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An Error-Proof Approach for Decision Making Using DEMATEL

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Abstract

Decision Making Trial and Evaluation Laboratory method of Multi-Criteria Decision Making has been being used very widely in many management studies (like Operation Management) to identify causal relationships among factors and draw attention to valuable insight for decision making. The scope of this system has reached the manufacturing industry, social activities, farming, financial system, environmental science, energy, and other areas, and has solved numerous practical problems. However, the author has found that the results are misleading as and when it is applied with global (or overall) consideration or even elements/category of unequal weights. To show the serious differences in the results misguiding decision-makers, an example has been demonstrated in this study. Result of the Decision Making Trial and Evaluation Laboratory from global calculation can be corrected if the calculation and analysis are done based on distinct elements (cluster wise). Grading success or failure factors as per distinct elements of a system and integrating them as per criticality found at the element level, is an added methodology to the existing knowledge of using Decision Making Trial and Evaluation Laboratory. With another example from the previous study, the new approach is justified as well. This new approach will help to find critical factors in a truly holistic way and implement any principles, policies, or system more confidently.

Keywords: DEMATEL method; multi-criteria; critical factor; decision making.

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1. Introduction

Researchers who study social science topics usually depend on statistics as a major analytical tool and seek to generalize from sample data collected from a population. The fundamental assumptions of the statistical approach, such as the assumed probabilistic distributions of data sets and the independence of variables, are unrealistic and unsuitable for certain real-world problems with complex and interrelated variables, attributes, and criteria (Liou & Tzeng, 2012). Here comes Multi-Criteria Decision Making (MCDM) study which is aimed at solving a predefined problem; therefore, more emphasis is placed on constructing models that may be close to the preference of decision-maker

(DM), and yield ideal or satisfactory guidance for decisions. In statistical methods and models, such as regressions, the effect of random errors is assumed to be generated independently from a normal distribution with zero mean and a specific variation. But the assumption for the probabilistic distribution of the effect of random errors is neither identifiable nor examinable (Berk & Freeman, 2003); however, it has certain effects on the obtained regression model (Tzeng & Shen, 2017). Hence researchers prefer MCDM method to solve practical problems.

Also, a research project based on statistics attempts to generalize its models to support its hypotheses and theories; consequently, such projects must collect data samples that are sufficiently large to be representative for the assumed population, which can only provide averaged numbers (Spronk et al., 2005) from the sample data. Such averaged results can describe or explain the relationships among the explanatory and response variables. By contrast, MCDM studies often address a predefined case in which DMs attempt to select the optimal decision (ranking or resource allocation). MCDM approach also avoids questionable probabilistic assumptions and seeks to solve problems. Again, the statistical approach tends to collect questionnaires from all available employees or shareholders to determine the average opinion; but the MCDM approach would query the preferences, knowledge, and experience of the managers of the company to devise an optimal strategy. Thus, the statistical approach puts more emphasis on examining the relationships among the variables for theoretical purposes, whereas the MCDM approach focuses on supporting DMs who must solve complicated decision problems in practice (Tzeng & Shen, 2017). Hence for the study of ranking success factors, enablers, or barriers based on experts' judgment, MCDM is preferable to statistical analysis tools and models.

Following Hwang and Yoon (1981), MCDM problems can be categorized into two subfields: "Multiple Attribute Decision-making" (MADM) and "Multiple Objective Decision-making" (MODM). MADM is concerned with ranking or selecting by weighing up predetermined alternatives, and MODM is aimed at identifying the most favorable outcome by searching for a competent frontier within a solution space under the given constraints. Most conventional MCDM research comprises these two subfields of MADM and MODM (Köksalan et al., 2011). MADM methods are mainly devised for evaluations. By contrast, MODM is more suitable for designing or planning by optimizing the allocation of limited resources.

While discussing on multi-criteria problems, Sivakumar et al. (2018) stated that criteria interaction is principal of two categories, namely, "criteria dependency and criteria interactivity." Again, criteria dependency is subdivided into three types, namely, "structural dependency causal dependency and preferential dependency." In causal dependency, cause and effect relationships among factors are identified, and the statistical results are drawn (Sivakumar et al., 2018). Gölcük & Baykasoğlu (2016) mentioned seven key techniques to find causal dependency: "Causal maps" (Rodrigues et al., 2017), "Decision Making Trial and Evaluation Laboratory" (DEMATEL) (Wu & Lee, 2007; Patil & Kant, 2013), "Fuzzy cognitive maps" (Salmeron et al., 2012; Ferreira et al., 2017), "Bayesian networks" (Zeng et al., 2016; Marvin et al., 2017), "System dynamics" (Xu & Coors, 2012), "Interpretive Structural Modeling" (ISM) (Purohit et al., 2016; Girubha et al., 2016; Agi & Nishant, 2017) and "Structural equation modeling" (SEM) (Bagozzi, 2010; Hair et al., 2012).

Causal maps demonstrate causal relationships of different factors using positive or negative loading of potency indicated with numbers ranging from zero to five (Rodrigues et al., 2017). The DEMATEL method identifies net causes and net effects; forms the interrelationship map (IRM) among factors based on threshold value; and finally, provides a structural framework for the system (Wu & Lee, 2007). Combining cognitive mapping with fuzzy logic, the fuzzy cognitive map is created (Salmeron et al., 2012), which represents the given system graphically. Bayesian networks also generate graphical models to represent information related to an undecided domain (Zeng et al., 2016). ISM is applied to identify relationships between factors and define problems clearly (Purohit et al., 2016). "System dynamics" defines problems dynamically presenting different stages of modeling and mapping (Xu & Coors, 2012), and guides to understand multifaceted problems while SEM also defines the structural relationship among factors but to provide statistical results (Bagozzi, 2010).

All these methods have some strengths and weakness, but DEMATEL methodology is more popular for the below reasons:

1. Relatively, it is not so inflexible (Bouzon et al., 2018).
2. Unlike ISM, it allows broad variations in relationships among factors (Yang & John, 2003; Zhu et al., 2011; Bai & Sarkis, 2013; Bouzon et al., 2018).
3. To compare with "Analytic hierarchy process" (AHP), Zhu et al. (2011) stated that "DEMATEL provides multiple directional relationships, while AHP has only a unidirectional relationship and multiple separate matrices requiring integration" (Sivakumar et al., 2018).
4. In comparison to the fuzzy set and probability theories, the most important benefit of DEMATEL method is its lesser requirement of sample data and higher flexibility in pattern recognition (Yang & John, 2003).

5. Another key advantage of DEMATEL over other systems is its confidence in its ability to produce possible results with the least amount of data (Bouzon et al., 2018).

6. The matrices portray contextual associations among system elements, where the numbers represent the strength of influences (Bouzon et al., 2018).

2. Problem Statement

“Most decision-making methods assume independence between the criteria of a decision and the alternatives of that decision, or simply among the criteria or the alternatives themselves. However, assuming independence among criteria/variables is too strict about overcoming the problem of dependent criteria. Therefore, some papers have discussed ways to overcome this problem. The DEMATEL method is used to detect complex relationships and build the IRM of relations among criteria. The methodology can confirm interdependence among variables/criteria and restrict the relations that reflect characteristics within an essential systemic and developmental trend” (Yang et al., 2008). However, the problem in DEMATEL may arise when some factors under a categorical element of a system like lean manufacturing, sustainable supply chain, etc. do not appear influencing other factors higher and these less influential factors are omitted as non-critical. To ensure the system works properly or even implemented effectively in the first place, all elements need to be well set in place. Especially, if the element is a distinct integral part of the system, it needs to be ensured to establish. Hence the factors related to that specific element requires pairwise comparison for critical. Otherwise, the system is not completely addressed and subsequently, may fail as a whole. Commonly, impact relations of some factors may not be in the higher rank in overall implementation, but for a specific element of a specific principle, they can be highly influential. Therefore, segregating factors as per elements of a management system; analyzing and identifying critical factors for all the elements separately, and then compiling them as per criticality found at the element level, is required to add to the existing knowledge of DEMATEL methodology.

3. Dematel Method

DEMATEL method was initially developed in the 1970s in the “Science and Human Affairs Program of the Battelle Memorial Institute of Geneva” to study the intricate and intertwined problematic group. It has been extensively acknowledged as one of the best tools to solve the cause and effect relationships among the evaluation criteria (Wu et al., 2015; Kusi-Sarpong et al., 2016; Dong et al., 2016; Gan & Luo, 2017; Gołąbeska, 2018; Sivakumar et al., 2018; Moktadir et al., 2018; Mangla et al., 2018) for its substantial benefits (Zhu et al., 2011; Bai & Sarkis, 2013; Bouzon et al., 2018) over other multi-criteria decision making methods. The procedure (Yu & Tseng, 2006; Liou et al., 2007; Tzeng et al., 2007; Yang et al., 2008; Wu & Lee, 2007; Shieh et al., 2010) of DEMATEL method is presented below in Figure 1.

Step 1: "Calculate the initial average matrix by scores. In this step, respondents are asked to indicate the degree of direct influence each factor/element i exerts on each factor/element j, which is denoted by A_{ij}. We assume that the scales 0, 1, 2, 3, and 4 represent the range from no influence to very strong influence. Each respondent would produce a direct matrix and an average matrix" (Yang et al., 2008). For each expert, an nxn non-negative matrix is constructed as $X^k = X^k{}_{ij}$, where k is the expert number of participating in the evaluation process with $1 \leq k \leq m$. Thus, X^1, X^2, X,..., X^m are the matrices from m experts (Liu et al., 2011; Sumrit & Anuntavoranich, 2013). To aggregate, all judgments from m experts, the average matrix $Z = [z_{ij}]$ is shown below (Sumrit & Anuntavoranich, 2013).

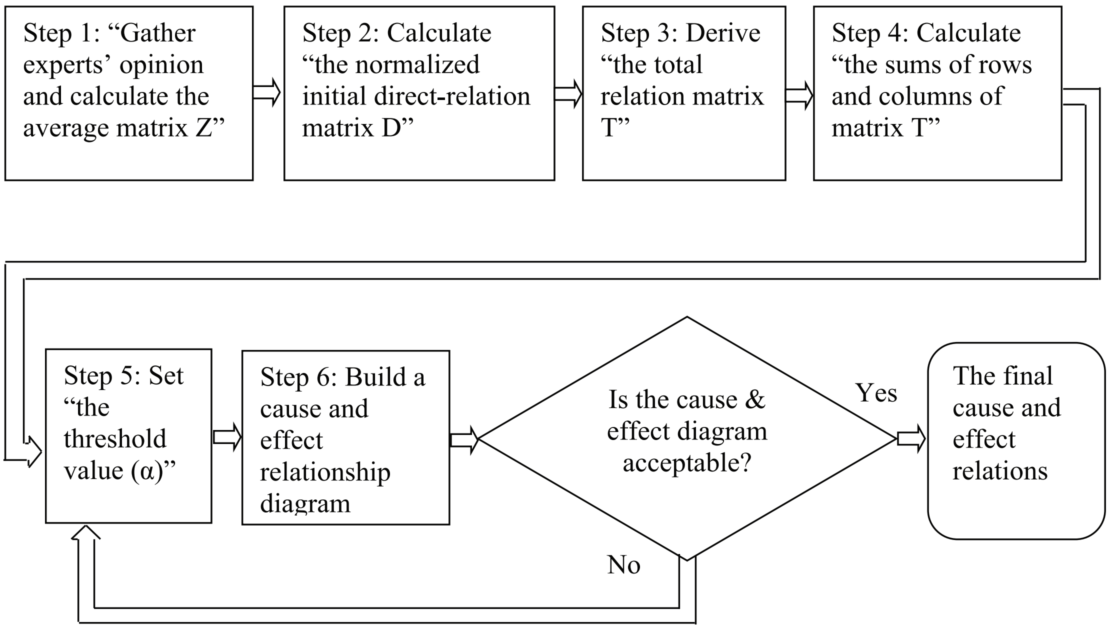

Figure 1: DEMATEL Analysis Flow Diagram (**Source:** Sumrit & Anuntavoranich (2013)).

$$Z_{ij} = (1/m)\sum\nolimits^{m}{}_{i=1} x^k{}_{ij} \quad (1)$$

Step 2: The "normalized initial direct-relation matrix" (Wu & Chang, 2015) D = [d_{ij}], where the matrix value is ranged between [0, 1]. The calculation is shown below (Yang et al., 2008; Sumrit & Anuntavoranich, 2013):

$$D = \lambda * Z \tag{2}$$

Where λ = *Min* [*1/(max 1≤i≤n)*$\sum^{n}_{i=1}$ |Z_{ij}|, *1/(max 1≤i≤n)*$\sum^{n}_{j=1}$ |Z_{ij}|]

Step 3: The "total-influence matrix T" is obtained by utilizing Equation 3, in which "I is an *n*×*n* identity matrix". The indirect effects of factor i on factor j are represented by The element of t_{ij}, then the total relationship between each pair of system factors is reflected in the matrix T (Liu et al., 2011; Sumrit & Anuntavoranich, 2013).

$$T = D(I - D)^{-1} \tag{3}$$

Step 4: In matrix T, the vectors r and c represent the sum of rows and the sum of columns, respectively:

$$r = [r_i]_{nx1} = (\sum{}^{n}{}_{i=1} t_{ij})_{nx1} \tag{4}$$

$$c = [c_j]'{}_{1xn} = [\sum{}^{n}{}_{j=1} t_{ij}]'{}_{1xn} \tag{5}$$

"[c_j]' is transposition matrix" (Liu et al., 2011; Sumrit & Anuntavoranich, 2013).

"Where r_i denotes the row sum of the i^{th} row of matrix T and shows the sum of direct and indirect effects of factor/element i on the other factors/elements. Similarly, c_j denotes the column sum of the jth column of matrix T and shows the sum of direct and indirect effects that factor/element j has received from the other factors/criteria. In addition, when i = j (i.e., the sum of the row and column aggregates) (r_i+c_i) provides an index of the strength of influences given and received, that is, (r_i+c_i) shows the degree of the central role that factor i plays in the problem" (Yang et al., 2008). "In contrast, the difference (r_i-c_i) represents the net effect that factor i contributes to the system. Specifically, if (r_i-c_i) is positive, factor i is a net cause, while factor i is a net receiver or result if (r_i-c_i) is negative" (Wu & Chang, 2015).

Step 5: "Set a threshold value and obtain the IRM. Setting a threshold value α to filter the minor effects denoted by the factors of matrix T is necessary to isolate the relation structure of the factors. Based on the matrix T, each factor t_{ij} of matrix T provides information about how to factor i affects factor j. In practice, if all the information from matrix T converts to the IRM, the map would be too complex to show the necessary information for decision making. In order to reduce the complexity of the IRM, the decision-maker sets a threshold value for the influence level: only factors whose influence value in matrix T is higher than the threshold value can be chosen and converted into the IRM. The threshold value can be decided through the brainstorming of experts. When the threshold value and relative IRM have been decided, the IRM can be shown" (Yang et al., 2008).

Many researchers (Chuang et al., 2013; Chien et al., 2014; Hwang et al., 2016; Si et al., 2018) have divided the IRM into four quadrants (Figure 2), by calculating the mean of r+c. As r+c represents prominence and r-c represents relation, "The factors in quadrant 'I' are identified as core factors or intertwined givers since they have high prominence and relation; the factors in quadrant II are identified as driving factors or autonomous givers because they have low prominence but high relation. The factors in quadrant III have low prominence and relation and are relatively disconnected from the system (called independent factors or autonomous receivers); the factors in quadrant IV have high prominence but low relation (called impact factors or intertwined receivers), which are impacted by other factors and cannot be directly improved. From Figure 2, decision-makers can visually detect the complex causal relationships among factors and further spotlight valuable insights for decision making" (Si et al., 2018).

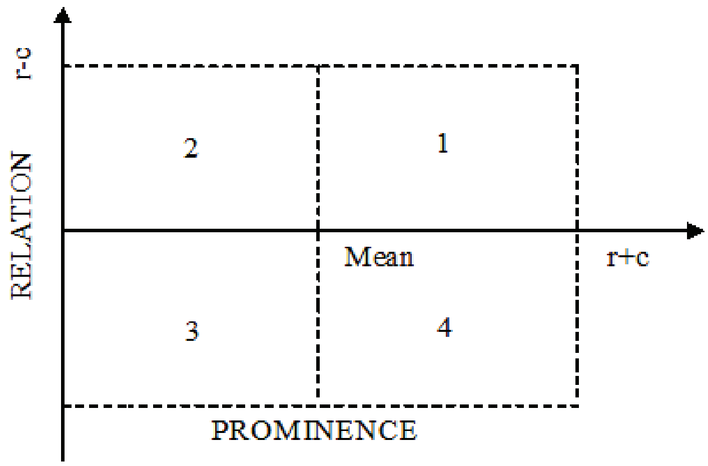

Figure 2: Four Quadrants IRM Structure (**Source:** Si et al., 2018).

4. Calculation and Analysis

Let us assume, Z matrix by applying Equation 1 for experts' scores of success factors to remain healthy like eating habit (F1), physical exercise (F2), sleeping order (F3), physical check-up (F4), social interaction (F5), moral consciousness (F6), sense of purpose (F8), financial solvency (F8) and community (F9) is in Table 1 below:

Table 1: Z Matrix for Factors of Health.

	F1	F2	F3	F4	F5	F6	F7	F8	F9
F1	0.0	0.0	3.0	0.0	1.0	0.0	1.0	0.0	0.0
F2	3.0	0.0	4.0	0.0	1.0	1.0	0.5	0.5	0.2
F3	3.0	2.0	0.0	0.0	2.0	1.0	0.0	0.5	0.0
F4	3.0	3.0	4.0	0.0	0.0	4.0	0.5	0.2	2.0
F5	0.0	0.0	1.0	1.0	0.0	0.0	3.0	3.0	3.0
F6	3.0	3.0	2.0	0.0	1.0	0.0	0.0	0.2	0.0
F7	3.0	2.0	2.0	2.0	2.0	3.0	0.0	1.0	1.0
F8	3.0	0.0	1.0	2.0	1.0	1.0	1.0	0.0	1.0
F9	2.0	2.0	0.5	1.0	2.0	0.5	1.0	0.5	0.0

Source: Authors' own work

Then, following Equation 2 and 3 the researchers can get the T matrix; and Equation 4 and 5 for corresponding 'r+c' & 'r-c' for factors of health as shown in Table 2 given below:

Table 2: T Matrix, and 'R+C' & 'R-C' for Factors of Health.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	r	c	r+c	r-c
F1	0.05	0.03	0.18	0.01	0.08	0.03	0.07	0.02	0.02	0.50	1.90	2.41	-1.40
F2	0.23	0.05	0.27	0.02	0.11	0.08	0.06	0.05	0.03	0.91	1.12	2.04	-0.21
F3	0.21	0.13	0.08	0.02	0.14	0.07	0.04	0.05	0.03	0.78	1.75	2.52	-0.97
F4	0.31	0.24	0.34	0.02	0.10	0.25	0.07	0.05	0.13	1.51	0.51	2.02	1.00
F5	0.14	0.08	0.15	0.10	0.08	0.07	0.19	0.18	0.19	1.19	1.04	2.22	0.15
F6	0.22	0.18	0.19	0.01	0.10	0.03	0.03	0.04	0.02	0.82	0.92	1.74	-0.10
F7	0.30	0.19	0.25	0.13	0.18	0.21	0.06	0.10	0.10	1.53	0.70	2.24	0.83
F8	0.24	0.07	0.15	0.12	0.10	0.10	0.09	0.03	0.08	0.99	0.59	1.58	0.40
F9	0.19	0.15	0.13	0.07	0.15	0.07	0.09	0.06	0.04	0.95	0.64	1.59	0.31

Source: Authors' own work

Considering, health has two distinct components of physical health (PH) and mental health (MH); success factors F1, F2, F3, F4, F5, and F6 have effects on PH and F4, F5, F6, F7, F8 and F9 influence MH; if the same steps are followed with the equations, the T matrix, and 'r+c' & 'r-c' values for PH and MH are shown in Table 3 and Table 4:

Finally, following step 5, three IRMs can be drawn as given in Figure 3 below:

5. Results and Discussion

If the global (or overall) IMR is followed, the factors F5 and F7 are the most critical factors; also, factor F4 can be considered as it is very close to average r+c value. However, the IRMs of components PH and MH are showing that in addition to factors F4, F5 and F7;

Table 3: T Matrix, and 'R+C' & 'R-C' for Factors of PH.

	F1	F2	F3	F4	F5	F6	r	c	r+c	r-c
F1	0.07	0.04	0.26	0.01	0.12	0.02	0.52	1.64	2.16	-1.12
F2	0.35	0.09	0.42	0.01	0.17	0.11	1.14	1.00	2.15	0.14
F3	0.31	0.19	0.15	0.01	0.21	0.10	0.98	1.83	2.81	-0.85
F4	0.49	0.37	0.56	0.01	0.17	0.36	1.97	0.13	2.10	1.84
F5	0.06	0.04	0.12	0.07	0.03	0.03	0.35	0.86	1.21	-0.50
F6	0.35	0.27	0.32	0.01	0.16	0.05	1.16	0.67	1.83	0.50

Source: Authors' own work

Table 4: T Matrix, and 'r+c' & 'r-c' for Factors of MH.

	F4	F5	F6	F7	F8	F9	r	c	r+c	r-c
F4	0.03	0.06	0.32	0.06	0.04	0.17	0.68	0.73	1.41	-0.05
F5	0.18	0.11	0.14	0.29	0.27	0.30	1.31	0.77	2.08	0.54
F6	0.02	0.08	0.01	0.02	0.03	0.02	0.19	1.04	1.23	-0.85
F7	0.20	0.21	0.30	0.07	0.13	0.16	1.07	0.69	1.76	0.38
F8	0.18	0.12	0.16	0.12	0.04	0.14	0.76	0.62	1.38	0.14
F9	0.12	0.19	0.11	0.13	0.09	0.07	0.70	0.86	1.57	-0.16

Source: Authors' own work

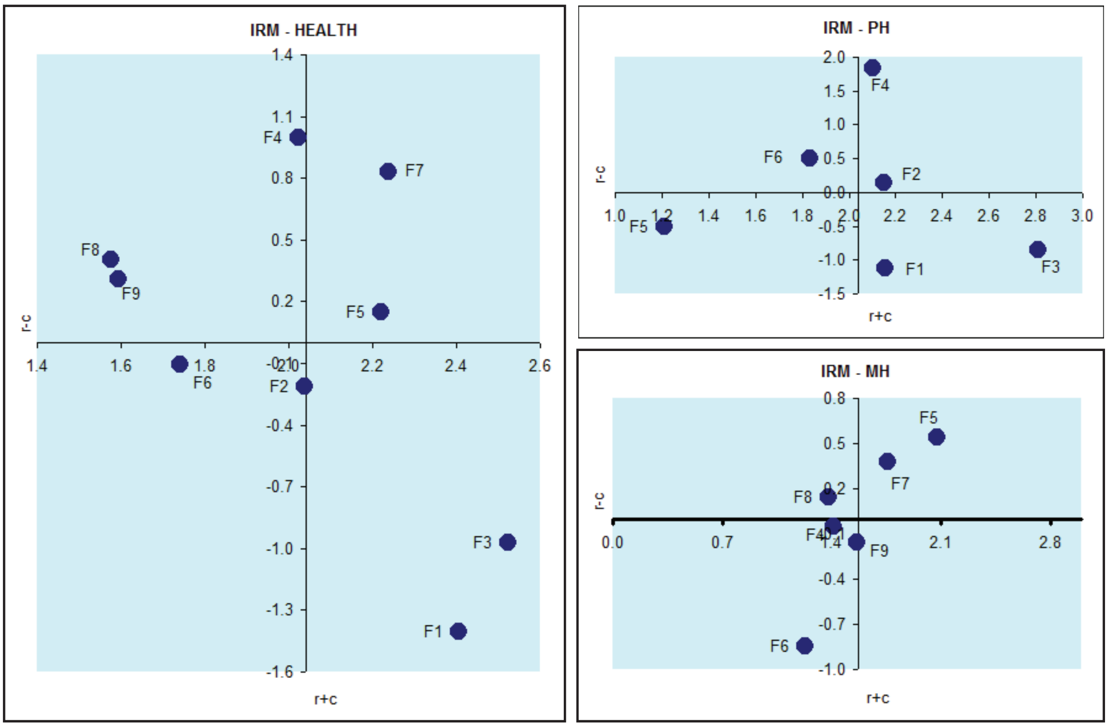

Figure 3: IRMs for factors of health, PH, and MH (**Source:** Authors' own work).

factor F2 is very critical for PH and subsequently for health as we can not ignore PH. To be perfectly decided, the factors F6 from IRM of PH and F8 from IRM of MH should be considered as quite critical; but in IRM of health, although factors F8 and F9 are in Q2 and far from the average r+c; factor F6 is in Q3 which is quite deceiving. Thus it is proved that to get reliable results from DEMATEL; factors need to be evaluated separately/independently for each part or element of the objective and then combine for a complete real set of critical factors.

This result can also be justified from previous researches. For example, researchers Moktadir et al. (2018) classified 20 “common barriers with the help of experts and academic feedback” out of their primary list of 35 barriers for “Sustainable Supply Chain Management” (SSCM) and then using DEMATEL, found nine critical barriers as given below:

Table 5: Barriers for SSCM.

“Category”	**Barrier (identification code)**	**Critical?**
“Environment”	“Lack of eco-literacy amongst supply chain partner (E1)”	Yes
	“Lack of environmental requirement (E2)”	
	“Lack of practice on reverse logistics (E3)”	
	“Lack of awareness of local customers in green product (E4)”	Yes
“Technology”	“Lack of technical expertise (T1)”	
	“Resistance to change and adopt innovation (T2)”	
	“Lack of cleaner technology (T3)”	Yes
	“Outdated machineries (T4)”	
“Knowledge & Support”	“Information gap (KS1)”	Yes
	“Lack of commitment from top management (KS2)”	Yes
	“Lack of training and education about sustainability (KS3)”	
	“Limited access to market information (KS4)”	Yes
“Society”	“Lack of government support & guideline to adopt sustainable supply chain practices (S1)”	Yes
	“Absence of society pressure (S2)”	Yes
	“Lack demand & pressure for lower price (S3)”	
	“Less of business friendly policy (S4)”	
“Financial”	“Cost of sustainability & economic condition (F1)”	Yes
	“Capacity constraints (F2)”	
	“Lack of funds for sustainable supply chain practices (F3)”	
	“Green power shortage (F4)”	

Source: Moktadir et al., 2018

Surprisingly, “Lack of funds for sustainable supply chain practices (F3)” did not come out as critical, especially, for a country like Bangladesh, a poor (Sultana & Mallick, 2015) and the most densely populated (Ipe, 1995; Islam, 2009) country in the world where most of the people basically depends on cheaper commodity! In general, if there is lack of funds to take initiatives to implement, there is no point of considering “Lack of eco-literacy amongst supply chain partner (E1)”, “Lack of cleaner technology (T3)” as critical; they all become secondary. If financial issues are not resolved, it may not matter whether access to market information is abundant or not. In this situation of the fund crisis, people may not get training continuously and even trained people can not apply their skills and knowledge. The first gap in this analysis is categorization which is not based on a distinct unit level. Hence the same weight of all parallel factors influenced the method incorrectly and moved towards misleading decisions.

Again, “Lack of commitment from top management (KS2)” may be the major reason for “Lack of funds for sustainable supply chain practices (F3)”. However, if the shareholders’ expectations are not addressed in the policy for sustainable development (Deloitte & Touche, 1992), top management commitment for sustainability may be treated as emotions only, not a practical idea to care it with the sacrifice of primary profits. “Information gap (KS1)”, another critical factor under” the category of “Knowledge & Support” may also remain as less influential.

“Cost of sustainability & economic condition (F1)” and “Lack of government support & guideline to adopt sustainable supply chain practices (S1)” may not be in control of organization implementing SSCM. These critical factors need to be clarified that they are considered from an organization or government point of view; in both cases, one of those will remain considerable, and the other is not. Moreover, simultaneously, both “Lack of government support & guideline to adopt sustainable supply chain practices (S1)” and “Absence of society pressure (S2)” have been identified as critical which have relation to social sustainability. But if there is enough social pressure, the government will support unavoidably (Scott, 1998). So, only S2 is critical. Again, among the other factors under this category, if DEMATEL was applied separately within this category only, in addition to “Absence of society pressure (S2)”, “Lack demand & pressure for lower price (S3)” might also appear as critical as it has a high impact on investors’ decisions (Hendershott & Menkveld, 2014).

6. Conclusion

DEMATEL is sensitive to data uncertainty. If “combined grey-based DEMATEL” (Moktadir et al., 2018) is used, such uncertainty is overcome. However, to take correct decisions, the DEMATEL analysis must be used for clusters of distinct components or elements of any system to emerge all critical factors and merge them to avoid any factors lost in the overall competition. Some factors may not be in the higher rank in overall implementation, but for a specific element of a specific element, they can be highly influential. The results may vary in a higher amount when a bigger number of any data (factors and elements) is in use. In that case, appropriate weights for elements may reduce the variation in results, but still, the elemental approach remains as the only correct way.

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