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# A MATHEMATICAL MODEL OF THE INOVATION INDICATOR

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ABSTRACT: The aim of the present paper is to set forth a thorough mathematical model for the innovation indicator (the innovative degree) of any type of organization or a country as well. In this respect, we plan to study and measure the complex process of innovation. Similar studies [7] have been performed so far for certain countries included in the EIS. The model set forth in the present paper has been created in the context of non-existing critical situations (earthquake, pandemic, flood, etc) and it can also be applied in the current global economic crisis. Mention should be made that this model requires some fundamental arithmetical and logical operations that can be performed by engineers, economists, and not by mathematicians only.
Keywords: innovation, EIS (European Innovation Scoreboard), entrepreneurship.

## 1. INTRODUCTION

In the context of a knowledge-based economy, innovation represents an essential element for increasing the output or the efficiency of organizations.

Therefore, the innovative strategy should represent a national priority and also a top priority for the leaders of such organizations. The quality of their activities, sustainable development, can only be attained provided they are grounded on a mathematical model of innovation, thus determining the measurement of the innovative process and the efficiency of innovation.

Innovation can be defined as a complex process, dynamic and difficult to measure, at the same time, which also explains the lack of any model that might describe it. The European Innovation Scoreboard (EIS) provides an innovation tool, at the initiative of the European Union, meant to measure the innovative efficiency regarding the European Union member-states, as well as for some other highly efficient states, in view of enabling an objective, thorough comparative approach. Though a helpful instrument for innovation measurement, EIS has been subject to criticism as it is not able yet to include all relevant dimensions of the process. Currently, the process is undergoing improvement [7].

Entrepreneurship, as the activity meant to promote innovation, is the safest way to thrive in a rapidly and continuously changing world. Our contemporary society has become a global one, based on knowledge and information, whereas education at all levels has to adapt to the challenges of the society, civilization and world. We all need to possess abilities and master competencies for lifelong learning and for capitalizing the results of recent scientific development in such a way that each of us can efficiently contribute to the sustainable development of economy, innovation and general welfare.

The strengthening, expansion and renewal of the relationship of any organization, either industrial or non-industrial, including universities and social communities, with society at large, represent issues for learning.

Strengthening the partnership between organization / university on the one hand and society on the other, associated with an ongoing adjustment to the challenging and quick dynamics of the evolution of the requirements of a sustainable social development, require a continuous re-design of innovation, scientific research and academic social actions.

Genuine entrepreneurship has become a feature as well as a generator of excellence, thus encouraging risk taking, tolerating failure and stimulating innovators to protect their project until final completion. It creates a flexible structure enabling creative/innovative employers to generate new successful projects. [5]

Entrepreneurial adjustment is the only way to turn threats into opportunities, and to make the end into a new beginning, thus representing the solution to withstand unforeseen challenges, to promptly adjust to market requirements, to gain competitive advantages well suited to the hypercompetitive environment and to capitalize the novelty of changes. Innovation, control, information dissemination as well as discovery represent the entrepreneur`s essential vision of the economic environment, or the guidelines to an entrepreneurial approach to market processes.

Specialized literature [1], [8] defines the economic and social indicators, however there is no mention of the innovation indicator.

## 2. A MATHEMATICAL MODEL OF THE INNOVATION INDICATOR

The technique of mathematical modelling proves to be useful in all scientific fields. It is well known that a qualitative description of any phenomenon subject to study as well as the expression of certain laws are not enough unless they are associated with a thorough analysis of the quantitative laws governing the respective phenomenon. Therefore, we wish to measure whatever can be measured as well as to make measurable whatever has not been measured yet.

A *mathematical model* [4] can be defined as the mathematical problem associated with any topic undergoing analysis. This model is not necessarily the most accurate or the most appropriate.

The study of dynamic systems, for instance, shows that the fundamental component of a mathematical model of any dynamic process (economic, educational, social, biological, chemical, etc) represents a set of equations connecting the variables and parameters that describe the state of the particular system or a purpose function, on the variables subject to limitations (restrictions).

In the process of selecting variables the researcher will always make a compromise between the complexity of the system and the manner of objective representation of the features considered essential to its analyses. The role of the parameters is to represent the control mechanism of the process as well as to adjust the model curve for experimental data.

In a dynamic process, the time variable, *t,* is always included, implicitly or explicitly. In this context, we can distinguish:

- short-term or long-term behaviour models;
- continuous or discreet models;
- the lack or presence of delayed effects in certain models.

Mathematical models are the result of an interdisciplinary study, performed continuously and consistently. There is no general method of drawing up a mathematical model.

The present mathematical model aims to generate an innovation model that might lead to hierarchy and which can also justify the choice of the indicators defining the innovative process.

We are going to refer to the following indicators in our analysis of the innovative influence:

$x_1$ is an indicator that measures human resources, labor force that is highly qualified and trained, thus considered a key element of innovation;

$x_2$ - is an indicator that reflects the funding of innovative processes; it refers to the degree that these and other innovative processes are supported by the European Union, state, ministries, various authorities, companies;

$x_3$ - is an indicator that expresses the investments of any type of organizations, that is their effort in view of supporting innovation, their investment for generating new products and processes;

$x_4$ - is an indicator related to entrepreneurship, this reflects enterprise and collaboration among innovative organizations;

$x_5$ - is an indicator that reflects performances, measures intellectual property rights resulting from the innovative process;

$x_6$ - is in indicator that expresses the gross average salary resulted from the innovative units / gross average salary in the overall economy;

$x_7$ – indicator reflecting payment corresponding to the work factor

$$x_7 = \frac{\text{total expenses entailed by innovators salary}}{\text{turnover}} \tag{1}$$

$x_8$ - indicator reflecting the awards percentage of the total amount of gross salary;

$$x_8 = \frac{\text{total amount of innovation bonuses/awards}}{\text{total amount of accomplished gross salary}}\,100 \tag{2}$$

$x_9$ - indicator of the percentage reflecting development and training expenses of the total amount of salary

$$x_9 = \frac{\text{training} - \text{related expenses}}{\text{total amount of accomplished gross salary}}\,100 \tag{3}$$

$x_{10}$ – indicator of the number of hours devoted to professional development and training of the total average recorded number of employees Ns

$$x_{10} = \frac{\text{total number of hours devoted to professional development and training}}{N_s} \tag{4}$$

$$N_s = \frac{\sum NZ}{Z}, \tag{5}$$

where: N is the number of daily recorded number of employees;

Z - the number of days preserving the respective recorded number of employees.

$x_{11}$ - indicator of staff mobility within innovation teams

$$x_{11} = \frac{I + E}{L}. \tag{6}$$

where: I represents the incoming staff in the innovation teams;

E - the outgoing staff from innovation teams;

L - the total number of staff in innovation teams.

$x_{12}$ – indicator reflecting the performance criteria of innovation units (number of scientific papers published in reviews + number of patents + number of products and technologies resulting from research/innovation activities, based on patents, patent acknowledgement or personal innovation + scientific papers presented at international conferences + number of physical, experimental, functional models, prototypes, norms, procedures, methodologies, regulations and technical plans).

$x_{13}$ – indicator expressing professional recognition of the innovation units (number of international awards + number of national awards by the Romanian Academy + number of doctoral advisors in the field, members of the research/innovation teams);

$x_{14}$ – indicator of data reflecting human resource training within innovation units (number of PhD and MA students working in the innovation units + number of doctoral theses);

$x_{15}$ – indicator reflecting innovation infrastructure (number of innovation centres and laboratories);

$x_{16}$ – indicator reflecting work efficiency:

$$x_{16} = \frac{CA}{N}\,(\text{direct expression}) \tag{7}$$

where: CA is the turnover

N is the average number of employees

$$CA = C + PB \text{ sau} \tag{8}$$

where: C is the turnover-related cost

PB - gross profit

$$CA = CA_k = \sum qp, \tag{9}$$

where: q is the quantity of sold products

p is the selling price

or

$$CA = CA_k = NZHW_k, \tag{10}$$

Where: N is the total number of employees

Z - number of working days

H - number of working hours/day

$W_h$ - hourly output

$$x_{16} = \frac{T}{NA} \text{(indirect expression)} \tag{11}$$

where: T is total time required for accomplishing turnover (CA);

$x_{17}$ - indicator reflecting the percentage of employment in high tech;

$$x_{17} = \frac{\text{number of employees involved in high tech}}{L} 100 \tag{12}$$

$x_{18}$ - know-how indicator (specific acquired knowledge)

$x_{19}$ - indicator of the percentage of newly sold products on the market

$$x_{19} = \frac{\text{new product value}}{\text{total turnover}}, \tag{13}$$

At the level of any organization (including universities), at the level of any country, each $x_i,\ i = \overline{1,19}$ indicator can be expressed on a Likert scale thus generating the following matrix:

| Levels / Indicators | N1 | N2 | N3 | N4 | N5 |
|---|---|---|---|---|---|
| $x_1$ | $a_{11}^{(k)}$ | $a_{12}^{(k)}$ | $a_{13}^{(k)}$ | $a_{14}^{(k)}$ | $a_{15}^{(k)}$ |
| ⋮ | … | … | … | … | … |
| $x_i$ | $a_{i1}^{(k)}$ | $a_{i2}^{(k)}$ | $a_{i3}^{(k)}$ | $a_{i4}^{(k)}$ | $a_{i5}^{(k)}$ |
| ⋮ | … | … | … | … | … |
| $x_{19}$ | $a_{19,1}^{(k)}$ | $a_{19,2}^{(k)}$ | $a_{19,3}^{(k)}$ | $a_{19,4}^{(k)}$ | $a_{19,5}^{(k)}$ |

(in a $T_k$ country;

for any type of $O_r$ organizations, belonging to the same branch, including universities)

$a_{ij}^{(k)}$ represents the number of organizations, of any type, including universities, from the $T_k$ country which is at the level $N_j,\ i = \overline{1,19},\ j = \overline{1,5}$ during a given time interval.

The indicator vector is $(x_1, x_2, \dots, x_{19})$.

Here is the definition of the innovation indicator for the $T_k$, country, on the r branch (for $O_r$ organizations):

$$I_r^{(k)} = \frac{\sum_{i=1}^{19}(1 \cdot a_{i1}^{(k)} + 2 \cdot a_{i2}^{(k)} + \dots + 5 \cdot a_{i5}^{(k)})}{15} \tag{14}$$

*(partial innovation indicator).*

The average innovation indicator for the $T_k$ country is:

$$I^{(k)} = \frac{\sum_r I_r^{(k)}}{r} \tag{15}$$

*(global innovation indicator).*

We can calculate an average value of the innovation indicators for all countries $T_k,\ k = \overline{1,m}$ (or all organizations $O_r$) belonging to the same branch from several countries:

$$M = \frac{\sum_{k=1}^{m} I^{(k)}}{m}. \tag{16}$$

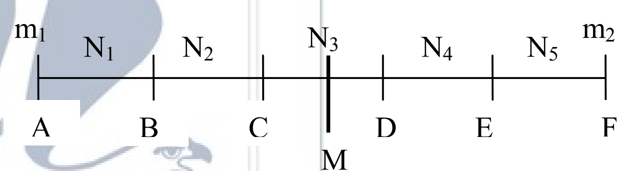
minimum value

$$m_1 = \min_{k=\overline{1,m}} I^{(k)} \tag{17}$$

maximum value

$$m_2 = \max_{k=\overline{1,m}} I^{(k)} \tag{18}$$

The result is the following scale:




$$I = \frac{m_2 - m_1}{5}, \tag{19}$$

$$A = A(m_1), \tag{20}$$

$$B = B(m_1 + I) = B\left(m_1 + \frac{m_2 - m_1}{5}\right) = B\left(\frac{4m_1 + m_2}{5}\right), \tag{21}$$

$$C = C(m_1 + 2I) = C\left(\frac{5m_1 + 2m_2 - 2m_1}{5}\right) = C\left(\frac{3m_1 + 2m_2}{5}\right), \tag{22}$$

$$D = D(m_1 + 3I) = D\left(\frac{5m_1 + 3m_2 - 3m_1}{5}\right) = D\left(\frac{2m_1 + 3m_2}{5}\right), \tag{23}$$

$$E = E(m_1 + 4I) = E\left(\frac{5m_1 + 4m_2 - 4m_1}{5}\right) = E\left(\frac{m_1 + 4m_2}{5}\right), \tag{24}$$

$$F = F(m_1 + 5I) = F(m_2). \tag{25}$$

The AB interval includes all countries or organizations evincing an unsatisfactory innovative performance;

the BC interval includes all countries or organizations evincing a satisfactory innovative performance;

the CD interval includes all countries or organizations evincing an average innovative performance;

the DE interval includes all countries or organizations evincing a good innovative performance;

the EF interval includes all countries or organizations evincing a very good innovative performance;

It is obvious that:

$$x_i = x_i(t), \quad i = \overline{1,19} \tag{26}$$

$$I^{(k)} = I^{(k)}(t), \quad k = \overline{1,m} \tag{27}$$

Where t stands for time, usually expressed in years. We can refer to 2009 as the starting year.

On the basis of the following formula

$$p_i^{(k)} = \frac{x_i}{I_p^{(k)}} \text{ sau } p_i^{(k)} = \frac{x_i}{I^{(k)}} \tag{28}$$

We can calculate the percentage of the $x_i$ indicator in $I_p^{(k)}$ or $I^{(k)}$, leading to comparisons, interpretations, predictions.

Another hierarchy of the countries or organizations in keeping with $x_1, x_2, \ldots, x_{19}$ indices as well as (partial or global) innovation indices, shall be performed according to the following algorithm: where $B = (b_{ij})_{\substack{i=\overline{1,n}\\ j=\overline{1,m}}}$ matrix of "accomplishments" of the respective countries or organizations:

| Organizations / Indices | $O_1 \ldots O_j \ldots O_m$ | |
|---|---|---|
| $x_1$ | $b_{11} \ldots b_{1j} \ldots b_{1m}$ | $\alpha_1$ |
| ⋮ | ⋮ … ⋮ … ⋮ | ⋮ |
| $x_i$ | $b_{i1} \ldots b_{ij} \ldots b_{im}$ | $\alpha_i$ |
| ⋮ | ⋮ … ⋮ … ⋮ | ⋮ |
| $x_n$ | $b_{n1} \ldots b_{nj} \ldots b_{nm}$ | $\alpha_n$ |
| | $\beta_1 \ldots \beta_j \ldots \beta_m$ | |

**Step 1.** Shall be determined:

$$\alpha_i = \max_{j=\overline{1,m}} b_{ij} \tag{29}$$

for each indicator $x_i, \ i = \overline{1,n}$;

**Step 2.** Shall be determined

$$\beta_j = \min_{i=\overline{1,n}} b_{ij} \tag{30}$$

for each $O_j, \ j = \overline{1,m}$;

**Step 3.** Shall be calculated

$$\alpha_{i_0} = \min_{i=\overline{1,n}} \alpha_i = \min_{i=\overline{1,n}} \max_{j=\overline{1,m}} b_{ij} \tag{31}$$

and

$$\beta_{j_0} = \max_{j=\overline{1,m}} \beta_j = \max_{j=\overline{1,m}} \min_{i=\overline{1,n}} b_{ij} \tag{32}$$

**Step 4.** Shall be calculated

$$\gamma_{ij} = |b_{ij} - \alpha_{i_0}|, \quad i = \overline{1,n}, \quad j = \overline{1,m} \quad \Gamma = (\gamma_{ij})_{\substack{i=\overline{1,n}\\ j=\overline{1,m}}} \tag{33}$$

**Step 5.** Shall be calculated

$$\gamma'_{ij} = |b_{ij} - \beta_{j_0}|, \quad i = \overline{1,n}, \quad j = \overline{1,m}; \quad \Gamma' = (\gamma'_{ij})_{\substack{i=\overline{1,n}\\ j=\overline{1,m}}} \tag{34}$$

A top-down hierarchy of the countries or organizations shall be performed, according to $\gamma_{ij}, \ i = \overline{1,n}$ values of the $\Gamma$ matrix. Thus, if $\gamma_{i_1 j} \geq \gamma_{i_2 j}$ therefore $T_{i_1} \leq T_{i_2}$ or $O_{i_1} \leq O_{i_2}$ ($T_{i_1}$ or $O_{i_1}$ evince a poorer innovation than $T_{i_2}$ or $O_{i_2}$).

Within the same country or organization, an optimal accomplishment of indicator hierarchy can be thus interpreted: if $\gamma'_{ij_1} \geq \gamma'_{ij_2}$, then $T_j, O_j$ performed a more efficient innovative activity in relation to $x_{j_2}$ indicator rather than the $x_{j_1}$. indicator.

Comments:

1. A particular case might be represented by $\alpha_{i_0} = \beta_{j_0}$, when the $T_{j_0}$ country or the $O_{j_0}$ organization evince an optimum innovative degree compared to other $T_j$ countries or $O_j$ organizations subject to analysis.
2. The algorithm can be programmed (e.g. in C and C++).
3. Some indicators are significant for certain organizations, some others not. Other indicators may be designed and added to the above-mentioned model.

## 3. OPEN TASKS

- genuine, accurate hierarchy of the states of the world or organizations, on the above-mentioned thorough scale; the study of their chronological (yearly) evolution represented on this scale;
- achieving correlations among indicators (e.g. in SPSS);
- applying the techniques of operational research and mathematical statistics in the application of the model. For instance, there might occur certain optimization problems, that will be solved by the simplex algorithm [1], [2], [4]

$$\begin{cases} \max(\min)\,(c_1 x_1 + \cdots + c_n x_n) \\ Ax = B \\ x_i \geq 0, \ i = \overline{1,n} \end{cases} \tag{35}$$

or statistical analyses of data may also be performed;

- calculating the inefficiency degree as opposed to the innovation indicator.
  - We consider that the inefficiency indicator $Ineff^{(k)}$ for the $T_k$ country or the $O_k$ organization may be expressed by means of a functional relation as follows:

$$Ineff^{(k)} = h(x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}, \tag{36}$$

$$x_{20}, x_{21}, x_{22}, x_{23}, x_{24}, x_{25}, x_{26}) \tag{37}$$

  - where:
  - $x_{20}$ is an indicator of the efficiency of research-related expenses

$$x_{20} = \frac{\text{research} - \text{related expenses}}{N} \text{ or} \tag{38}$$

$$x_{20} = \frac{\text{research} - \text{related expenses}}{CA} \text{ or} \tag{39}$$

$$x_{20} = \frac{\text{number of patents}}{CA} \tag{40}$$

$x_{21}$ - indicator reflecting the efficiency rate of total expenses

$$x_{21} = \frac{\text{total expenses}}{\text{total income}} 1000 \tag{41}$$

$x_{22}$ - expenses entailed by protection equipment and materials

$x_{23}$ – indicator reflecting the percentage of bonuses (seniority, difficult/dangerous/toxic working conditions) of the total amount of salary

$$x_{23} = \frac{\text{total accomplished bonuses}}{\text{total amount of accomplished gross salary}} 100 \quad (42)$$

$x_{24}$ – total number of staff involved in the research-innovation activities (number of degree 1,2,3 researchers + number of research assistants + total number of employed auxiliary staff);

$x_{25}$ – indicator of organizational wellness;

$x_{26}$ - indicator of the encouragement for generating new ideas (brainstorming, focus group, etc).

Therefore:

$$Inef^{O0} = x_9^{-\alpha_1} x_{10}^{-\alpha_2} x_{11}^{\alpha_3} x_{12}^{-\alpha_4} x_{13}^{-\alpha_5} x_{14}^{-\alpha_6} x_{15}^{-\alpha_7} x_{16}^{-\alpha_8} x_{20}^{-\alpha_9} \quad (43)$$

$$x_{21}^{\alpha_{14}} x_{22}^{-\alpha_{11}} x_{23}^{-\alpha_{12}} x_{24}^{-\alpha_{13}} x_{25}^{-\alpha_{14}} x_{26}^{-\alpha_{15}}, \alpha_i \geq 0, \; i = \overline{1,15} \quad (44)$$

- creating a mathematical model of the inefficiency sources, creating certain optimization problems (mathematical programming) where the purpose function depends on the inefficiency sources and thus be minimized;
- determining new, significant $x_i$ indicators for a Tk country or an Ok organization;
- building up innovation teams on several innovative trends at the level of a Tk country or Ok organization;
- building new innovation laboratories (centres);
- comparisons among innovation indicators calculated in keeping with age or gender groups, departments, specializations, organization as a whole, as well as setting forth concluding remarks regarding the dissemination of results and suggesting solutions for the optimization of result dissemination.

## 4. CONCLUSIONS

The mathematical model set forth in the present paper helps to achieve an accurate, thorough measurement of innovation, to perform genuine reports on the innovation degrees of an organization, to compare among similar types of organizations, having the indicator of innovation as the common denominator and criterion.

It is imperative that universities promote genuine academic value, focus on educational management strategies, sustainable development management, quality management, research management and quality; therefore it is a must for universities to encourage entrepreneurship and innovation.

Academic entrepreneurship can be defined as applied intelligence and intellectual mobility in the management of all the aspects that might contribute to the accomplishment of the major objective of training future generations with professional competencies, entrepreneurial abilities and aptitudes, with an innovative goal [3,5,6].

The concluding remark formulated by the authors is that the innovation model set forth in the present paper is worth being implemented on the basis of the following considerations:

- the necessity of innovation measurement;
- scientific foundation of hierarchical processes.

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