Investigating Cause and Effect Relationships and Prioritizing of GM Assessment Indexes based on Economic, Resources, Energy and Environmental Attributes and PSR Framework using Gray DEMATAL

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ABSTRACT

Nowadays the role of green manufacturing (GM) in sustainable development is evident and irrefutable therefore organizations seek to introduce themselves green in order to maintain their image toward their community. The usual method of sustainability and greenness assessment of a system is making use of indicators and indexes which are classified into several groups based on their characteristics. An important type of index categorization is based on four sustainability attributes including economic, energy, environment and recourses as well as pressure-state-response model (PSR). Because of the research gap about interactions relationships on indexes and investigating their influence others and influence by others. Since, indexes in each group could be effective on other indexes and be overlapped to some extent, it is necessary to prioritize and evaluate cause and effect relations by use of an appropriate method. We consider the relationship and prioritize most important indexes to evaluate manufacturing' greenness based on aforementioned sustainability attributes and PSR model. Purpose data is gathered by survey GM experts questionnaires, including 41 indexes plus 4 mentioned attributes, totally as 45 factors in 13 groups. In order to data analysis, with respect to the non-certainty and insufficient information, Grey DEMATEL method is used.

Keywords: Green Manufacturing; Gray DEMATEL; Greenness and Sustainable Assessment; Indexes and Indicators.

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Causing challenges resulting from manufacturing development such as rapid erosion of natural resources, water, air and soil contamination, and human health hazards created several threats for sustainable development so that the need to green manufacturing (GM) was experienced. Green manufacturing which is known as sustainable manufacturing, environmentally benign manufacturing, clean manufacturing, conscious manufacturing, is an advanced manufacturing model that considers the effects of production process on resources and environment. (Mittal 2013; Yang et al. 2003). Furthermore, Mittala & Sangwanb (2014) believe that GM is to design, produce and consumption of those products which have the lowest negative effects on environment and society in a manner that will be sustainable from the viewpoint of economy. Several researches were conducted about different aspects of GM in the recent years. Fei et al. (1999) in their study consider operational nature of GM from the viewpoint of system integration. Pleshette et al. (2000), from another point of view, consider the combination of performing different ecological chain mechanisms of industry by use of Life cycle theory. Timothy et al. (2005) analyze and briefly stated GM development in Europe, Japan and United States. Sezan & Cankaya (2013) considered the influence of green manufacturing and economical innovations on the performance of sustainability attributes.

One of the main applicable aspects of GM is system greenness assessment. In order to evaluate system greenness or sustainability, different methodologies can be used such as life cycle analysis, benefit cost analysis, environment impact assessment, multi criteria decision analysis, and index assessment (Ahadi & Khosraghi Alijani 2012). By reviewing previous studies it is evident that Azadeh et al. (2007), evaluated energy efficiency by use of data envelopment analysis (DEA) as an analytical technique. Tsai et al. (2013) proposed a mathematical programming model for profitability analysis in order to mix materials by use of theory of constraints (TOC) and activity based costing (ABC) conforming to new GM technologies. Ahmad Salem & Ahmad Deif propose an integrated approach related to greenness assessment in systemic level of manufacturing industries. In addition to GM description, they demonstrate that why do we need it. They also state different methods of GM that leads to contamination and wastage reduction (Salem & Deif 2014). One of the most important methods of assessment in literature is using index assessment in which indicators and indexes are applied for evaluating. Several proposed indexes divided based on main sustainability attributes, including economic, Energy, Environmental and resources that are stated by Yang et al.l (2003). Also according to this classification approach, Ahmad Salem & Ahmad Deif collected most applicable indicators which are observable in reference (Salem & Deif 2014). Singh et al. in 2012 introduce and overview the most important applied indexes in the field of sustainability (Singh et al. 2012). Other researchers that have used index system are Yang et al. (2003) who evaluate green manufacturing by use of green product audit method. They used an index system including 4 sustainability attributes (Yang et al. 2003). In a different study, Wang Qingsong et al. (2010) establishes a GM assessment system by use of indexes so that these indexes are categorized based on life cycle theory and PSR framework. This framework which was formed in the early 1990 based on environmental reports and assessments of Organization for Economic Co-operation and Development (OECD), comprise three elements of pressure, state and response that demonstrate human activities such as contamination impose pressure on environment which could cause some changes resulting in a state in which society inevitably react to it with a series of policy guidelines and options such as tax and law enactment (OECD 1993).Focus on sustainability of territorial systems, broken down into the three columns of economy, society and environment, each matter of local sustainable development is partly determined by its relations with the other dimensions. (Rizzil et al. 2018)

Reviewing previous studies stated that several researches were conducted about models, greenness and sustainable assessment, and besides mutual dependence of greenness assessment factors were not considered in this study. Therefore in the present study we consider cause and effect relationship of greenness assessment factors in a PSR model and prioritize indexes based on the four attributes of economic, environmental, energy and resources discussed in Wang Qingsong research because using the same indexes that have similar application is expensive and sometimes time consuming and condensing these indexes could be a motivation for manufacturers in order to reach sustainability. In order to review cause and effect relations of the indexes and consequently prioritize and condensing them, we use gray DIMATEL method as a decision making technique which can consider factors interactions and classify them in two groups of cause and effect. To reach this purpose totally 45 factors are including 41 indexes and 4 attributes of economic, environmental, energy, and resources categorized in 13 groups so that prioritized factors and their cause and effect relations are determinate in each group.

The paper is organized as follows: a background of grey DEMATEL method is given in section 2. Research method is described in section 3. Analyses and results are provided in section 4. Conclusion and recommendation are presented in section 5.

Background of Grey DEMATEL Method

DEMATEL is a decision making method which use experts' opinions to conduct pair comparison in order to create structural models among complicated factors. Foundation of

DEMATEL method is based on that a system includes a set of criteria which could be model by mathematical equations (see Chang et al. (2011), Mehrabi et al. (2014), Tseng (2009), Xiaoyong et al. (2011), Büyüközkan & Çifçi (2012)). Grey theory can describe an overview of a system by focusing on a limited section of information. (Su et al. 2015; Mohammadi & Nabi 2010)

Table 1 shows the grey equivalent of pair comparison language phrase.

Table 1. Gray pair comparison scale.

Gray equivalent	Language phrase
(0.0)	Unimportant
(0.0 - 0.25)	Ordinary
(0.25 - 0.5)	Important
(0.5 - 0.75)	High Importance
(0.75 - 1)	Especially important

Source: The Author

Suppose that X is a universal set. Then the gray collection G of X denotes by $\overline{\mu_G}(X)$ and $\underline{\mu}_G(X)$ as upper and lower bound of membership function of respectively like (1):

$$\overline{\mu_G}(X) : X \to [0,1] \; \underline{\mu}_G(X): X \to [0,1] \tag{1}$$

Where $\overline{\mu_G}(X) \geq \underline{\mu}_G(X)$, which it will convert to an equation from gray collection G to a fuzzy set (see Mehrabi et al. 2014). This shows that gray theory contains the fuzzy case and it is flexible whenever it faced with non-certainty problems (Mehrabi et al. 2014; Tseng 2009). In this paper, we consider the gray number $\oplus X_{ij}^P$ for P decision maker which assess the effects of factor i on j.

$$\oplus . X_{ij}^P = [\underline{\oplus} X_{ij}^P, \overline{\oplus} X_{ij}^P] \tag{2}$$

The deterministic method of the gray numbers for the critical factors is as the following there steps:

1. Normalizing

$$\Delta_{min}^{max} = \max_j \overline{\oplus} X_{ij}^P - \min_j \underline{\oplus} X_{ij}^P \tag{3}$$

$$\underline{\oplus} \tilde{X}_{ij}^P = \frac{\underline{\oplus} X_{ij}^P - \min_j \underline{\oplus} X_{ij}^P}{\Delta_{min}^{max}} \tag{4}$$

$$\overline{\oplus} \tilde{X}_{ij}^P = \frac{\overline{\oplus} X_{ij}^P - \min_j \overline{\oplus} X_{ij}^P}{\Delta_{min}^{max}} \tag{5}$$

2. Calculation of normalized crisp number:

$$\mathrm{Y}_{\mathrm{ij}}^{\mathrm{P}} = \frac{\left(\underline{\oplus}\,\tilde{X}_{ij}^{P}(1-\underline{\oplus}\,\tilde{X}_{ij}^{P}) + (\overline{\oplus}\,\tilde{X}_{ij}^{P} \times \overline{\oplus}\,\tilde{X}_{ij}^{P})\right)}{\left(1-\underline{\oplus}\,\tilde{X}_{ij}^{P} + \overline{\oplus}\,\tilde{X}_{ij}^{P}\right)} \tag{6}$$

3. Calculating of crisp number:

$$Z_{\mathrm{ij}}^{\mathrm{P}} = \min_{j} \underline{\oplus}\, X_{ij}^{P} + \mathrm{Y}_{\mathrm{ij}}^{\mathrm{P}} \Delta_{min}^{max} \tag{7}$$

Because there subsists P decision makers, in each one of the questions cognate to the vigor of the effect of I factor on j factor we should enter the mean of views in the matrix, so to reach this aim we use formula (8):

$$\mathrm{Z}_{\mathrm{ij}} = \frac{1}{P}\left(Z_{ij}^{1} + Z_{ij}^{2} + \cdots + Z_{ij}^{P}\right) \tag{8}$$

Now let $T = [t_{ij}]$ be the direct-influence matrix, which T is a matrix of $n \times n$ and it shows the mutual effect of factors. In other words, t_{ij} is the effect of factor i on j: $T = |T_{ij}|_{n\times n}$.

Also let $S = [S_{ij}]$ be the normalized direct relationships matrix, where $0 \le S \le 1$ and its building used (9) and matrix T as follows:

$$K = \frac{1}{MAX_{1\le i\le n} \sum_{j=1}^{n} a_{ij}} \tag{9}$$

$$S = K \times T \tag{10}$$

Then, the total-influence matrix M derives as equation (11):

$$M = S(I-S)^{-1} \tag{11}$$

So that I is shown as the identity matrix.

Finally let R and D be the sum of all rows and columns of M, respectively. Then R and D are calculated from equation (12), (13), (14) (see Mehrabi et al. (2014), Tseng (2009)):

$$M = m_{ij}\ i,j = 1,2,\dots,n \tag{12}$$

$$R = \left[\sum_{j=1}^{n} m_{ij}\right]_{n\times 1} \tag{13}$$

$$D = \left[\sum_{j=1}^{n} m_{ij}\right]_{1\times n}' \tag{14}$$

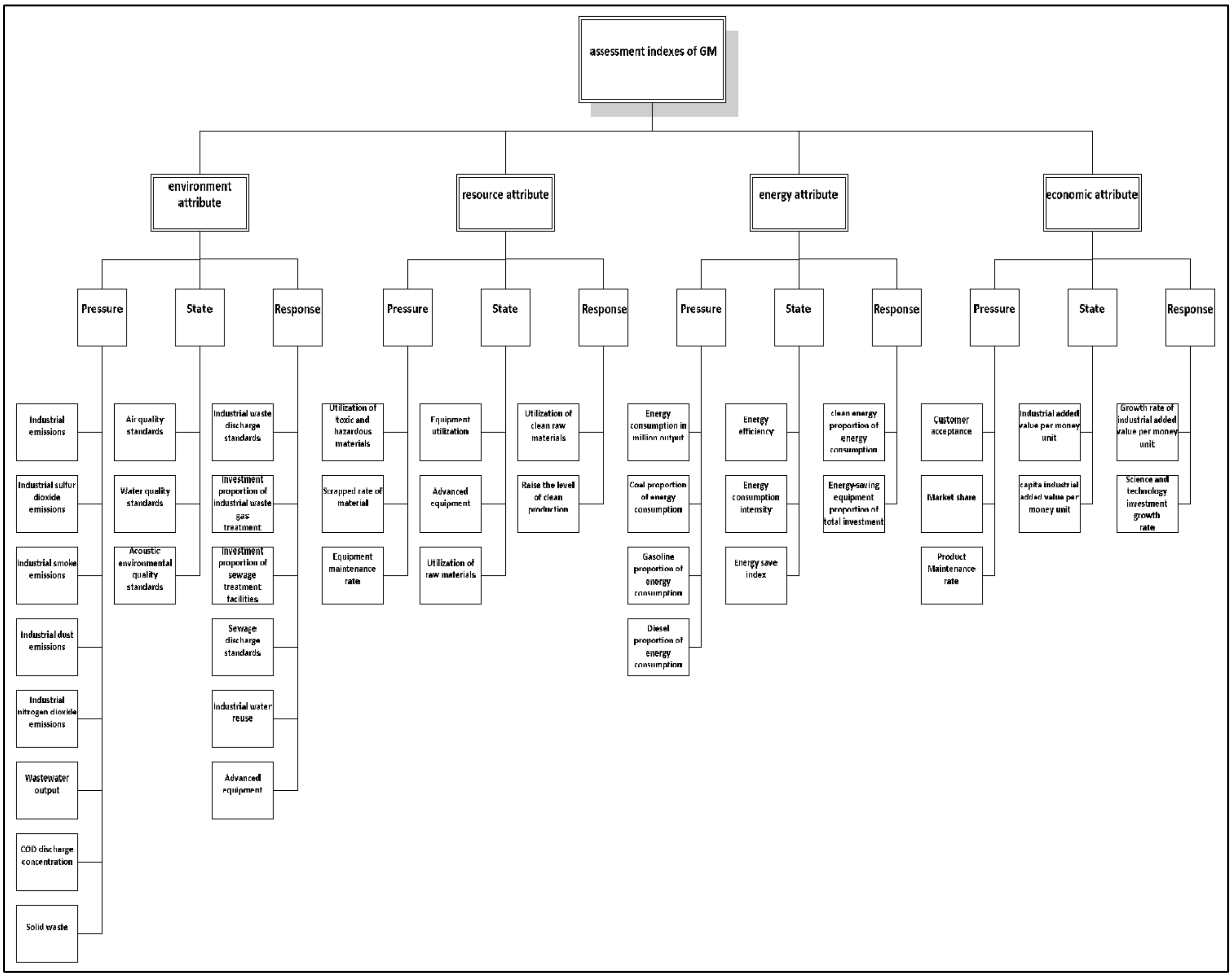
Hence, we can determine the values of $(R + D)$ and $(R - D)$ from adding D to R and reducing D from R, respectively (Chang et al. 2011).

Research Method

As it observed in research literature, none of conducted studies consider the factors from the viewpoint of cause and effect relations and therefore factor prioritizing is not performed.

Thus in this paper, first GM assessment indexes are selected from research literature. To this end study of Qingsong et al. (2010) is cited. Figure 1 shows the categorized indexes based on PSR framework and four sustainable attributes. Then we continue by considering cause and effect relations among these indexes by use of grey DEMATEL method. The applied research method is descriptive analytical in nature and it is developmental applicable considering its goal.

Figure 1. Categorized indexes based on PSR framework and four sustainable atributes.



Source: Authors.

In order to consider cause and effect relations and prioritize the factors, 41 indexes and 4 effective attributes of sustainability on GM assessment were used in 13 categorized groups or tables so that grey DEMATEL was selected as the assessment method of this research. These factors according to the aforesaid categorization were provided for experts in the form of a questionnaire in order to get grey numbers. Experts of this research consist of GM clear sighted. Since the questionnaire be answered by 7 experts, relying on their judgment to analyze cause and effect relations will be sufficient. After gathering experts' judgment based on Table 1 and by use of formulas (3) to (7), finalizing grey numbers was done and then by use of formula (8), finalized opinions of experts were became one single comment. After that with respect to obtained numbers and also by use of formulas (9) to (14), finalized numbers were set into DEMATEL formula and the sum of rows and columns were obtained.

RESULTS AND ANALYSIS

According to achieved results are gathered in tables 2 to 14 and factor analysis will be performed based on these tables.

The achieved results for 8 pressure branch indexes related to environmental attribute is seen in Table 2. Since index analysis R has the most effect of factors on each other's, referring to obtained numbers from this table shows that index factor of wastewater output has the most effect comparing other factors and appropriates the most score of this order. Next factor is industrial dust emission index factor which is in second priority. Industrial nitrogen dioxide emissions index factor is in the third rank. Accordingly next priorities include COD discharge concentration, industrial smoke emissions, solid wastes, industrial sulfur dioxide emissions, and industrial emissions.

Table 2. Results of pressure branch from environmental attribute.

	Industrial emissions	**Industrial sulfur dioxide emissions**	**Industrial smoke emissions**	**Industrial dust emissions**	**Industrial nitrogen dioxide emissions**	**Waste water output**	**COD discharge concentration**	**Solid waste**
R	0.175063	0.317659	0.872443	1.40036	1.334584	1.646082	1.062031	0.742175
D	1.830077	0.599842	1.030735	1.342407	0.369632	0.558223	1.289526	0.529957
$R+D$	2.005141	0.9175	1.903178	2.742767	1.704216	2.204305	2.351557	1.272132
$R-D$	-1.65501	-0.28218	-0.15829	0.057954	0.964953	1.087859	-0.22749	0.212218

Source: The Author

Analysis of index D demonstrated the most affected by other factors. With respect to obtained numbers from Table 2 and analysis based on index D, it can be mentioned that factor of industrial emissions which had the least effectiveness others, in analysis R, has the most affected by other factors in this analysis. Then industrial dust emissions factor is in the second priority. Accordingly other priorities including COD discharge concentration, industrial smoke emissions, industrial sulfur dioxide emissions, wastewater output, solid waste, and industrial nitrogen dioxide emissions.

Index $R + D$ analysis state the most interactions of factors; it means that it has the most effective and the most affected by others. According to obtained numbers, factor of industrial dust emissions has the most rate of interaction and it is naturally an important factor. Next priorities are as follows respectively: 1. Industrial dust emissions, 2. COD discharge concentration, 3. Wastewater output, 4. Industrial emissions, 5. Industrial smoke emissions, 6. Industrial nitrogen dioxide emissions, 7. Solid waste, 8. Industrial sulfur dioxide emissions.

Index analysis $R - D$ includes factors' cause and effect relations. Therefore some factors can be the cause of other factors existence thus this analysis is important. In this index, those factors that have positive values are cause factors and those that have negative values are effect factors. By these discussions, factors according to their priorities are as follows: 1. Industrial wastewater output, 2. Industrial nitrogen dioxide emissions, 3. Solid waste, 4. Industrial dust emissions.

Order of effect factors according to the most negative factors: 1. Industrial emissions, 2. Industrial sulfur dioxide emissions, 3. COD discharge concentration, 4. Industrial smoke emissions.

Table 3 shows the achieved results of 3 state branch indexes related to environmental attribute. According to this Table, in the branch of state from environmental attributes based on R analysis, acoustic environmental quality standards has the most effective, and water and air quality standards are in the second rank. According to analysis D, factor of water quality standards has the most affected by others and factors of air quality standards and acoustic environmental quality standards are in the next ranks. According to analysis R+D, factor of acoustic environmental quality standards has the most interaction with other factors and factors of water and air quality standards are in the next ranks. According to analysis R-D, factor of acoustic environmental quality standards is cause factor and other two factors are effect factors. Therefore factor of acoustic quality standards is the most important factor of this branch.

Table 3. Results of state branch from environmental attribute.

	Air quality standards	**Water quality standards**	**Acoustic environmental quality standards**
R	0.56	0.56	1.56
D	0.84	1.0925	0.7475
$R + D$	1.4	1.6525	2.3075
$R - D$	-0.28	-0.5325	0.8125

Source: The Author

The achieved results for 6 response branch indexes related to environmental attribute is shown in Table 4. According to the result of this Table, and also analysis R, factor of sewage discharge standards is the most effective and other ranks are as follows: industrial water reuse, solid waste recycling, investment proportion of industrial waste gas treatment, investment proportion of sewage treatment facilities, and industrial waste discharge standards. According to analysis D, factor of sewage discharge standards has the most affected by others and factors of industrial water reuse and industrial waste discharge standards are in the next ranks. According to analysis $R + D$, factor of sewage discharge standards has the most interaction with other factors, and factors of industrial water reuse and solid waste recycling are in the next ranks. According to analysis $R - D$, factors of industrial water reuse, solid waste recycling, sewage discharge standards and Investment proportion of industrial waste gas treatment are the most causative factors and factors of industrial waste discharge standards, investment proportion of sewage discharge standards have the most effect factors.

Table 4. Results of response branch from environmental atribute.

	Industrial waste discharge standards	**Investment proportion of industrial waste gas treatment**	**Investment proportion of sewage treatment facilities**	**Sewage discharge standards**	**Industrial water reuse**	**Solid waste recycling**
R	2.841752	3.456378	3.422232	4.445922	4.002712	3.682363
D	3.682416	3.422232	3.423129	4.234186	3.682416	3.40698
$R + D$	6.524169	6.87861	6.845361	8.680108	7.685128	7.089343
$R - D$	-0.84066	0.034146	-0.0009	0.211736	0.320296	0.275383

Source: The Author

The achieved results about 3 indexes of pressure branch related to resource attribute are seen in Table 5. According to this Table and based on analysis R, two factors of utilization of toxic and hazardous materials and equipment maintenance rate have the most effective simultaneously. According to analysis D, again the two above mentioned factors have the most affected by others, and also have the most interaction. According to analysis $R - D$ it can be concluded that all the three factors are both cause and effects.

Table 5. Results of pressure branch from resource attribute.

	Utilization of toxic and hazardous materials	**Scrapped rate of material**	**Equipment maintenance rate**
R	17.46154	15	17.46154
D	17.46154	15	17.46154
$R + D$	34.92308	30	34.92308
$R - D$	0	0	0

Source: The Author

Table 6 shows the achieved results of 3 state branch indexes related to resource attribute. According to Table 6 and based on analysis R, factor of advanced equipments has the most effective. According to analysis D, factor of equipment utilization has the most affected by other factors. According to analysis $R+D$ factor of advanced equipment has the most interactions with other factors. But according to analysis $R-D$, factor of advanced equipment is the causative factor and factor of equipment utilization is the effect factor, and also factor of utilization of raw materials is both cause factor and effect factor.

Table 6. Results of state branch from resource attribute.

	Equipment utilization	Advanced equipment	Utilization of raw materials
R	-3	1	-1
D	0	-2	-1
$R+D$	-3	-1	-2
$R-D$	-3	3	0

Source: The Author

The obtained results for 2 response branch indexes related to resource attribute are seen in Table 7. As it shows in this table, according to all 4 analyses, it cannot be stated that which of the factors has the most effective or affected by others and interaction with other factors. It can also be mentioned that both factors are cause factor and effect factor.

Table 7. Results of response branch from resource attribute.

	Utilization of clean raw materials	Raise the level of clean Production
R	-4.5	-4.5
D	-4.5	-4.5
$R+D$	-9	-9
$R-D$	0	0

Source: The Author

The achieved results for 4 pressure branch indexes related to energy attribute are shown in Table 8. According to this Table and based on analysis R, diesel proportion of energy consumption has most effective factors. The factor of coal proportion of energy consumption is in the next rank. According to analysis D, energy consumption in million outputs has the most affected by others, and two factors of gasoline and diesel proportion of energy consumption are in second rank. According to analysis $R+D$, factor of gasoline proportion of energy consumption has the most interaction and factors of energy consumption in million output and gasoline proportion and coal proportion of energy consumption are in the next ranks. Also according to analysis $R-D$ it can be sated that the factors of coal proportion and gasoline proportion are among the most causative factors and gas proportion in energy consumption and energy consumption in million outputs are the most effect factors.

Table 8. Results of pressure branch from energy attribute.

	Energy consumption in million output	**Coal proportion of energy consumption**	**Gasoline proportion of energy consumption**	**Diesel proportion of energy consumption**
R	3.0422172	3.811943	2.033655	4.131505
D	4.56341539	1.180118	3.637893	3.637893
$R+D$	7.6	4.99	5.67	7.77
$R-D$	-1.5	2.63	-1.6	0.49

Source: The Author

Table 9 indicates the obtained results of 3 state branch indexes related to energy attribute. With respect to this table, it can be stated that based on analysis R, factor of energy save index has the most effective on other factors and also according to analysis D, this factor also has the most affected. On the other hand, analysis $R+D$ also has the most interaction with other factors and according to analysis $R-D$ factors of energy efficiency, energy saving and energy consumption intensity are the most causative factors respectively.

Table 9. Results of state branch from energy attribute.

	Energy efficiency	**Energy consumption intensity**	**Energy save index**
R	2.148148148	2.567901235	3.358025
D	2.567901235	2.518518519	2.987654
$R+D$	4.716049383	5.086419753	6.345679
$R-D$	-0.419753086	0.049382716	0.37037

Source: The Author

Table 10 shows the achieved results of 2 indexes for response branch related to energy attribute. As it can be found from this Table, according to the first three analyses, factor of clean proportion of energy consumption has the most effective, affected, and interaction. According to $R-D$ analysis both of them are cause factor and effect factor.

Table 10. Results of response branch from energy attribute.

	clean proportion of energy consumption	**Energy-saving equipment proportion of total investment**
R	5.333333	4.333333
D	5.333333	4.333333
$R+D$	10.66667	8.666667
$R-D$	0	0

Source: The Author

The obtained results for 3 pressure branch indexes related to economic attribute are seen in Table 11. According to this Table and based on analysis R, all the three factors have the same effectiveness. According to analysis D, factor of customer acceptance has the most affected by others, and also according to analysis $R+D$, this factor has the most interaction with other factors. According to analysis $R-D$, factor of product maintenance rate is a cause factor and factors of customer acceptance and market share are effect factors.

Table 11. Results of pressure branch from economic attribute.

	Customer acceptance	market share	Product Maintenance rate
R	5.333333	5.333333	5.333333
D	6	5.411765	4.588235
$R+D$	11.33333	10.7451	9.921569
$R-D$	-0.66667	-0.07843	0.745098

Source: The Author

Table 12 indicates the achieved results of 2 state branch indexes related to economic attribute. According to this Table and based on the first three analyses, factor of capita industrial added value per money unit is most effective and affected by other and has the most interaction, and according to analysis $R-D$ both of the factors are cause factor and effect factors.

Table 12. Results of state branch from economic attribute.

	Industrial added value per money unit	capita industrial added value per money unit
R	4.333333	5.333333
D	4.333333	5.333333
$R+D$	8.666667	10.66667
$R-D$	0	0

Source: The Author

The achieved results for 2 response branch indexes related to economic attribute is seen in Table 13. According to this Table and based on the first three analyses, growth rate of industrial added value per money unit have the most effective and the most affected and also the most interaction, and both factors are cause factor and effect factor based on analysis $R-D$.

Table 13. Results of response branch from economic attribute.

	Growth rate of industrial added value per money unit	Science and technology investment growth rate
R	5.333333	4.333333
D	5.333333	4.333333
$R+D$	10.66667	8.666667
$R-D$	0	0

Source: The Author

The obtained results for 4 sustainability attributes are shown in Table 14. According to this Table and based on analysis R, factor of environment attribute has the most effective and factors of energy attribute, economic attribute, and resource attribute are in the next ranks respectively. According to analysis D, factor of resource attribute has the most affected by others and factors of economic, energy, and environment attributes are in the next ranks respectively. According to analysis $R+D$, factor of resource attribute has the most interaction with other factors and factors of economic, energy and environment attributes are in the next ranks respectively. According to analysis $R-D$, factor of environment attribute is a cause factor. Environment attribute is cause factor, resource and economic attributes are both the effect factors and energy attribute is cause factor and effect factor.

Table 14. Results of four sustainability attributes.

	environment attribute	resource attribute	energy attribute	economic attribute
R	11.32978	10.27294	10.36353	10.36353
D	9.207612	11.42886	10.36353	11.32978
$R+D$	20.54	21.7	20.7	21.69
$R-D$	2.12	-1.15	0	-0.96

Source: The Author

Conclusion

Concentration of this research was on the evaluation of GM indexes. Numerous amounts of indexes that occasionally bewilder their users and also their overlapping that impose lots of time and money expenses on organizations make the appropriate selection of these indexes necessary. With respect to significance of the topic it can be stated that by reviewing cause and effect relations among indexes and their prioritizing, programmers and audits will be had more and better options to use. In other words programmers are able to use these analyses as a method to select various indicators and indexes for assessment. In addition to reviewing various indexes for greenness assessment industries, in the present research we perform index prioritizing into different groups such as environmental, economical, resource and energy indexes, and accordingly determine effective and affected indexes of each group. Since cause and effect indexes can be useful in GM assessment, therefore each index is investigated from this aspect. Grey DEMATEL method which is used in this paper converts experts' opinions into interval numbers, in addition to reviewing the relationship between criteria and different choices. In fact the present certainty in system structure and uncertainty in decision making system's inputs have been considered. According to calculated results, environment and resource attributes have the most effective and affected by others respectively, also resource attribute has the most interaction with other attributes. Among 4 groups of sustainability attributes, environment attribute is cause factor, resource and economic attributes are effect factor and energy attribute is both cause and effect factors. Furthermore, in pressure branch of environment attribute that is belong to cause factor of greenness assessment of manufacturing, according to experts' opinions and conducted calculations, indexes of industrial sewage output, industrial nitrogen dioxide emissions, solid waste, and industrial dust emissions are considered as cause factors.

Since the focus of this study was on effective indexes of GM assessment, it can be argued that less research has pointed to the factors with this comprehension. Therefore we suggest that in order to final prioritizing of criteria with respect to their interrelations the present approach applies in other subjects of GM.

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Investigando Relacionamentos de Causa e Efeito e Priorização dos Índices de Avaliação de GM baseados em Atributos Econômicos, de Recursos, Energéticos e Ambientais e Estrutura de PSR usando Gray DEMATAL

Resumo

Atualmente, o papel da manufatura verde (GM, *Green Manufacturing*) no desenvolvimento sustentável é evidente e irrefutável, portanto, as organizações procuram se apresentar "verdes" para manter sua imagem em sua comunidade. O método usual de avaliação da sustentabilidade e do verdor de um sistema é o uso de indicadores e índices que são classificados em vários grupos com base em suas características. Um tipo importante de categorização de índices é baseado em quatro atributos de sustentabilidade, incluindo econômico, energia, meio ambiente e recursos, além do modelo pressão-resposta-estado (PSR, *Pressure-State-Response*). Tendo em vista a lacuna de pesquisa sobre as relações de interações em índices faz-se necessário investigar a influência de outros e quais são influenciados por outros. Como os índices em cada grupo podem ser efetivos em outros índices e serem sobrepostos em certa medida, assim é essencial priorizar e avaliar as relações de causa e efeito pelo uso de um método apropriado. Consideramos o relacionamento e priorizamos os índices mais importantes para avaliar o verdor da manufatura com base nos atributos de sustentabilidade e no modelo de PSR. Os dados são coletados por questionários especializados em GM, incluindo 41 índices mais os 4 atributos mencionados, totalizando 45 fatores em 13 grupos. A fim de analisar os dados, no que diz respeito às informações não seguras e insuficientes, é utilizado o método Gray DEMATEL.

Palavras-Chave: Manufatura Verde; Gray DEMATEL; Avaliação de Verdor e Sustentabilidade; Índices e Indicadores.

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