Karolina **OGRODNIK**

THE USE OF THE DEMATEL METHOD TO ANALYSE CAUSE AND EFFECT RELATIONSHIPS BETWEEN SUSTAINABLE DEVELOPMENT INDICATORS

Karolina **Ogrodnik**, PhD Eng. – *Bialystok University of Technology*

Correspondence address:
Faculty of Civil and Environmental Engineering
Wiejska Street 45E, Białystok 15-351, Poland
e-mail: k.ogrodnik@pb.edu.pl

ABSTRACT: The paper proposes the use of the DEMATEL method (Decision Making Trial and Evaluation Laboratory) for the identification and analysis of cause and effect relationships between sustainable development indicators. The literature studies presented, among other things, the application potential of the selected multi-criteria method, with particular emphasis on the decision-making problems related to sustainable development. Then, on the selected example of the group of sustainable development indicators, the algorithm of the DEMATEL method was presented, its potential advantages and limitations in the context of update Sustainable Development Indicator modules of the Central Statistical Office. The priority objective of the work was to present the DEMATEL method and its main element, i.e. cause-effect chain (impact-relation map) as an alternative approach to the known P-S-R system, i.e. the division of indicators into three functional groups: pressure/cause indicators, state/effect indicators, and response indicators.

KEY WORDS: an indicator, the DEMATEL method, a cause and effect chain

No. 4(67) 2018 • pages: 60-72 JEL: C49

Introduction

The emergence and dynamic dissemination of the concept of sustainable development both in science and in the various development strategies have made it necessary to develop methods to measure it. At present, the most popular way of measuring the concept of sustainable development is through analyses based on statistical data (Bal-Domańska, 2016, p. 151). In the case of Poland, the main source of information in this respect is the Application of Sustainable Development Indicators, made publicly available by the Central Statistical Office (CSO). The application covers a wide range of indicators divided both according to the Sustainability Targets, as well as classically into four areas: social, economic, environmental and institutional-political. Importantly, the above indicators refer to the national, regional and local levels (http://wskaznikizrp.stat.gov.pl/).

It is worth stressing that the CSO database is constantly updated, and among the proposed directions of development of the Sustainable Development Indicator modules, there is an example of the need to structure the indicators in a cause-and-effect system (Bal-Domańska, 2016, pp. 156-157). As Bal-Domańska points out (2016, p. 157): *"databases built for the needs of analyses may be a source of much valuable information not only about the state of phenomena in various areas but also about the processes taking place. The implementation of the database function as an analytical tool of processes requires the structuring of indicators according to the process sequence, i.e. from the identification of the state to the tool of influencing the process and effects".*

The pressure-state-response scheme developed by the Organization for Economic Development and Cooperation is a well-known tool for analyzing indicators in cause-and-effect order. Importantly, this scheme is one of several possible cause-and-effect systems of indicators. This approach has evolved over the last years, Borys (2005, p. 82) has distinguished the following five stages:

1. No sequence (1 – part): S-indicators (state/effects) or P-indicators (pressure/causes).
2. 2-part sequence: P→S indicators (pressure/causes → state/effects).
3. 3-part sequence: P→S→R indicators (pressure/cause indicators → state/effects→ response).
4. 5-part sequence: indicators D→P→S→I→R (causal factors → pressure/causes → state/effects → impact → response).
5. Enhanced 5-part sequence.

Examples of applications, e.g. the P→S→R scheme, can be found primarily in the works of the aforementioned authors: Borys (2015) and Bal-Domańska (2016). Selected environmental and socio-economic indicators (e.g. the problem of poverty or access to the labor market) were the subject of analysis. Application of the pressure-state-response scheme brought some recognition of its application potential in the field of sustainable development indicators. Among the difficulties encountered, Bal-Domańska (2016, p. 160) indicated, among others, the problem of an unambiguous classification of indicators into independent functional groups of indicators, i.e. indicators of the cause, state, and reaction.

Therefore, the priority objective of this paper is to present the DEMATEL (DEcision MAking Trial and Evaluation Laboratory) algorithm and its usefulness in the context of the analysis of cause and effect relationships that could potentially combine sustainable development indicators.

At this point it is worth to add, that the DEMATEL method is one of the multiple criteria decision making methods. MCDM (Multiple Criteria Decision Making)/MCDA (Multiple Criteria Decision Analysis) is a branch of operational research, which also uses and combines existing knowledge from other fields: mathematics, economics, econometrics, information systems etc. (Behzadian et al., 2012, p. 13051). MCDM/MCDA is a wide and diversified group of methods, which causes difficulties in its clear definition and classification. Dytczak (2010) proposes two main groups of MCDM: MCDA (Multi-Criteria Decision Analysis) and MODM (Multi-Objective Decision Making). The difference between these two groups concentrates on the issue of decision alternatives. MODM methods allow to generate decision alternatives of the selected decision problem. In turn, within MCDA methods only the previously identified potential options are assessed (Dytczak, 2010, p. 35). DEMATEL method is classified within MCDA methods (Dytczak, 2010, p. 48). On the other hand, Michnik (2013) proposes a division into methods of decision support (for example ELECTRE, VIKOR-S, AHP) and methods of structural modeling (for example DEMATEL, ANP, WINGS).

To sum up, the MCDM/MCDA methods allow the evaluation of decision alternatives under criteria by a single decision maker or by a group of experts (Behzadian et al., 2012, p. 13051 based on Lootsma, 1999). Some of these methods also allow to conduct the analysis of criteria, above all the DEMATEL method and ANP (Analytic Network Process). An important advantage of the DEMATEL method (compared to ANP) is a relatively simple algorithm that can be implemented in an usual spreadsheet.

DEMATEL method – basic information and examples of its implementation

The DEMATEL method was developed in Switzerland in the 1970s by E. Fontel and A. Gabus (Dytczak, Ginda, 2015, p. 631) and thanks to the use of simple mathematical formulas and point scale (the exact algorithm is presented in the next part of this paper) it enables the construction of cause-effect chains and the analysis of their components.

On the basis of literature studies, it can be concluded that multi-criteria methods are currently of great interest all over the world. However, the popularity of the DEMATEL method (compared to other methods of multi-criteria support/decision making, e.g. AHP or TOPSIS) is lower, especially in Poland. So far, the work of Polish authors concerned the analysis and evaluation of the usefulness of the DEMATEL method for selected issues and decision-making problems in the field:

- civil engineering (Dytczak, Ginda, Wojtkiewicz 2011a; Dytczak, Ginda, Wojtkiewicz, 2011b; Dytczak et al., 2011; Radomski, Bandurski, Mróz, 2017),
- management (Michnik, 2013),
- real estate (Ogrodnik, 2014),
- transport (Dytczak, Ginda, Jastrząbek, 2014; Duchaczek, 2015),
- spatial planning (Ogrodnik, 2015).

On the basis of the review of international literature and research carried out in the world, it can be concluded that the DEMATEL method is a universal method, which is confirmed by its implementation in many fields, e.g. computer sciences, engineering, sociology, management, mathematics, economics (Michnik, 2013, pp. 66-67; Dou, Sarkis, Bai, 2014, p. 576; Si et al., 2018, p. 25). Importantly, the DEMATEL method and its modification on fuzzy sets, i.e. Fuzzy DEMATEL (the theory of fuzzy sets has become popular in multi-criteria methods, especially in decision-making problems characterized by a high degree of uncertainty and ambiguity (Ocampo, Tan, Sia, 2016, p. 13)) is also applied to issues related to sustainable development, and as some examples can be indicated:

- the choice of management system in small and medium-sized enterprises in the context of sustainable development implementation (Tsai, Chou, 2009),
- the analysis of factors hindering the development of green government procurement in China (Dou, Sarkis, Bai, 2014),
- an assessment of the suitability of the land for the development of wind energy, based on the example of the province of Ardabil in Iran (Azizi et al., 2016),

- model for identifying the degree of suitability of the land for the development of ecotourism, using the example of the Dunavski kljuc region in Serbia (Gigović et al., 2016),
- the identification and analysis of the relationship between sustainability factors of the biofuel industry in China (Liang et al., 2016),
- the identification and analysis of the relationship between sustainable lifestyle factors in terms of electricity consumption, based on the example of Nigeria (George-Ufot, 2017),
- the identification and analysis of the relationship between sustainable consumption and production factors (Uniyal et al., 2018).

The above examples, of course, do not exhaust the catalog of potential implementations of the selected method. However, they prove that DEMATEL can be considered as a tool for decision support also in the field of sustainable development, all the more so as the main objective of the developers of this method was to "determine the cause and effect relationships between global and regional economic, social and economic problems" (Dytczak, Ginda, 2015, p. 632).

Calculation algorithm

Multi-criteria analysis using the DEMATEL method consists of the following stages (Tamura, Akazawa, 2005, pp. 64-65; Dytczak, 2010, pp. 126-129; Michnik, 2013, pp. 67-68; Ogrodnik, 2015, pp. 48-51):

I. Determination of direct relations between the considered indicators. Direct relationships are assessed using a scoring scale from 0 to 4 (the Fontel and Gabus scale), where: 0 – no direct impact; 1 – low impact; 2 – medium impact; 3 – high impact; 4 – very high impact. The assessment is made in pairs (by a single decision-maker or a group of experts, which increases the degree of objectivity), and the effect of these comparisons is a so-called matrix of direct relations M (table 1). The matrix of direct relations is a square matrix, where the main diagonal elements equal 0 (in DEMATEL method it is not possible to influence of the indicator on itself). While, the element m_{ij} of matrix M denotes the direct influence from factor *i* to factor *j*, in accordance with the Fontel and Gabus point scale.

II. Normalization of the matrix of direct relations. The normalization procedure in the DEMATEL method consists in dividing the elements of the matrix of direct relations by the highest value of its linear sums, formula 1 (table 2):

$$M' = \lambda \cdot M, \tag{1}$$

where:
λ = 1/the highest value of linear sums of matrix M,
M – matrix of direct relationships,
M' – a standardized matrix of direct relationships.

III. Calculation of the total impact matrix (direct and indirect relations) (table 3). The following formula 2 is used to determine this matrix:

$$T=M'(I-M')^{-1}, \quad (2)$$

where:
T – total impact matrix (direct and indirect),
M' – a standardized matrix of direct relationships,
I – unit matrix.

The element t_{ij} of matrix T denotes the direct and indirect influence from indicator *i* to indicator *j*.

IV. Calculation of the value of significance indicators and relations. On the basis of the elements of the total impact matrix (row and column sums), it is possible to calculate the value of two key indicators of the DEMATEL method: the significance indicator (formula 3) and the relation indicator (formula 4). The significance indicator shows the activity in the cause-effect chain, while the relation indicator indicates the role of the element in the chain (cause-effect) (table 4).

$$s_i = \sum_{j=1}^{n} t_{ij} + \sum_{j=1}^{n} t_{ji}, \quad (3)$$

$$r_i = \sum_{j=1}^{n} t_{ij} - \sum_{j=1}^{n} t_{ji}, \quad (4)$$

where:
s – the significance indicator,
r – the relation indicator,
t_{ij} – total (direct and indirect) influence from indicator *i* to indicator *j*,
n – the number of indicators.

V. Construction of cause-effect chain (impact-relation maps). The OX axis is dedicated to the significance indicator, while the OY axis is dedicated to the relation indicator. Elements located above the horizontal axis, i.e. elements which obtained positive values of the relation index are the cause, while elements below the horizontal axis, with negative values of the relation index, are the effect in the cause-effect chain created (figure 1).

Cause-and-effect analysis of sustainable development indicators – a case study

The example uses archival sustainability indicators from the national module, which illustrate the theme of 'poverty and living conditions' in the field of social governance (http://wskaznikizrp.stat.gov.pl).

The main assumptions made for the case study are presented below:

- 6 selected indicators of sustainable development were adopted for analysis (it is only an example of a set of indicators, which allows to present the DEMATEL method),
- the main objective was to create a cause-and-effect chain of selected indicators for sustainable development, making it possible to determine which indicator is the most dominant and has the greatest impact on the others,
- for the determination of direct relations between the indicators, the Fontel and Gabus 5-point scale (0-4) was used (points were assigned by the author, in case more specific analysis, expert interviews is recommended),
- direct and indirect relations between indicators were calculated using formula 1,
- the cause-and-effect chain was developed on the basis of significance and relationship indicators,
- calculations were made in a spreadsheet.

The following indicators were the subject of multi-criteria analysis (http://wskaznikizrp.stat.gov.pl):

I1. The risk of persistent poverty: *"Percentage of persons whose disposable equivalent income (net of social transfers income) is below the poverty line set at 60% of the median equivalised disposable income in the country in the current year and at least two of the three years preceding the survey (total)".*

I2. At-risk-of-poverty or social exclusion rate: "*Percentage of people at risk of poverty or severe material deprivation or in households with very low work intensity".*

I3. Inequality of income distribution: *"The quintile differentiation rate is calculated by dividing the total income of the 20% of people with the highest income level (the highest quintile) by the total income of the 20% of people with the lowest income level (the lowest quintile)".*

I4. Household debt: *"The indicator shows the ratio of households' debt (loans, borrowings and other liabilities of households in banks) to their gross disposable income (the amount at the disposal of households that can be used for consumption or savings)".*

I5. Average monthly disposable income per person in the household: *“The ratio of the total current household income from different sources (less personal income tax advances paid by the payer on behalf of the taxpayer, property income taxes, taxes paid by the self-employed and social security and health insurance contributions) to the average number of persons in the household”.*

I6. The number of dwellings completed per 1 000 inhabitants aged 25-34: “*The number of dwellings handed over for use in accordance with the building regulations per 1000 inhabitants aged 25-34”.*

Table 1. The matrix of direct relations M

	I1	I2	I3	I4	I5	I6
I1	0	4	0	4	0	0
I2	4	0	0	4	0	0
I3	3	3	0	3	3	0
I4	4	4	0	0	3	0
I5	4	4	4	4	0	0
I6	0	1	0	0	0	0

Source: author’s own work.

Table 2. A standardized direct relationship matrix M′

	I1	I2	I3	I4	I5	I6
I1	0,000	0,250	0,000	0,250	0,000	0,000
I2	0,250	0,000	0,000	0,250	0,000	0,000
I3	0,188	0,188	0,000	0,188	0,188	0,000
I4	0,250	0,250	0,000	0,000	0,188	0,000
I5	0,250	0,250	0,250	0,250	0,000	0,000
I6	0,000	0,063	0,000	0,000	0,000	0,000

Source: author’s own work.

Table 3. Total effect matrix T

	I1	I2	I3	I4	I5	I6	SUM
I1	0,253	0,453	0,022	0,453	0,089	0,000	1,270
I2	0,453	0,253	0,022	0,453	0,089	0,000	1,270
I3	0,557	0,557	0,077	0,557	0,306	0,000	2,053
I4	0,559	0,559	0,067	0,359	0,267	0,000	1,810
I5	0,705	0,705	0,297	0,705	0,188	0,000	2,601
I6	0,028	0,078	0,001	0,028	0,006	0,000	0,142
SUM	2,555	2,605	0,486	2,555	0,945	0,000	

Source: author's own work.

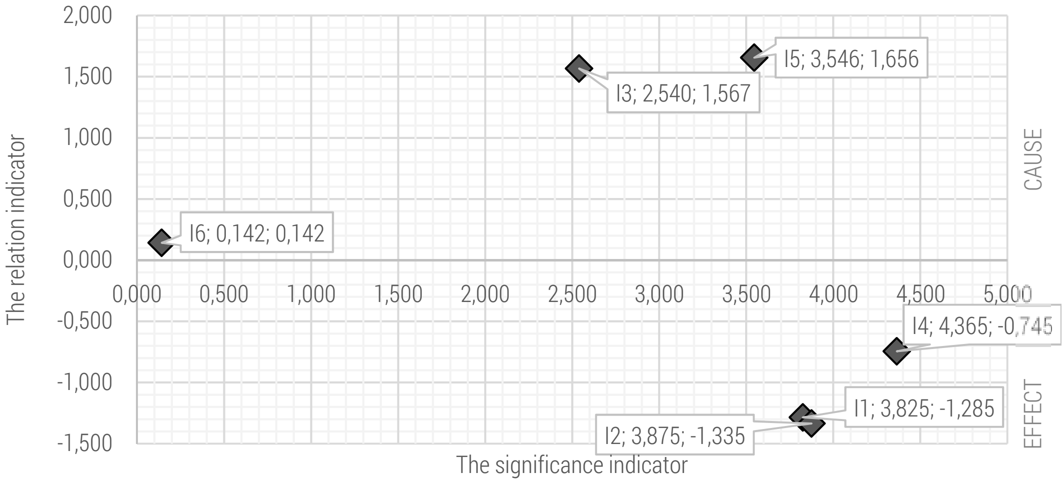
Table 4. The values of significance indicator (s) and relation indicator (r)

No.	SUSTAINABLE DEVELOPMENT INDICATOR	The value of the significance indicator s	The value of the relation indicator r	The position in the cause-and-effect chain
I1	The risk of persistent poverty	3,825	-1,285	Effect
I2	At-risk-of-poverty or social exclusion indicator	3,875	-1,335	Effect
I3	Inequality in the distribution of income	2,540	1,567	Cause
I4	Household debt	4,365	-0,745	Effect
I5	Average monthly disposable income per person in the household	3,546	1,656	Cause
I6	The number of dwellings completed per 1,000 inhabitants aged 25-34	0,142	0,142	Cause

Source: author's own work.

On the basis of the calculations carried out (table 4 and figure 1), it can be concluded that the most dominant indicator, influencing to the greatest extent the others (in the dataset under consideration) is indicator no. 5 (average monthly disposable income per person in the household), which received the highest value of the relation index, and thus constitutes the cause in the created causal chain. In addition, two other indicators are also in the position of causes: inequality in the distribution of income and the number of dwellings completed. Indicators 1 (at risk of permanent poverty), 2 (at risk of poverty or social exclusion) and 4 (household debt) received negative values of the relation indicator, which indicates their impact.

Figure 1. Cause-effect chain (impact-relation map)



Source: author's own work.

Conclusions

The DEMATEL method can be a useful tool for the analysis of cause and effect relationships. Among the main advantages of the chosen method, it is worth mentioning:

- relatively easy calculation algorithm, which can be implemented in a traditional spreadsheet,
- the possibility of examining the dependence on the situation of incomplete information,
- the possibility of expressing preferences with the use of a point scale proposed by the authors of the method,
- the possibility of taking into account expert opinions in order to increase the degree of objectivity (at the stage of creating the matrix of direct relations),
- the possibility of testing any number of indicators,
- the possibility of clearly assigning the indicators to the 'causes' group and to the 'effects' group (based on the value of the significance indicator and the relation).

On the other hand, among the potentially weaker points of the DEMATEL method in the context of the decision problem under consideration it should be pointed out that:

- the subjectivity of assessments at the stage of building the matrix of direct relations (the solution to this problem may be the use of expert interviews or the use of the theory of fuzzy sets);
- division of indicators into two groups of effect/cause only, without distinguishing a group of response indicators, which is taken into account in the traditional pressure-state-response scheme.

In summary, the DEMATEL method is commonly used in many fields (see: Si et al., 2018). The decision problem of this article concerns the analysis of sustainable development indicators. The proposal of use of the DEMATEL method in this decision problem was connected with the need to update Sustainable Development Indicator modules of Central Statistical Office (see: Bal-Domańska, 2016). The example of the calculation presents the usefulness of this method in classification of indicators into independent functional groups, i.e. indicators of the effect and indicators of the cause. However, some research limitations also were noticed. The point scale of DEMATEL is one of the most debatable elements of the algorithm. In the traditional DEMATEL method, the decision maker determines the strength of the direct influence between indicators, therefore, among directions of further research, it is suggested to extend the analysis with an expert study, as well as, the use of the Fuzzy DEMATEL method.

Acknowledgements

The research has been completed within the research project S/WBiIŚ/4/16 and financed by public funds of Polish Ministry of Science and Higher Education.

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