Joanna ŁABĘDZKA
Institute for Sustainable Technologies – National Research Institute, Radom
joanna.labedzka@itee.radom.pl

AN EXTRACTION OF KEY VARIABLES FOR LONG-TERM TRENDS USING A MODIFIED CROSS-IMPACT MATRIX

Key words

Key variables, key factors, cross impact matrix, structural analyses, long-term forecasting, computer science, strategic planning, foresight.

Abstract

The traditional approach to forecasting lies in the assumption that, by applying a set of powerful analytic tools, the future could be predicted accurately enough to choose an appropriate strategic direction for it. The process often involves underestimating either expert knowledge or quantitative methods side in order to lay out a vision of long-term future to be captured in scenarios. Computer science offers a variety of methods and computer tools to facilitate the process of strategy formulation.

The identification of impactful changes, called “key variables,” “key factors,” “rely variables” or “driving forces,” within the environment that are likely to take place helps to reduce the uncertainty of the future and could be utilised throughout the strategy making process. Key variables shaping the long-term future are identified by some of the following questions: What are the driving forces? What is uncertain? What is inevitable?

This paper demonstrates an original approach to variable selection by modelling a comprehensive dataset of variables using a wide variety of both technical and non-technical parameters indicated by experts. The extraction of key variables that significantly influence future changes of technological, environmental, political, and social phenomena is done with the modified cross-impact matrix. The proposed method contains a sequence of qualitative and quantitative procedures to overcome some obstacles that occur within the classical cross-impact method.

1. The significance of key variables in the process of strategic planning

Long-term planning is an exercise aimed at formulating a long-term strategy to meet future needs that are usually estimated by the extrapolation of present or known needs. It begins with the current status and charts out a path to the projected status, and generally includes short-term (operational or tactical plans) for achieving interim goals. When the future is truly uncertain, it is important to feed organisations with knowledge concerning triggers of future development. However, this approach might be best marginally helpful and at worst utterly dangerous, because of the fact that underestimating uncertainty could result in strategies that neither defend a company against the threats nor take advantage of the opportunities that higher levels of uncertainty provide. Another danger lies at the other extreme: If decision makers are unable to formulate a strategy that works under traditional analysis, they may abandon the analytical rigor of their planning process altogether and base their decisions on gut instinct.

Strategic planning helps determine the direction and scope of an organisation over the long-term, matching its resources to its changing environment and, in particular, its markets, customers, and clients, so as to meet stakeholder expectations. If decision makers are more aware of the mechanisms and variables of the change, they could more consciously shape their behaviour and influence their development.

A capability of efficient selection of key factors influencing the development of the environment is crucial for the generation of comprehensive possible future paths of the development. Methods that have been used to select or filter variables particularly in technology foresight are mainly based on a qualitative approach. Therefore, precise key variable selection is a critical but largely unaddressed issue in future studies.

Key variables are considered to be crucial in the process of strategic planning, because their change significantly influences the development of the area under investigation. Key variables are defined as those having an equally high impact and dependence on the paths of the future development of the analysed environment, such as technologies, research, society, science, industry, medicine, etc. Knowledge about crucial factors of change allows one to intentionally shape the dynamics of variables that are could be adjusted to future visions, for instance, the number of employees or the equipment required for developing the most promising technologies or research directions assessed as those having the highest innovative and competitive potential.

Therefore, more objective key variables selected in the precisely designed process could become a central thread to base scenarios on what could simultaneously increase the scenarios' consistency and plausibility.

2. Classical approach to cross-impact analysis

There are many different methods applied to extract key variables; however, in future studies that take into account long-term trends such as technology foresight, structural analyses based on the cross-impact method are commonly used. The cross-impact method enables one to assess the mutual influence of various groups of variables that have an impact on the development of certain technological, social, or environmental phenomena under investigation.

The identification of interrelations between selected variables, in order to elicit the key variables (driving forces) around which scenarios might be built for the future vision, is done with matrices of direct and indirect influences with the use of the analytical technique MICMAC (fr. Matrice d'Impacts Croisés Multiplication Appliquée à un Classement). The MICMAC analyses based on Boolean logic result in the map of groups of variables that affect the area under investigation (Fig. 1).

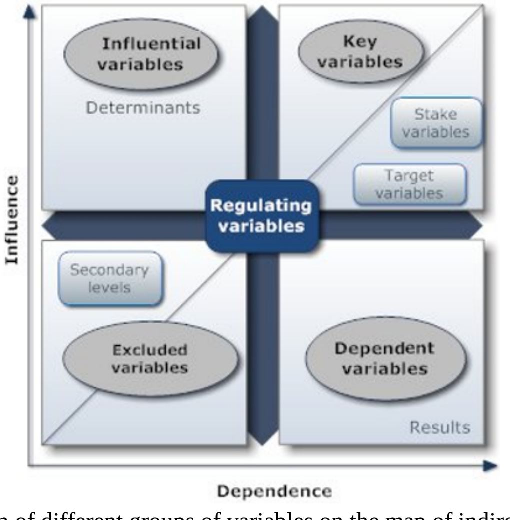

Fig. 1. The configuration of different groups of variables on the map of indirect influences

Source: Author, based on J. Arcade, M. Godet, F. Meunier, F. Roubelat, Structural analysis with the MICMAC method & Actors' strategy with Mactor method, AC/UNU Millennium Project Futures Research Methodology, 1994.

Since key variables are extremely crucial for strategy formulation, the cross-impact method allows one to indicate a group of the most influential and dependent variables (the top right square), which experts use to select key variables. Hence, the extraction of key variables is highly subjective and based on imprecise criteria that lead to low repeatability of this method.

The aforementioned disadvantage of the cross-impact analysis should be minimised, since selected key variables are then plotted on axes, constructing scenario quadrants – each representing a different perspective on how the future may unfold. Mistakes in key-variable extraction might hamper the scenario complexity and dynamics.

3. The proposed approach to the cross-impact method

In order to indicate the precise criteria for the elicitation of the key variables, the mathematical notation for the cross-impact methods is as follows:

$[r_{ij}]_{n(C)\times n(C)}$ – square matrix of direct influences

$$R = \begin{bmatrix} 0 & r_{12} & \dots & r_{1n(C)} \\ r_{21} & 0 & \dots & r_{2n(C)} \\ \dots & \dots & \dots & \dots \\ r_{n(C)1} & r_{n(C)2} & \dots & 0 \end{bmatrix} \quad (1)$$

where,

n(C) is a number of variables,

value $r_{ij} \in (0, 1, 2, 3)$ is a measure for the assessment of influence of the variable c_i on a variable c_j.

The extraction of key variables c_j includes the following stages:

1. Determination of the dependence vector $k_c = [k_{c1}, k_{c2}, ..., k_{c_{n(C)}}]^T$ for a variable c_i from other variables:

$$k_{c_i} = \sum_{j=1}^{n(C)} r_{ij} \quad (2)$$

2. Determination of the influence vector $w_c = [w_{c1}, w_{c2}, ..., w_{c_{n_C}}]$ for variable c_i on other variables $(c_1, c_2, ..., c_{i-1}, c_{i+1}, ..., c_{n(C)})$:

$$w_{c_i} = \sum_{j=1}^{n(C)} r_{ij} \quad (3)$$

3. Determination of minimum and maximum values from vectors $\mathbf{k_c}$ and $\mathbf{w_c}$:

$$k_{c\,min} = \min_{i \in J^C}(k_{c_i}) \tag{4}$$

$$k_{c\,max} = \max_{i \in J^C}(k_{c_i}) \tag{5}$$

$$w_{c\,max} = \max_{i \in J^C}(w_{c_i}) \tag{6}$$

$$w_{c\,min} = \min_{i \in J^C}(w_{c_i}) \tag{7}$$

4. Determination of values for dependence and influence vectors:

$$\Psi = \{ \langle k, w\rangle : k \in [k_{c\,min}, k_{c\,max}] \wedge w \in [w_{c\,min}, w_{c\,max}]\}$$

Based on (2) and (3) each c_j has been assign a vector attribute A_j:

$$A_j =< k_{c_j}, w_{c_j} >\in \Psi \tag{8}$$

where $A_j \le A_{max} = \langle k_{c\,max}, w_{c\,max}\rangle$.

5. Division of the Ψ area on 4 quarters Ψ_1, Ψ_2, Ψ_3, Ψ_4 with points k_s and w_s:

$$k_s = (k_{c\,min} + k_{c\,max})/2 \text{ i } w_s = (w_{c\,min} + w_{c\,max})/2 \tag{9}$$

$$\Psi_1 = \{ \langle k, w\rangle : k \in [k_{c\,min}, k_s] \wedge w \in [w_s, w_{c\,max}]\}$$
$$\Psi_2 = \{ \langle k, w\rangle : k \in [k_{c\,min}, k_s] \wedge w \in [w_{c\,min}, w_s]\}$$
$$\Psi_3 = \{ \langle k, w\rangle : k \in [k_s, k_{c\,max}] \wedge w \in [w_{c\,min}, w_s]\}$$
$$\Psi_4 = \{ \langle k, w\rangle : k \in [k_s, k_{c\,max}] \wedge w \in [w_s, w_{c\,max}]\}$$

The membership of a vector A_j to Ψ_1, Ψ_2, Ψ_3, or Ψ_4 decides what kind variables are found:

- influent variables, if $A_j \in \Psi_1$;
- excluded variables, if $A_j \in \Psi_2$;
- depending variables, if $A_j \in \Psi_3$, and;
- key variables, if $A_j \in \Psi_4$.

6. Division of the Ψ_4 area on 4 quarters Ψ_{41}, Ψ_{42}, Ψ_{43}, Ψ_{44} with points k_{ss} and w_{ss}:

$$k_{ss} = (k_s + k_{c\,max})/2 \text{ i } w_{ss} = (w_s + w_{c\,max})/2 \tag{10}$$

$$\Psi_{41} = \{ \langle k, w\rangle : k \in [k_s, k_{ss}] \wedge w \in [w_{ss}, w_{c\,max}]\}$$
$$\Psi_{42} = \{ \langle k, w\rangle : k \in [k_s, k_{ss}] \wedge w \in [w_s, w_{ss}]\}$$
$$\Psi_{43} = \{ \langle k, w\rangle : k \in [k_{ss}, k_{c\,max}] \wedge w \in [w_s, w_{ss}]\}$$
$$\Psi_{44} = \{ \langle k, w\rangle : k \in [k_{ss}, k_{c\,max}] \wedge w \in [w_{ss}, w_{c\,max}]\}$$

7. Vectors $A_j \in \Psi_{44}$ represent the most influent and depending variables.

8. Set of variables belonging to Ψ_{44} is normalised by the following equitation:

$$\rho\left(c_j\right)=\sqrt{\left(k_{c\,max}-k_{c_j}\right)^2+\left(w_{c\,max}-w_{c_j}\right)^2} \tag{11}$$

If the maximum value of the norm ρ_{max} is set, it is possible to regulate n^{Ck} – number of key variables as:

$$Ck = \{c_j \in C: \rho(c_j) \leq \rho_{max}\}$$

The simulation of the proposed criteria for key variable extraction is presented in Figure 2.

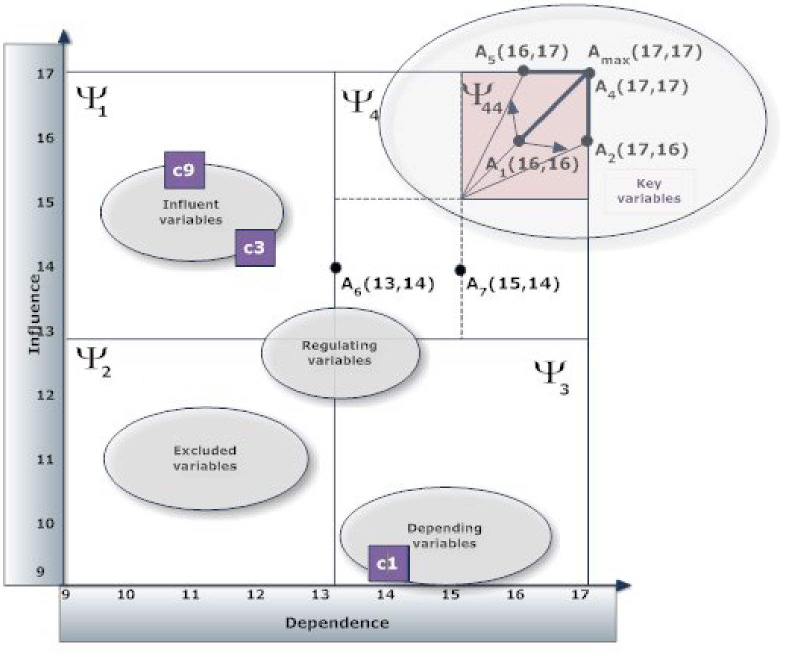

Fig. 2. The structure of the computer platform PINF

Source: Author.

After gaining qualitative data from experts, mathematical methods, i.e. Euclidean metrics, were employed in order to extract three variables A_2, A_4, and A_5 that were objectively indicated as the most influential and dependent. The variables listed should be checked to see whether any of the forces are actually amenable to a change that should also be taken into account while building strategic visions of the future. The indicated key variables drive or restrain change in the investigated area, and they should be considered in the process of scenario formulation.

Summary

Traditional management methods demand a fundamental rethink to adequately accommodate a complex reality characterized by discontinuous change. The paper more attentively explores the potential of the modified cross-impact method that is more formalised and gives more precise criteria for the extraction of key variables that affect the future development of the area under investigation. The overall conclusion is that the proposed approach increases the objectivity and repeatability of the results obtained and influences the consistency, complexity, and plausibility of future scenarios based on extracted variables.

The significant added value of the presented modified cross-impact matrix consists in the practical implementation of its results in the form of the future scenarios for specific industrial technologies.

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Ekstrakcja czynników kluczowych determinujących trendy długoterminowe z wykorzystaniem zmodyfikowanej macierzy krzyżowej analizy wpływów

Słowa kluczowe

Czynniki kluczowe, macierz wpływów bezpośrednich, analizy strukturalne, prognozowanie, informatyka, planowanie strategiczne, foresight.

Streszczenie

Dynamika i charakter zachodzących we współczesnym świecie zmian implikuje tworzenie nowych lub modyfikację istniejących metod i technik wspomagających przewidywanie przyszłych warunków badanego systemu i makrootoczenia. Tradycyjny model prognozowania bazuje na założeniu, że wykorzystanie zaawansowanych narzędzi analitycznych umożliwia na tyle precyzyjnie przewidzieć przyszłość, by móc na tej bazie wyznaczać kierunki strategiczne prowadzące do ustalonej wizji przyszłości. W procesie identyfikacji prognoz długoterminowych występuje z jednej strony niedocenienie wartości wiedzy eksperckiej lub też z drugiej przeszacowanie możliwości podejścia czysto ilościowego. Współczesne systemy informatyczne oraz wiedza matematyczna oferują ogromne możliwości i zasoby narzędzi, metod i technik wspomagających proces formułowania strategii oraz integrujących podejście ilościowe i jakościowe. Wiedza w zakresie czynników kluczowych zmian w przyjętym horyzoncie czasowym dla analizowanego obszaru nauki czy techniki umożliwia redukcję niepewności oraz intencjonalne kształtowanie dynamiki czynników w celu osiągnięcia zaprogramowanej wizji przyszłości.

W artykule zaprezentowano autorską modyfikację metody wpływów krzyżowych, w wyniku której dotychczas otrzymywano rezultaty charakteryzujące się wysoką subiektywnością i niską powtarzalnością. Zaproponowano zastosowanie aparatu matematycznego, który umożliwił zdefiniowanie precyzyjnych kryteriów ekstrakcji czynników zmian, efektywne modelowanie wiedzy eksperckiej oraz zwiększenie obiektywności i powtarzalności otrzymywanych wyników, co ma istotne znaczenie dla spójności i wiarygodności formułowanych na tej podstawie planów strategicznych.