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Problematique Approach to Analyse Barriers in Implementing Industrial Ecology in Philippine Industrial Parks

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Industrial ecology is recognized as an important framework toward a circular economy wherein industrial systems minimize their environmental burden by mimicking the material cycles and energy cascades found in biological ecosystems. Advocates of such framework in planning of eco-industrial parks suggest that both economic and environmental gains can be attained by transforming the industrial production from a linear to a closed loop system. However, it is imperative first to understand and analyze systematically the barriers in implementing the concept of industrial ecology in industrial parks even at the early planning stage. This work thus proposes a problematique approach to understand and analyse such barriers toward a successful development of eco-industrial parks. A problematique is a term coined by Warfield referring to concepts and tools for a structural model of relationships among members of a set of problems. The problematique is shown to be effective in analyzing the structure that underlies problematic situations, thus increasing the potential for crafting solution through human intervention. An illustrative case study was presented using a methodological framework built from Decision Making Trial and Evaluation Laboratory (DEMATEL), Interpretive Structural Modeling (ISM) and Analytic Network Process (ANP). Among the identified barriers in an industrial park situated in Philippines, the method reveals the strength and direction of interaction, hierarchical network structure, prioritization of components, and the causal loop mapping to aid stakeholders in systems thinking and problem solving for such complex issues.

1. Introduction

With the growing global resource consumption coupled with increasing population growth, eco-industrial parks (EIPs) are being promoted as a promising strategy to achieve sustainability in a circular economy. EIPs use the framework of industrial ecology particularly industrial symbiosis (IS) wherein industrial systems minimize their environmental burden by mimicking the material cycles and energy cascades found in biological ecosystems (Frosch and Gallopoulos, 1989). One of the most popular examples of EIP is that of the Kalundborg Park in Denmark (Jacobsen, 2006) which has been found to evolve spontaneously as a result of limited resources. Since then, attempts at improving the environmental performance of the industrial system has been done within eco-industrial parks such as those found in Australia (Roberts, 2004) and Korea (Park et al., 2008) to name a few. However, despite the documented benefits of EIPs, challenges towards its implementation still exist and thus it is important to conduct a rigorous evaluation of the problem structure and the parameters which affect the implementation of IS in industrial parks. The work of Chiu and Yong (2004) for example have emphasized that for Asian Developing Countries (ADC) eco-industrial development should be viewed as a strategy for economic development rather than a practical or technical instrument. The barriers to implementing IS may also vary depending on local or regional factors as well external or global trends (Mannino et al., 2015). It is imperative to have a more rigorous evaluation of how such factors which influence the implementation of IS interact with each other in order to provide insights on how strategies can be

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developed and where they should be focused on. This paper thus extends the work of Bacudio et al (2016), and develops a hybridized method based on problematique (Warfield and Perino, 1999) which integrates Decision Making Trial and Evaluation Laboratory (DEMATEL), Interpretive Structural Modeling (ISM) and Fuzzy Analytic Network Process (ANP) in one framework.

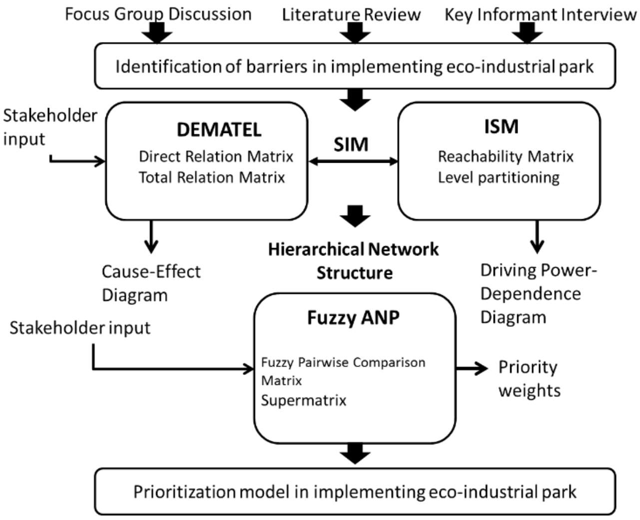


Figure 1: Methodological framework for the problem analysis and prioritization model in implementing eco-industrial park

2. Methodology

Figure 1 describes the methodological framework used in this study. Firstly, problem structuring is done through focus group discussion (FGD), literature review and key informant interview (KII) to identify for example, the barriers in designing and implementing eco-industrial parks. In a multi-participant decision making environment, nominal group thinking (NGT) and Delphi technique could be used to facilitate toward a group consensus on the definition of the problem and its decomposition. After the group agreed to the list of ***n*** barriers or sub-problems, the structural inter-relation matrix (SIM) typically used in ISM can facilitate the elicitation from stakeholders as regard to any inter-relationship among these barriers. This includes the identification of whether there is a direct relation or not; whether the direction of influence is one-way or two ways; and if it's one way only, then in what direction.
DEMATEL approach is then used to populate the direct relation matrix (**D**) of order ***n***. It is a square matrix which shows the direct relation among barriers. This matrix contains the intensity of influence of a barrier in the row ***i*** to the barrier in the column ***j***. The stakeholders provide the intensity, for example using a 5-point rating scale wherein zero means no influence and 4 is for "very high" influence, to populate the direct relation matrix. Then, this matrix is transformed to a normalized direct relation matrix (**M**), for example, by dividing each entry in **D** matrix with its largest row sum. The total relation matrix ($\mathbf{T = M (I-M)^{-1}}$) is then computed from the **M** matrix where **I** is an identity matrix. Each entry in the total relation matrix (**T**) contains the intensity that accounts for both direct and indirect relationship. The row sum (P_i) of this **T** matrix is an indicative of the barrier's influence in the system in the said row. On the other hand, the column sum (Q_i) of this matrix is an indicative of how the barrier is influenced in the system. The sum ($P_i + Q_i$) indicates how prominent the connections or interactions of that barrier in the system whereas the difference ($P_i - Q_i$) indicates how the barrier can be classified either as a causal (positive value) or effect factor (negative value). The cause-effect diagram is just the plot of ($P_i - Q_i$) vs ($P_i + Q_i$). Those barriers above the horizontal axis are causal factors whereas those below are effect factors. The DEMATEL-based approach thus provides the classification of barriers according to the net intensity of their influence on the other barriers in the system.
Results from DEMATEL can then be used to complement the results from ISM in elucidating the hierarchical network structure of the system. The reachability matrix (**R**) in ISM is a binary matrix representation of the digraph that describes structurally how the barriers are connected to each other. An entry of "1" in this matrix indicates that the barrier in the row ***i*** can reach and influence the barrier in the column ***j***; otherwise, it is "0". From the total relation matrix (**T**), a threshold value (τ) can be set to define the significant relationship and

simplify the depiction of the digraph. Accordingly, an entry in the reachability matrix is “1” if the corresponding entry in the total relation matrix is greater than the said threshold; otherwise, the entry is “0”.

Using the reachability matrix, the driving power-dependence diagram can be plotted. The row sum of the reachability matrix (Y_i) is indicative of the relative driving power of a barrier to influence other barriers whereas the column sum (Z_i) is indicative of the dependency of that barrier to other barriers in the system. MICMAC (cross-impact matrix multiplication applied to classification) analysis is then used to classify the barriers into four quadrants. These are the so-called “autonomous”, “dependent”, “linked”, and “driver” cluster. The “autonomous” are barriers with weak driving power and weak dependence. They are weakly connected from the system and may have few links that are strong. The “dependent” are the barriers with weak driving power but have strong dependence on the other barriers of the system. On the other hand, the “linked” are barriers with relatively strong driving power as well as strong dependence. The “driver” are those barriers with very strong driving power but have weak dependence on the system, i.e., few or no barrier in the system can influence them.

In addition, level partitioning of barriers can also be done from the reachability matrix by identifying the reachability sets and antecedent sets. The reachability set consists of the barrier itself and the other barriers that it may influence whereas the antecedent set consists of the barrier itself and the other barriers that may influence it. The intersection of these sets is derived for all barriers and the hierarchical levels where these barriers belong are determined. These levels thus aid in building the digraph of a multi-level hierarchical network structure of the fuzzy Analytic Network Process (FANP) model.

The proposed integration of DEMATEL-ISM could aid stakeholders not only to describe quantitatively the intensity of influence among barriers but also to further illuminate the causal interrelationship in the said structural model. However, this structural model may only account for the strength of relationship among these barriers but it does not clearly measure the priority of the barrier itself. This hybrid method, which is built from fuzzy ANP (Promentilla et al, 2014), provides a systems approach to capture both the inherent strength or importance of the barrier itself, and the intensity of influence among these barriers. The supermatrix (**S**) is analogous to a Markov matrix, i.e., a partitioned matrix wherein each submatrix ($\mathbf{W_{ij}}$) expresses a relationship between two *a priori* defined clusters in a system. These submatrices contain local priority vectors (w_k). For example, when an element in a row has no direct dependence from the element in the column (i.e., no arrow that connects the node to the other node in the digraph), the priority of an element is assigned zero. Otherwise, the priorities are the normalized ratio-scale weights associated with the dominance of one element over the other element within the cluster, or another element in another cluster of the system. Such dominance or strength can be interpreted in terms of importance, preference, likelihood of one element over the other element in the cluster or subsystem. As for the submatrix in the supermatrix indicating the interdependence among barriers, the column-normalized **T** is used to measure the influence weights among barriers. The rest of the submatrices which expresses other inner or outer dependence between clusters or levels in the fuzzy ANP model are populated with priorities derived from pairwise comparison matrix (**A**). Such ratio of weights are indicative of the intensity of dominance of element ***i*** over element ***j*** which is typically elicited from stakeholders in order to compute these priorities (w_k). In this study, these local priorities are derived using the method proposed in Promentilla et al. (2016) wherein the intensity of dominance is represented by a calibrated fuzzy scale, and solution ratios ($a_{ij}=w_i/w_j$) are approximated using a nonlinear-type fuzzy preference programming (Promentilla et al., 2015). After the supermatrix of a strongly connected hierarchical network is populated with local priorities, the eigenvector of that supermatrix is computed which gives the global priority values of an element in the system (Promentilla et al., 2008). This eigenvector also provides the limiting priority weights of the barriers as such eigenvector can also be normalized just within the cluster. Note that this is analogous to the synthesizing concept of the limit supermatrix (Saaty, 2001) resulting from raising the supermatrix into a large power; in doing so, the transmission of influence along all possible paths defined in the hierarchical network structure is captured in the process.

The proposed prioritization model has an advantage over the typical ANP in terms of a facilitated problem structuring through the combined DEMATEL-ISM and a lesser number of pairwise comparison questions that need to be elicited from stakeholders to derive the priority weights. To demonstrate the method and further understand the step-by-step procedure, an illustrative case study is presented in the next section.

3. An Illustrative Case Study

This case study considers an initiative of a certain industrial park situated in Luzon, Philippines to showcase an industrial symbiosis network among their locators. Table 1 summarizes the ten potential barriers that were identified to implement an eco-industrial park as described in detail in Bacudio et al., (2016). Figure 2 describes the sample output of DEMATEL-ISM based from the input of one of the stakeholders during the focus group discussion. The SIM (see Figure 2(a)) provides the pairwise elicitation of the relationship between the barriers. The stakeholder then provided the rating, i.e., intensity of influence of the pertinent barrier to the other barriers in each row of the direct relation matrix (see Figure 2(b)). Succeeding calculations were done (see Figures 2(c) - (d)) to obtain the total relation matrix. From this **T** matrix, the causal-effect diagram can be plotted as shown in Figure 4(a). Results indicate causal barriers such as that of B3 (lack of top management support), B4 (lack of training for implementing industrial symbiosis, and B5 (lack of policy to incentivize initiative of industrial symbiosis). In addition, the effect barriers are identified such as that of B1 (lack of trust among locators) and B8 (lack of institutional support for integration, coordination and communication). Addressing the problem of these causal barriers such as the lack of top management support (B3) could affect for example in resolving the effect barriers such as the problem of lack of institutional support (B8).

Table 1: Identified barriers in the planning, design and implementation of eco-industrial park

Code	Definition
B1	Lack of trust among locators (i.e., industrial plant)
B2	Lack of information sharing among locators
B3	Lack of top management support
B4	Lack of training for implementing industrial symbiosis
B5	Lack of policy to incentivize initiative of industrial symbiosis
B6	Lack of funding to promote industrial symbiosis
B7	Lack of technology and infrastructure readiness
B8	Lack of an institutional support for integration, coordination and communication
B9	Lack of willingness to collaborate
B10	Lack of awareness of industrial symbiosis concepts

	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1
B1	O	X	X	O	O	A	O	A	X	
B2	X	X	X	O	X	X	X	X		
B3	X	X	X	A	V	X	X			
B4	X	X	X	X	X	X				
B5	X	X	X	X	X					
B6	X	X	X	X						
B7	X	X	X							
B8	X	X								
B9	X									
B10										

V: barrier *i* influences barrier *j*
A: barrier *j* influences barrier *i*
X: barrier *i* and barrier *j* influencing each other
O: no relationship between barrier *i* and barrier *j*

a) Structural Inter-relation Matrix

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0	3	0	0	0	0	0	2	4	0
B2	3	0	4	1	2	1	0	3	4	2
B3	1	4	0	4	4	4	0	4	4	4
B4	0	3	3	0	3	1	1	3	3	4
B5	2	2	3	2	0	3	3	4	4	4
B6	0	2	0	2	1	0	4	3	2	3
B7	0	0	3	2	1	1	0	2	2	3
B8	3	3	2	2	2	1	1	0	2	3
B9	4	4	3	3	3	1	3	3	0	3
B10	0	3	4	2	4	3	2	3	3	0

b)Direct Relation Matrix (D)

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.07	0.14	0.00
B2	0.10	0.00	0.14	0.03	0.07	0.03	0.00	0.10	0.14	0.07
B3	0.03	0.14	0.00	0.14	0.14	0.14	0.00	0.14	0.14	0.14
B4	0.00	0.10	0.10	0.00	0.10	0.03	0.03	0.10	0.10	0.14
B5	0.07	0.07	0.10	0.07	0.00	0.10	0.10	0.14	0.14	0.14
B6	0.00	0.07	0.00	0.07	0.03	0.00	0.14	0.10	0.07	0.10
B7	0.00	0.00	0.10	0.07	0.03	0.03	0.00	0.07	0.07	0.10
B8	0.10	0.10	0.07	0.07	0.07	0.03	0.03	0.00	0.07	0.10
B9	0.14	0.14	0.10	0.10	0.10	0.03	0.10	0.10	0.00	0.10
B10	0.00	0.10	0.14	0.07	0.14	0.10	0.07	0.10	0.10	0.00

c) Normalized Direct Relation Matrix (M)

	B3	B4	B5	B7	B9	B10	B2	B1	B6	B8	Y(i)
B3	1	1	1	0	1	1	1	0	1	1	8
B4	1	1	1	0	1	1	1	0	0	1	7
B5	1	1	1	1	1	1	1	0	1	1	9
B7	0	0	0	1	0	1	0	0	0	0	2
B9	1	1	1	0	1	1	1	1	0	1	8
B10	1	1	1	0	1	1	1	0	1	1	8
B2	1	0	1	0	1	1	1	0	0	1	6
B1	0	0	0	0	0	0	0	1	0	0	1
B6	0	0	0	0	1	1	0	0	1	1	4
B8	0	0	0	0	1	1	1	0	0	1	4
Z(i)	6	5	6	2	8	9	7	2	4	8	

d) Level partitioning

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	1	0	0	0	0	0	0	0	0	0
B2	0	1	1	0	1	0	0	1	1	1
B3	0	1	1	1	1	1	0	1	1	1
B4	0	1	1	1	1	0	0	1	1	1
B5	0	1	1	1	1	1	1	1	1	1
B6	0	0	0	0	0	1	0	1	1	1
B7	0	0	0	0	0	0	1	0	0	1
B8	0	1	0	0	0	0	0	1	1	1
B9	1	1	1	1	1	0	0	1	1	1
B10	0	1	1	1	1	1	0	1	1	1

e) Reachability matrix (R)

$\tau > 0.27$

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	P(i)
B1	0.09	0.21	0.11	0.08	0.10	0.06	0.06	0.18	0.25	0.11	1.25
B2	0.25	0.25	0.35	0.22	0.28	0.19	0.14	0.36	0.40	0.32	2.76
B3	0.25	0.47	0.33	0.39	0.43	0.35	0.21	0.50	0.51	0.49	3.92
B4	0.17	0.36	0.35	0.21	0.34	0.21	0.19	0.39	0.39	0.41	3.01
B5	0.25	0.38	0.39	0.31	0.27	0.30	0.28	0.46	0.47	0.45	3.55
B6	0.12	0.25	0.19	0.21	0.21	0.12	0.24	0.30	0.28	0.30	2.24
B7	0.11	0.19	0.27	0.21	0.20	0.16	0.11	0.26	0.26	0.29	2.06
B8	0.23	0.32	0.27	0.23	0.26	0.18	0.16	0.24	0.32	0.32	2.53
B9	0.31	0.43	0.38	0.32	0.36	0.23	0.26	0.42	0.34	0.41	3.47
B10	0.18	0.39	0.40	0.30	0.39	0.29	0.24	0.42	0.42	0.32	3.34
Q(i)	1.95	3.26	3.04	2.48	2.82	2.09	1.88	3.54	3.62	3.42	

f) Total relation matrix (T)

Figure 2: Sample matrix output from the integrated DEMATEL-ISM for problem analysis

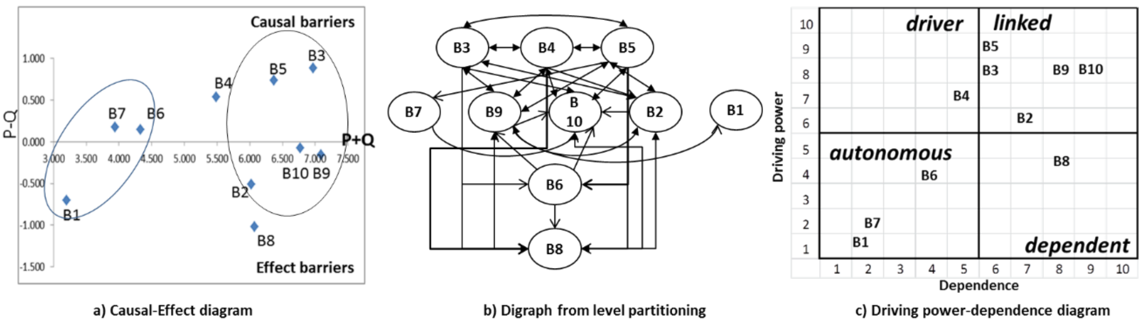
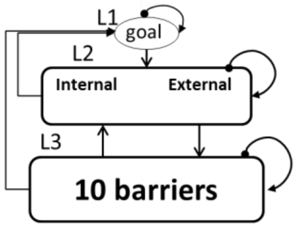


Figure 3: Visual output from the integrated DEMATEL-ISM for problem analysis

To further understand the problem structure, a digraph was formed using ISM to visualize the significant relationship among these barriers and structured the causal relations as a multi-level hierarchical network. A threshold based on the median of the computed influence intensity in the total relation matrix was used to define the binary relation in the reachability matrix. Note that the influence of the barrier to itself is also considered in the **R** matrix and the level partitions for each barrier were derived as shown in Figures 2(d) and 3(b). In addition, Figure 3(c) describes how the barriers were classified based on the MICMAC analysis.



a)Digraph of a multi-level hierarchical network

$$S = \begin{bmatrix} W_{11} & W_{12} & W_{13} \\ W_{21} & W_{22} & W_{23} \\ W_{31} & W_{32} & W_{33} \end{bmatrix}$$

b) Supermatrix representation of the digraph

	Go	EXT	INT	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Go	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
EXT	1.00	1.00	0.00	0.00	0.00	0.33	1.00	1.00	1.00	0.49	0.12	0.00	1.00
INT	1.00	0.00	1.00	1.00	1.00	1.00	0.00	0.00	0.13	1.00	1.00	1.00	0.33
B1	0.00	0.00	0.11	0.27	0.44	0.27	0.21	0.22	0.18	0.22	0.36	0.49	0.23
B2	0.00	0.00	0.40	0.81	0.53	0.86	0.57	0.65	0.55	0.50	0.72	0.79	0.64
B3	0.00	0.40	0.00	0.79	1.00	0.81	1.00	1.00	1.00	0.75	1.00	1.00	1.00
B4	0.00	0.06	0.00	0.54	0.77	0.87	0.53	0.78	0.61	0.67	0.77	0.77	0.83
B5	0.00	0.06	0.00	0.81	0.80	0.96	0.79	0.64	0.85	1.00	0.92	0.92	0.92
B6	0.00	0.06	0.00	0.37	0.53	0.48	0.55	0.48	0.35	0.87	0.61	0.54	0.62
B7	0.00	1.00	0.11	0.34	0.40	0.67	0.54	0.47	0.45	0.38	0.52	0.52	0.59
B8	0.00	0.40	1.00	0.75	0.68	0.68	0.59	0.60	0.50	0.56	0.48	0.62	0.66
B9	0.00	0.00	0.11	1.00	0.90	0.95	0.83	0.83	0.65	0.94	0.84	0.68	0.83
B10	0.00	0.80	0.11	0.58	0.82	1.00	0.76	0.90	0.84	0.86	0.83	0.83	0.65

c) Initial supermatrix of the Fuzzy ANP model

	v	w
Go	0.135	1
EXT	0.078	0.464
INT	0.090	0.536
B1	0.029	0.042
B2	0.068	0.097
B3	0.093	0.134
B4	0.070	0.101
B5	0.082	0.118
B6	0.053	0.075
B7	0.060	0.086
B8	0.074	0.106
B9	0.080	0.116
B10	0.087	0.126

d) principal eigenvector

Figure 3: An example of Fuzzy ANP model including its supermatrix representation and eigenvector

Table 2: Summary of results obtained from the problem analysis and prioritization model

Barriers	DEMATEL	ISM-MICMAC	Fuzzy ANP[a] Priority (Rank)	Fuzzy ANP[b] Priority (Rank)
B1	Effect Barrier	autonomous	0.048 (10)	0.042 (10)
B2	Effect Barrier	linked-dependent	0.098 (6)	0.097 (7)
B3	Causal Barrier	linked-driver	0.135 (1)	0.134 (1)
B4	Causal Barrier	driver-linked	0.107 (5)	0.101 (6)
B5	Causal Barrier	linked-driver	0.124 (2)	0.118 (3)
B6	Causal Barrier	autonomous	0.081 (8)	0.075 (9)
B7	Causal Barrier	autonomous	0.076 (9)	0.086 (8)
B8	Effect Barrier	dependent	0.090 (7)	0.106 (5)
B9	Effect Barrier	linked	0.121 (3)	0.116 (4)
B10	Effect Barrier	linked	0.119 (4)	0.126 (2)

[a]Model 1 assumes equally important barriers regardless of whether it is an internal or external issue
[b]Model 2 considers priority weights of barriers with respect to internal or external issue with feedback dependence

Indication suggests that the following barriers in the boundary of driver-linked quadrant namely B3, B4 and B5 are the key driving barriers in the system. These barriers are perceived to be a relatively strong driving barrier with high degree of connectedness with the other barriers (see Figures 3(b) and 3(c)). On the other hand, B1 and B7 are classified as autonomous which indicate their weak relationship with the other barriers. Although the lack of technology and infrastructure readiness (B7) is considered as a causal barrier, it is also classified as autonomous and thus may not be a prominent barrier to consider. However, prioritization of these barriers based on their interrelationship and intensity of influence to each other may provide an incomplete picture of the whole problem if the inherent importance or strength of these barriers is not considered. In such case, the proposed Fuzzy ANP model addresses this issue in a more systematic way (see Figure 3).

This study models the decision problem of prioritizing the barriers in terms of a hierarchical network structure. For example, the priority weights of these barriers are influenced by how important they are with respect to internal and external issue of implementing an eco-industrial park. Here the differentiation of internal and external is defined by the systems boundary of an eco-industrial park which includes the locators and people working in the industrial park. As shown in Figure 3(a), the goal, which is to prioritize the barriers that need to be addressed, would influence (W_{21} in the supermatrix) on which internal or external issues should be given emphasis as depicted by a downward arrow from the 1st level (L1) to the second level (L2). The downward arrow from L2 to the third level (L3) represents the outer dependence (W_{32} in the supermatrix) associated with the relative importance of each barrier respect to either an internal or external issue. For example, B8 is perceived to be the most important internal barrier whereas B7 is the most important external barrier. On the other hand, the upward arrow from L3 to L2 indicates feedback dependence (W_{23} in the supermatrix) between these two levels or clusters. The arc (loop in the digraph) represents the inner dependence among barriers within each level. For example, an identity matrix such as that of W_{22} indicates that the internal and external issues are mutually independent to each other. On the other hand, the interdependence among the barriers is expressed in the submatrix W_{33} which contain inputs derived from the total relation matrix. Note that the supermatrix (Figure 3(d)) is populated with priority weights normalized by the maximum priority in the column within the cluster. Summary of the results from such fuzzy ANP model is shown in Table 2 in comparison with the output from DEMATEL and ISM. The results from this illustrative case study demonstrate how the separate techniques complement with each other to understand the factors which are relevant to the problem or issue.

4. Conclusions

This study proposes a methodological framework that combines DEMATEL, ISM and Fuzzy ANP to analyse the barriers of designing and implementing an eco-industrial park in the Philippines. This novel approach not only reveals the strength and direction of interaction in a multi-level hierarchical network structure, but also provides a systematic way of prioritizing the barriers in the system. Visual output through the causal loop mapping and the driving power-dependence diagram could aid stakeholders to understand their mental model as regard to the complex inter-relationship of these components underlying the problem. In this illustrative case study, indication suggests that the lack of top management (B3), lack of awareness of industrial symbiosis concepts (B10), and lack of policy to incentivize initiative of industrial symbiosis (B5) are the key barriers that need to be prioritized and addressed to resolve the problem that can be potentially encountered in implementing eco-industrial parks. In principle, the proposed problematique approach can also be used to other problem domains wherein complex issues require systems thinking and problem analysis. Future studies will also incorporate techniques to address uncertainties involved in problem analysis and in the prioritization model.

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