).

Deficient regulatory framework and enforcement

There is poor legal framework for effective management of electronic waste worldwide. Expeditious expansion of e-waste and ineffective legal framework has given rise to deficient waste handling strategies in both developed and developing nations, causing serious impact on environment (Puckett & Smith, 2002; Robinson, 2009; Wong, Duzgoren-Aydin, Aydin & Wong, 2007). Wath et. al. (2010) mentioned that India is deprived of actual legalisation coping with e-waste. Set back in law implementationis one the considerable difficulty for India to handle e-waste and has no specificstandards focusing on e-waste problems and challenges (Rajesh, 2011; Wath et. al., 2010).

Improper recycling and disposal

Another crucial problem in e-waste management is the innate challenges of the e-recycling system. Inappropriate recycling and disposal activities discovered in various cities in India usually include open burning of plastic waste. As a consequence, harmful substances are dumped into the land, air and water, which leads to grave environmental problem in India (Wath, Dutt& Chakrabarti, 2011).

Lack of Infrastructure

E-waste receiver nations had no policy and infrastructure to manage electronic waste (Orisakwe et. al., 2019), consequentlycausing hazard to health and environment. E-waste management system is impeded because of dearth of advance technologies for recycling, paucity of accumulation and storage centre and lack of effective transport system (Wath, Vaidya, Dutt& Chakrabarti, 2010; Lau & Wang, 2009).

Lack of advanced technology

At present, China and other developing nations dispose of bulk of electronic waste in backyards or small workshops adopting prime technique like hand-operateddismantling and open burning (Liu, Tanaka & Matsui, 2006). E-waste handlers employ primitive methods of handling e-waste through open burning and incineration in dumpsites (Bakhiyiet. al., 2018).

Illegal Export of e-waste in developing nations

Basel Action Network (BAN), KoreaZero Waste Movement Network (KZWMN) and Greenpeace uncovered that momentous volumeof extremely polluting precarious e-waste are illegitimately discharging into developing nations. Dumping of e-waste into developing nations will be swelled not just because of inflated quantity of e-waste yet in addition by the inappropriate treatment technology (Osibanjo & Nnorom, 2007).

The cost of appropriate disposal of e-waste results in the shipment of massive quantity of e-waste to India, China, Pakistan, Nigeria and other developing nations (Sthiannopkao & Wong, 2013; Rao, 2014).

Approximately 80% of the e-waste generated by global north was sent out unlawfully to developing nations in the global south (Yu, Akormedi, Asampong, Meyer & Fobil, 2017).More than 90% of electronic waste was really traded illicitly under the pretence of second-hand device (Hopson & Puckett, 2016).

Unavailability of finance

Funds are necessary for handling e-waste. Cost factors are major setback in commercial recycling (Ravi & Shankar, 2005; Shi, Peng, Liu & Zhong, 2008). Chauhan et al. (2016) revealed that lack of fund is the most significant barrier that is required to be addressed for enhancing the recycling infrastructure in India.

Methodology

Warfield (1973) first proffered Interpretive Structural Modelling to examine complex socioeconomic systems. It is a technique that facilitate individual or group to demonstrate domain knowledge into a framework of interrelationships to improve the comprehension of its complexity (Colin, Estampe, Pfohl, Gallus & Thomas, 2011). Sage (1977) and Warfield (1974) revealed that the framework attained by employing Interpretive Structural Modelling technique can be employed to determine and encapsulate linkages among a particular element that express a problem or an issue. To accomplish objectives of study, a step-by-step process is expounded below: -

The steps entailed in ISM methodology (Warfield 1973)

1. The elements (barriers in this case) are determined on the basis of applicability to the problem from the literature review and interview with realm experts involving members from academic and organization.
2. To from the linkages between each pair of barriers which are determined in step one.
3. A structural self-interaction matrix is formed which details the pair wise relationships among the barriers under examination.
4. The formation of reachability matrix from SSIM is performed in this step. The SSIM is transformed into the initial reachability matrix by replacing the four characters i.e., V, A, X or O of SSIM by 1 or 0 binary digits in the initial reachabilitymatrix and laterally it is examined for transitivity.
5. The reachability and antecedent sets are acquired from the final reachability matrixto split it into various levels.
6. The ISM digraph is sketched with the assistance of final reachability matrix and various levels acquired in step 4 and step 5 respectively. To demonstrate the direct linkages, the transitivity links are eliminated.
7. The final digraph is transformed into an ISM framework by substituting the nodes of the barriers with statements.
8. The ISM framework is examined for conceptual inconsistencies, if needed the alterations are done.
9. MICMAC testing is carried out to understand the scope of each barrier on the basis of driving and dependence power.

Application: Modelling barriers of e-waste management in developing countries

Determination of Barriers

The present study examines the 10 barriers. The barriers are drawn from literature review and discussion with five experts; two from academia and three from State Pollution Control Board.

Barriers, which impede the developing countries to implement effective e-waste, are extracted theoretically from different literature genesis and experts' opinions.

Table 1: Determined barriers of e-waste in developing countries

S. No	Critical Barriers
1	Dearth of awareness
2	Unavailability of finance
3	Lack of consistent definition of e-waste
4	Lack of infrastructure
5	Deficient regulatory framework and enforcement
6	Dearth of reliable information of e-waste
7	Inadequate advanced technology
8	Dearth of formal sector
9	Illegal exporting of e-waste in developing countries
10	Improper recycling and disposal

Source: Compiled by author extracted from review of literature

Developing SSIM

The purpose of this research paper is to construct linkages among established barriers and stratify these barriers based on their driving and dependence power. The opinions from experts are adopted in constructing the linkages matrix, which was consequently employed in the building of Interpretive Structural Modelling framework. These barriers are extracted from different literature origin and experts' opinions.

The ISM technique can be employed to determine various relationships among the barriers (Bolaños, Fontela, Nenclares& Pastor, 2005). In this paper, contextual linkages are adopted to define association between e-care waste management barriers. The relationships among barriers are decided from the discussion with experts from academics and organization.

To form the SSIM matrix, four linkages are delineated (barriers i and j), using four characters:

V: forward linkage: "i" influences "j"

A: Backward linkages: "j" influences "i"

X: Cross-linkages: "i" and "j" influences each other

O: No linkages between "i" and "j"

Table exhibits the SSIM matrix extracted from the brainstorming session and displaying the relationship among all e-waste barriers.

Table 2: Structural Self Interaction Matrix

Fi → Fj	10	9	8	7	6	5	4	3	2	1
1	V	V	V	V	O	A	X	O	A	
2	V	O	V	V	O	O	V	O		
3	V	V	V	O	V	A	O			
4	V	O	V	A	V	O				
5	V	V	V	V	V					
6	A	A	A	O						
7	V	O	V							
8	V	A								
9	A									
10										

Source: Compiled by auther based on experts opinion

Depends on contextual linkages, the SSIM is formed for all the ten barriers of e-waste management in developing countries (Table 2)

Forming initial reachability matrix

The SSIM matrix (Table) transformed into initial binary matrix (the initial reachability matrix in Table 3). The linkages are replaced into binary form employing following principals:

1. If cell (i,j) = A, then insert 1 in the ij cell and 0 in the j,i cell;
2. If cell (i,j)= B, insert 0 in the corresponding cell and 1 in the cell "ji";
3. If cell (i,j)= X, then insert 1 in both the cells "(ij)" and "(j,i)"
4. If the cell (i,j)= O, then insert 0 in the both the cells i,j and j ,i

Table 3: Initial reachability matrix

Fi ↓ → Fj	1	2	3	4	5	6	7	8	9	10
1	1	1	0	1	0	0	1	1	1	1
2	0	1	0	1	0	0	1	1	0	1
3	0	0	1	0	0	1	0	1	1	1
4	1	0	0	1	0	1	0	1	0	1
5	1	0	1	0	1	1	1	1	1	1
6	0	0	0	0	0	1	0	0	0	0
7	0	0	0	1	0	0	1	1	0	1
8	0	0	0	0	0	1	0	1	0	1
9	0	0	0	0	0	1	0	1	1	0
10	0	0	0	0	0	1	0	0	1	1

Source: Computed by auther

Forming final reachability

Here the initial reachability matrix changed into a final reachability matrix by encompassing all transitivity entries, which indicates the indirect linkages between barriers. Transitivity concept expounds that if element 1 influences element 2 and element 2 influences element 3, then element 1 necessarily influences element 3. The final reachability matrix is exhibited in Table V, which reveals each factor's driving and dependence power. The barriers driving power renders all barriers it leads and the dependence power is all barriers that are led. Therefore, depended on specific barrier's driving and dependence power, it is levelled (Table4). 1* indicates transitivity.

Table 4: Final reachabilitymatrix

Fi ↓ → Fj	1	2	3	4	5	6	7	8	9	10	Driving Power
1	1	1	0	1	0	1*	1	1	1	1	8
2	1*	1	0	1	0	1*	1	1	1*	1	8
3	0	0	1	0	0	1	0	1	1	1	5
4	1	1*	0	1	0	1	1*	1	1*	1	8
5	1	1*	1	1*	1	1	1	1	1	1	10
6	0	0	0	0	0	1	0	0	0	0	1
7	1*	1*	0	1	0	1*	1	1	1*	1	8
8	0	0	0	0	0	1	0	1	1*	1	4
9	0	0	0	0	0	1	0	1	1	1*	4
10	0	0	0	0	0	1	0	1*	1	1	4
Dependence Power	5	5	2	5	1	10	5	9	9	9	60/60

Source: Computed by author

Level apportions

For each barrier the reachability set and antecedent set are drawn from the final reachability matrix. The elements of reachability set are, the element itself and all others elements led by the element under examination. The antecedent set includes the element itself and other elements which lead the element under examination. An intersection set is built from these two sets, which incorporate common elements in the reachability set and antecedent sets. If the reachability and intersection sets are the identical for an element, they possess position 1 in ISM hierarchy framework (Table 5). After obtaining all first level elements, those elements are eliminated from the table and the process are repeated until the level of last remaining element is drawn from the process. The process of iteration is encapsulated of all elements in Table 5-Table 8

Table 5: Iteration I

Barriers	Reachability Set	Antecedent Set	Interaction Set	Level
1	1,2,4,6,7,8,9,10	1,2,4,5,7	1,2,4,7	
2	1,2,4,6,7,8,9,10	1,2,4,5,7	1,2,4,7	
3	3,6,8,9,10	3,5	3	
4	1,2,4,6,7,8,9,10	1,2,4,7	1,2,4,6,7	
5	1,2,3,4,5,6,7,8,9,10	5	5	
6	6	1,2,3,4,5,6,7,8,9,10	6	IV
7	1,2,4,6,7,8,9,10	1,2,4,5,7	1,2,4,7	
8	6,8,9,10	1,2,3,4,5,7,8,9,10	8,9,10	
9	6,8,9,10	1,2,3,4,5,7,8,9,10	8,9,10	
10	6,8,9,10	1,2,3,4,5,7,8,9,10	8,9,10	

Table 6: Iteration 2

Barriers	Reachability Set	Antecedent Set	Interaction Set	Level
1	1,2,4,7,8,9,10	1,2,4,5,7	1,2,4,7	
2	1,2,4,7,8,9,10	1,2,4,5,7	1,2,4,7	
3	3,8,9,10	3,5	3	
4	1,2,4,7,8,9,10	1,2,4,7	1,2,4,6,7	
5	1,2,3,4,5,7,8,9,10	5	5	
7	1,2,4,7,8,9,10	1,2,4,5,7	1,2,4,7	
8	8,9,10	1,2,3,4,5,7,8,9,10	8,9,10	III
9	8,9,10	1,2,3,4,5,7,8,9,10	8,9,10	III
10	8,9,10	1,2,3,4,5,7,8,9,10	8,9,10	III

Table 6: Iteration 3

Barriers	Reachability Set	Antecedent Set	Interaction Set	Level
1	1,2,4,7	1,2,4,5,7	1,2,4,7	II
2	1,2,4,7	1,2,4,5,7	1,2,4,7	II
3	3	3,5	3	II
4	1,2,4,7	1,2,4,7	1,2,4,7	II
5	1,2,3,4,5,7	5	5	
7	1,2,4,7	1,2,4,5,7	1,2,4,7	II

Source: Compiled by author

Table 8: Iteration 4

Barriers	Reachability Set	Antecedent Set	Interaction Set	Level
5	5	5	5	I

Source: compiled by author

Development of ISM framework

The structural framework (Figure 1) is developed from the final reachability matrix by vertices and edges (Jharkharia& Shankar, 2005) and the diagraph is sketched. Out of ten barriers, one is placed at the bottom level and one is placed on the top level of ISM framework. Deficient regulatory framework and enforcement is placed at the bottom level of framework. Dearth of reliable information of waste is placed at top level of framework. Dearth of informal sector, illegal exporting of e-waste in developing countries, improper recycling and disposal, dearth of awareness, unavailability of finance, lack of consistent definition of e-waste, lack of infrastructure and inadequate technological advancement are placed between bottom and top level of framework. Further, MICMAC testing has been performed for stratifying ten barriers.

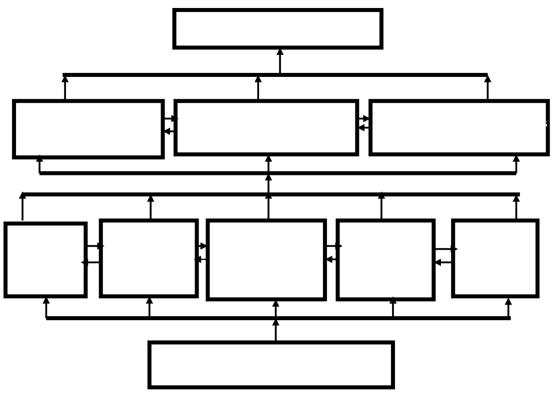
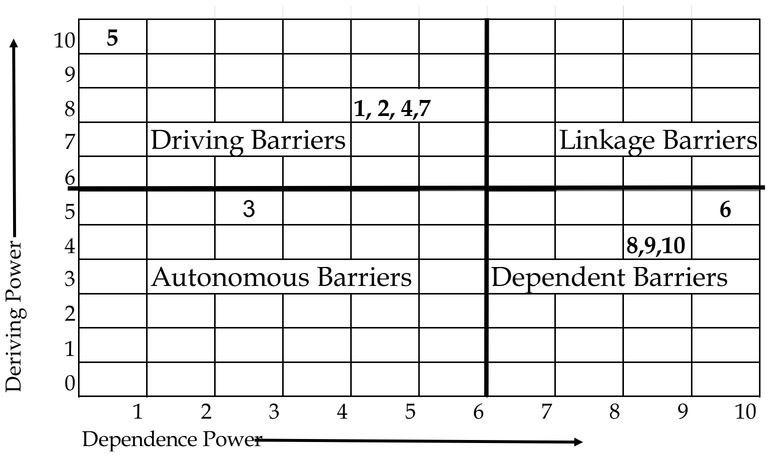


Figure 1: ISM framework portraying the relationship among the e-waste barriers

MICMAC Testing

MICMAC (Matriced' Impacts Croise's Multiplication Appliquée a UN Classement) can analyze the mutual relationship among element and impact of each element on the systems.From Table (Final Reachability Matrix) driving and dependence power are procured by summing the rowsand columns' entries for each barrier (Mandal & Deshmukh, 1994). The barriers can be clustered into four categories hinge on their driving and dependence power: autonomous, dependent, linkage and independent.



Graph 1: Deriving and dependence graph

The barriers have been stratified into five clusters, as per their grouped location on the graph (refer graph 1), as follows: -

Cluster 1 - The autonomous barriers under cluster-1have weaker driving and dependence power. It is delineated from Graph 1 that barrier of autonomous category is 3 (lack of consistent definition of e-waste). Barrier 3 is not closely linked to other barriers of the system. Therefore, this barrier is not the centre of attention.

Cluster II - The barriers of this category are 6,8,9 and 10. These barriers are outcome barriers, which have high dependence power and low driving power. Their upgradation mainly depends on the upgradation of other barriers of the system. These barriers have been kept on the top level of the framework, so the attention ought to be paid to lesser consideration in contrast with the barriers on which they depend.

Cluster III- No barriers are placed in linkage category which is related with each other, which delineated that all determined barriers are stable.

effective e-waste management. It can assist the top management to determine the activity required for effective implementation of e-waste management. The driving and dependence power map (graph 1) supplies some important bits of knowledge about the relative significance and interdependencies among the e-waste barriers. The administrative implication arising out of the investigation are as per the following: -

1. The driving and dependence power map reveals that one barrier comes in the autonomous group. The barriers in the autonomous group have weak driving and dependence power consequently it does not have a lot of effect on the framework. The management should pay less attention to this barrier.

2. It can be noticed form Graph 1 that dearth of reliable information of e-waste, dearth of formal sector, illegal exporting of e-waste in developing nations and improper recycling and disposal of e-waste are the weak barriers but strongly dependent on other barriers. These four barriers are kept on the top of the ISM hierarchy framework. Therefore, administration should pay high attention in tackling these barriers.

3. It is noticed that deficient regulatory framework, dearth of awareness, unavailability of finance, lack of infrastructure and inadequate technology advancement has strong power and less dependency and these are kept at the bottom of ISM hierarchy. Therefore, administration should focus on these barriers more cautiously in the implementation of e-waste management. These barriers give rise to outcome barriers, which are placed on the top of ISM hierarchy. Therefore it is suggested that the administration should frame the strategies to mitigate the effect of these barriers.

Limitation and Future Scope

The main limitations of this research are that only ten barriers have been identified to form ISM framework, but more e-waste barriers can be incorporated to build ISM framework. Further, in this study, the linkages among the determined barriers have not been statistically validated. Structural equation modelling has the ability to prove such sort of hypothesized linkages and thus it very well may be considered as future scope of study.

Conclusion

The motivation behind this study was to recognize the barriers of e-waste management in developing nations and comprehend the linkages among the barriers. These barriers were extracted from literature review and the interpretive structural modelling was adopted to determine and display the relationship. The linkages determined among the barriers are derived from the experts' opinion.

Therefore, the result of the study would be very significant to the policy makers and administrative officers in developing the strategies for an effective e-waste management plan by paying attention on the most influential barriers.

The major contributions of this research are:

1. Dearth of awareness, unavailability of finance, lack of infrastructure, deficient regulatory framework and enforcement and inadequate advanced technology are the most vital barriers because of its strong driving and weak dependence power among all the determined barriers of e-waste.

2. The building of contextual linkages among the various determined barriers of e-waste and the examination of their driving and dependence power.

3. The propounded ISM based framework ascertains barriers of e-waste and build the hierarchy of action for the enforcement of effective e-waste management.

4. The MICMAC analysis assists in map out barriers as per to their significance in the model and propose policy makers are strategically oriented to the obstruction in the cluster four.

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