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# METHODS OF COMPOSITE INDICES CONSTRUCTION COMPLYING VOLATILITY AND DYNAMICS OF PHENOMENA IN ANALYSIS OF LEVEL OF INFORMATION SOCIETY DEVELOPMENT

**Summary**

A review of commonly used methods for measuring the information society allows confirming the hypothesis adopted in the introduction that they did not take into account the dynamics and variability of the studied phenomenon sufficiently. They ignore the dynamic aspect and the variability in most cases, appointing it only before or after the calculation of the measure. To be able to use the valuable information better, taking into account the dynamics and variability, an attempt to develop the concept of alternative methods of composite indices construction based on the arithmetic increments was made.

Example presented in the article focuses on the problem of taking into account the volatility in developing the rankings. Construction of index based on vector calculus would allow complying of dynamics during the whole process of calculating the composite indicator's value as well. Connecting these two aspects in one index would be the subject of further research. With regard to the issue of examining the level of information society development and other complex phenomena it can contribute to obtaining more accurate and reliable rankings of countries or regions.

**Keywords:** information society, composite indicator, dynamics, volatility

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## Introduction

Composite indices are very popular and often-used way of measuring different phenomena which cannot be expressed with the use of single indicators, for example socio-economic development, level of life or level of information society development (Land et al. 2012; Łogwiniuk 2011; United Nations Development Programme 2011). Most of the rankings based on composite indices are created in regular intervals – every month, every quarter, every year. A common approach is that every time a new ranking is based only on updated values of single indicators, with no reference to the previous results. The absence of dynamics' compliance in such measurements deprives researchers of in-formation about the pace of phenomenon's development and stability of the classification. This article presents the possibilities of creating reliable rankings of objects with the compliance of dynamics and volatility. The possible methods are presented on the basis of the review of international literature. Some advantages and disadvantages of presented solutions are described and also an example of an alternative approach is shown. Features of the new composite indicator's construction method are presented on the basis of measurements of information society development's level.

## 1. Overview methods for creating composite indices including the dynamics and variability

Methods of composite indices construction presented in the literature can be divided into groups considering the approach to dynamics' compliance:

- determining the dynamics of the object in the considered period of time,
- calculating the dynamics for the following values of the composite index,
- consideration of dynamics at the level of single indicators,
- calculating the dynamics for a set of objects,
- examining the dynamics on the basis of the reference point in the base year.

Each of the abovementioned approaches is a little bit different. Their main assumptions, methods and most important advantages and disadvantages are shown in the next subsections of this article.

### 1.1. Determining the dynamics of the object in the considered period of time

In case of determining the dynamics for one object during few years, the value of the composite indicator can be calculated as the distance between the reference point and the points which represent an object in the following years (Pluta 1977). Comparing changes in composite indicators' values in subsequent years allows the estimation of dynamics' changes as it is shown in Figure 1.

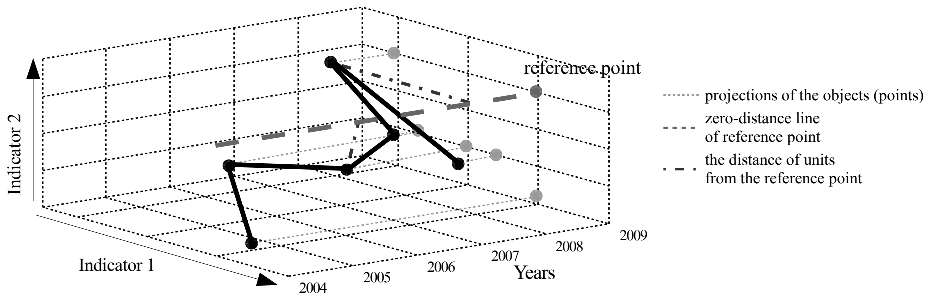



Figure 1. Determining the dynamics of the object in the considered period of time

Source: own elaboration.

An important advantage of this approach is its simplicity, but it is limited to the analysis of a single object, making it impossible to compare the dynamics of different objects and create their rankings. This inconvenience is eliminated in another approach to this issue.

### 1.2. Calculating the dynamics for the following values of the composite index

Next approach, calculating the dynamics for the following values of the composite index is based on determining dynamics after setting the indicator's value. The idea is shown in Figure 2. However, this time index is calculated for multiple objects in time.

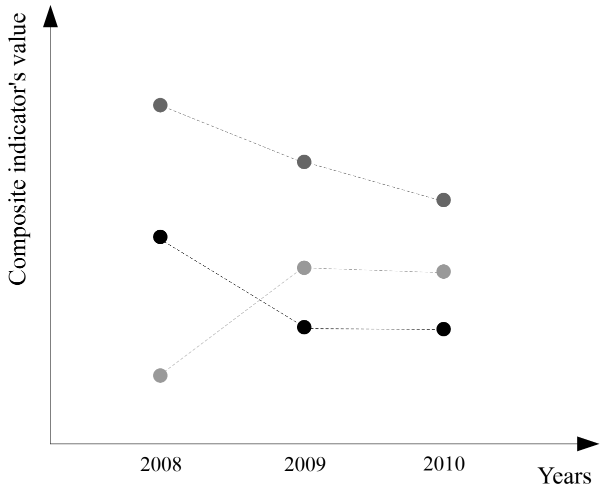



Figure 2. Calculating the dynamics for the following values of the composite index
Source: own elaboration.

Dynamics can be determined on the basis of formula (Dittman 1975):

$$z_i^k = \frac{m_i^k - m_i^{k-1}}{m_i^{k-1}} \cdot 100 \qquad (1)$$

where $m_i^k$ is the composite index value of $i$-th object in the $k$-th period. The differences of index for each object in the subsequent years (Pluta 1977) or the calculation of the dynamics on the basis of indicator's trend (Nowak 1990) can also be used. Making comparisons between examined objects in this approach is possible; however, indices express only mutual relations of examined countries. The pace of indicator's growth expresses here the pace of changes in the country's position in relation to others not the pace of the country's development (Grabiński et al. 1989).

### 1.3. Consideration of dynamics at the level of indicators

In the next group of methods emphasis is placed not on the dynamics of composite index itself but on the dynamics of the individual indices which create it. In this approach, the value of the index is calculated on the basis of values expressing single indicators' dynamics – and their dynamics is aggregated, not the values of indices themselves. Dynamics of indices can be determined with the use of linear or exponential trend (Grabiński et al. 1989) or as the quotient of the value of the reference year to the base year value (Cherchye et al. 2007). Schematically it is presented in Figure 3.

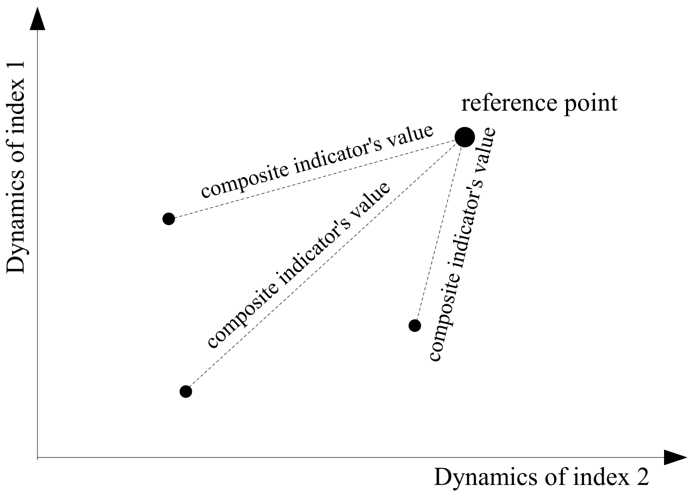



Figure 3. Consideration of dynamics at the level of indicators
Source: own elaboration.

Such an approach refers to a very important issue of transferring the dynamics of single indicators to the value of composite index. However, in this case, this value itself is not calculated. As a composite index, the dynamics of individual indicators are treated. By creating rankings on this basis, the results can be misleading, because the value of the dynamics does not directly reflect the dynamics of development of the phenomenon. It can be even observed that highly dynamic objects tend to have little value of the composite index, but they develop much more rapidly and quickly to the level already achieved by the more advanced, in terms of the studied phenomenon, objects.

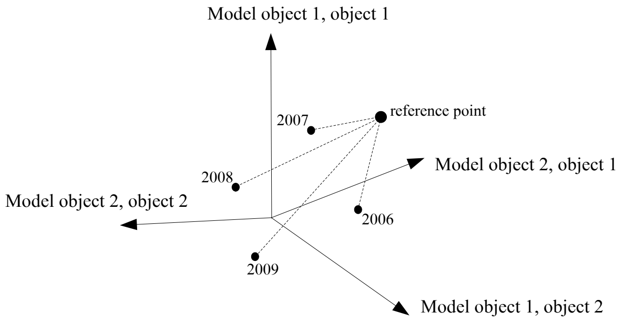
### 1.4. Calculating the dynamics for a set of objects

The following approach focuses on the dynamics calculation for a set of objects. The value of the composite index is calculated as the distance between the reference point and the points representing all the objects together in the subsequent years. Dynamics is determined by comparison of changes in the composite indicator's value (Pluta 1977) or on the basis of the formula (Tarczyński 2004):

$$\text{dynamics value} = \sqrt{\frac{1}{\text{number of objects}}} \cdot \text{distance} \tag{2}$$

Both cases are shown in Figures 4 a) and b).

a)




b)

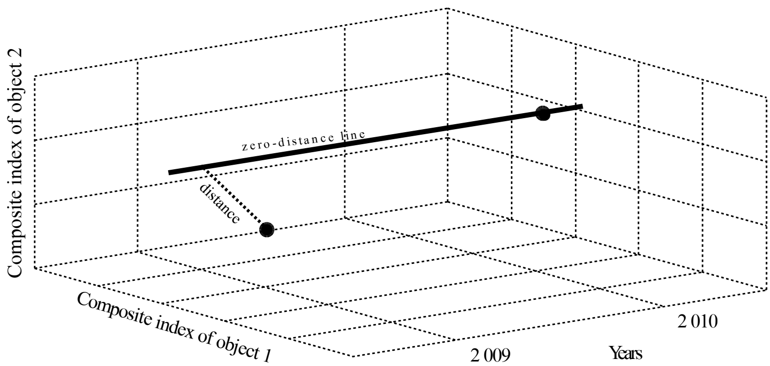



Figure 4. Calculating the dynamics for a set of objects

Source: own elaboration.

A limitation of these methods is analysing a set of objects as a whole, it is not possible to compare the dynamics of different objects with each other. It does not allow creating rankings that are the main effect and informative value of using the composite indices in the evaluation of the level of development of the studied phenomenon.

## 1.5. Examining the dynamics on the basis of the reference point in the base year

The last approach proposes research based on the dynamics of the reference point in the base year. The analysis of the dynamics is done by comparing the vector composite indicator in years by applying the same reference points (Nermend 2009), what is depicted in Figure 5.

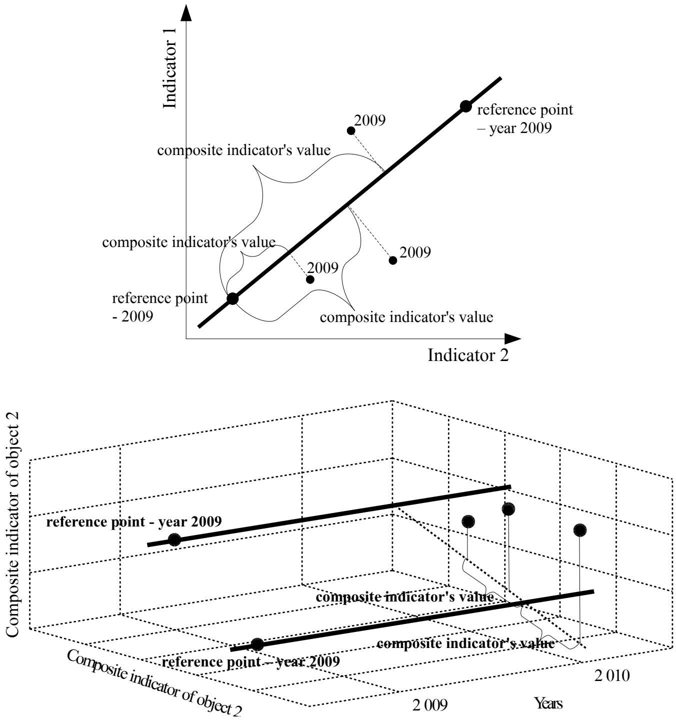



Figure 5. Examining the dynamics on the basis of the reference point in the base year
Source: own elaboration.

It should be noted that none of the described approaches takes into account the volatility of the studied phenomenon, as it is shown in Table 1, and in all these approaches (except the last) growth rate is calculated before or after the aggregation of indicators. Therefore, an open question remains determining the value of composite indicator and determination of its volatility on the basis of volatility of indicators from which it is composed at the same time and investigating the possibility of simultaneous consideration of the volatility and dynamics.

Table 1

Summary of the presented methods which comply the dynamics

| Authors | Composite index of the indicators' dynamics | The dynamics for the following values of the composite index | Composite index of the object in the considered period of time | The dynamics for a set of objects | The dynamics on the basis of the reference point in the base year | The study of indicators volatility |
|---|---|---|---|---|---|---|
| Dittman, Pisz 1975 | – | + | – | – | – | – |
| Pluta 1977 | – | + | + | + | – | – |
| Nowak 1990 | – | + | – | – | – | – |
| Grabiński, Wydymus, Zeliaś 1989 | + | – | – | – | – | – |
| Tarczyński 2004 | – | – | – | + | – | – |
| Cherchye, Lovell, Moesen, Puyenbroeck 2007 | + | – | – | – | – | – |
| Nermend 2009 | – | – | – | – | + | – |

Source: own elaboration.

## 2. Methodological basics of composite indicator's construction based on the arithmetic of increments

The method which could solve the problem that was formulated at the end of the previous point is based on arithmetic of increments (see Borawski 2009; Borawski 2011a; Borawski 2001b; Borawski 2012). In this arithmetic each indicator is represented by a number consisting of the mean and standard deviation ($\overline{x}$; $\sigma$) and the mean and variance of the indicator ($\overline{x}$; $\sigma^2$). Standard deviation and variance are in this case the measure of the indicator's volatility in the considered period of time. The mean values, standard deviations and variances of the indicators during this period are counted according to the corresponding formulas based on the value of indicators in the following years:

$$\bar{x}_{\underset{i}{j}} = \frac{\sum_{k=1}^{p} x_{\underset{i}{j,k}}}{p} \tag{3}$$

$$\sigma_{\underset{i}{j}} = \sqrt{\frac{\sum_{k=1}^{p}\left(x_{\underset{i}{j,k}} - \bar{x}_{\underset{i}{j}}\right)^2}{p-1}} \tag{4}$$

where $p$ is number of years, $i$ – number of object and $j$ – number of indicators. Conceptually this is shown in Figure 6, more formally, in Figure 7.

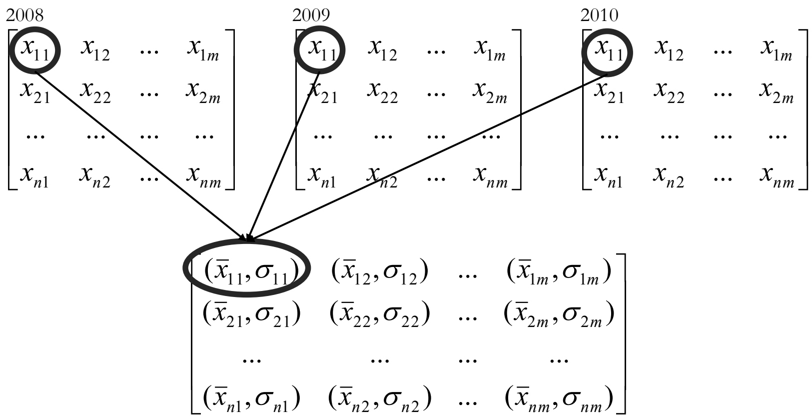



Figure 6. The idea of determining the two-element numbers

Source: own elaboration.

On the basis of mean values, standard deviations and variances, using the special calculation procedure based on vector space properties, composite indicator's values (means) and its volatility (standard deviations and variances) are determined. The result of the calculation is not directly a value representing the volatility, but the interval in which the value is located, determined by the standard deviation and the variance. With calculations performed in this way, the value of relevant indicators is reflected in the composite index.

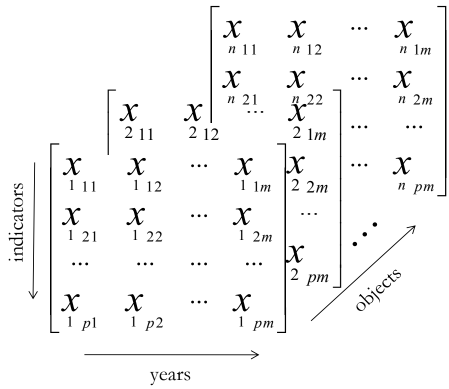



Figure 7. Formal record of the three-dimensional matrix of single indicators to determine the values of two-element numbers during certain period

Source: own elaboration.

As mentioned earlier, the consideration of the indices' dynamics during the whole process of calculation is possible by using a vector composite index and the examination of the dynamics using the reference point in the base year.

Together with a methodology based on the arithmetic of increments, through a combination of both methods is assured that both growth and volatility will be included in the whole process of determining the composite indicator's value.

## 3. The use of composite indicator based on the arithmetic of increments for the analysis of the information society development

Measurement of information society (IS) development, because of the multiplicity of its aspects, causes significant problems. Analysis of IS on the basis of individual indicators could be only one-dimensional. It does not give the possibility for coherent description of such complex phenomenon. It is the reason why composite indicators are used. Their formula is based on appropriately selected group of single indices (Luterek 2005).

Despite the difficulties in measuring information society with composite indicators, they are very often used because they offer the possibility to present the development with numbers. They show levels of IS development in particular societies in quantitative way. The adequacy of the results obtained with composite indices to the actual state of society can be varied depending on the methodology used to create them. Numerous attempts of creating objective indicators, taking into account as many aspects of information society as possible are undertaken. This issue is researched by many organisations, both at European (European Commission) and global (International Telecommunication Union, the Economist Intelligence Unit, World Economic Forum) scale. Table 2 shows some of the indices used in the last four years.

Table 2

Chosen composite indicators of information society development

| Name | Organisation | Latest data | Description |
|---|---|---|---|
| ESPON 1.2.3. (Project ESPON 1.2.3. 2007) | European Commission | 2007 | Number of indicators: 15<br>Categories of indicators: technological aspect, economic aspect, social aspect |
| Digital Opportunity Index (International Telecommunication Union 2007b) | International Telecommunication Union | 2007 | Number of indicators: 11<br>Categories of indicators: usage, infrastructure |
| ICT Opportunity Index (International Telecommunication Union 2007a) | International Telecommunication Union | 2007 | Number of indicators: 17<br>Categories of indicators: networks, skills, absorption, intensity |
| E-Readiness Index (Economist Intelligence Unit 2009) | Economist Intelligence Unit | 2009 | Number of indicators: 31<br>Categories of indicators: connectivity, business environment, applications, legal and political determinants, society and culture, promoting e-services |
| ICT Development Index (International Telecommunication Union 2009) | International Telecommunication Union | 2010 | Number of indicators: 11<br>Categories of indicators: access, connectivity, usage, policy |
| Network Readiness Index (World Economic Forum 2011) | World Economic Forum | 2010 | Number of indicators: 48<br>Categories of indicators: the state of socio-economic environment, state of ICT readiness, state of ICT usage |
| e-Intensity Index (Boston Consulting Group 2011) | Boston Consulting Group | 2011 | Number of indicators: 5<br>Categories of indicators: Internet infrastructure, Internet activities, expenditure on e-commerce and Internet advertising |

Source: own elaboration.

Unfortunately, none of the mentioned indicators complies volatility and dynamics of level of IS development. All are calculated from the values of one year. In view of the fact that presented composite indicators and previously discussed methods of such indicators creation do not meet expectations for the accuracy analysis of the level of information society development, later in the article it is proposed to use the method based on arithmetic of increments and vector calculus.

Computational example illustrating the stages of formation of indicator was based on the composite index ESPON 1.2.3. This measure is based on the individual indicators divided into three groups (Project ESPON 1.2.3. 2007):

1. Indicators for the technological dimension:
   - availability of Digital Subscriber Lines (DSLs);
   - proportion of businesses with own homepage;
   - proportion of businesses using:
     - Internet,
     - DSL;
   - proportion of households using:
     - Internet,
     - DSL.
2. Indicators for the economic dimension:
   - R&D Expenditure as share of regional GDP,
   - relative number of patents by region,
   - ICT sector value added as share of total value added,
   - ICT sector employment,
   - employment in R&D as share of regional labour force,
   - proportion of population with completed secondary/tertiary education.
3. Indicators for the social dimension:
   - regional participation in e-government,
   - participation of population having used the internet for educational or training purposes,
   - participation of population in e-commerce activities.

Due to the data availability on the regional level NUTS 1 between years 2008–2010 in Eurostat database, only five indices of above mentioned were selected:

- proportion of households using Internet,
- proportion of households using DSL,

– proportion of population with completed secondary/tertiary education,
– participation of population in e-commerce activities,
– proportion of population using the Internet (as a substitute for proportion of businesses using Internet).

Calculations were performed for the countries for which data were available over the considered period of time, at the appropriate regional level for all indicators. They were: Austria, Belgium, Germany, Denmark, Spain, Finland, Greece, Hungary, Ireland, Italy, Poland, Portugal, Romania, Sweden and Slovenia. The steps of creating the composite index are presented in Figure 8.

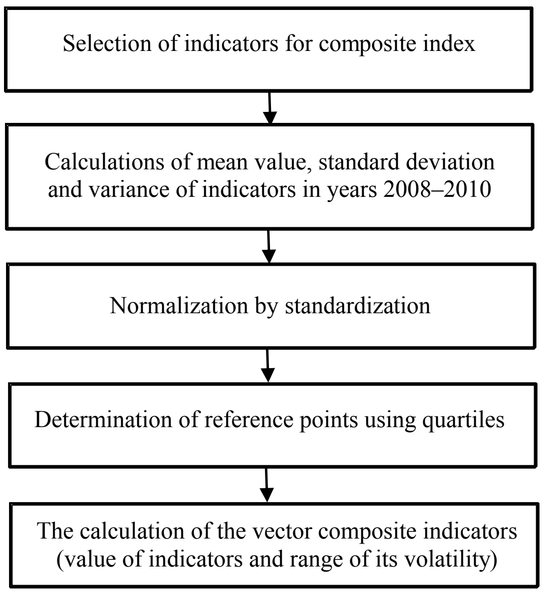



Figure 8. Stages of composite indicator’s construction
Source: own elaboration.

After the selection of indicators according to the described criteria, in the next stage of procedure calculations of mean value, standard deviation and variance were made. This action is being undertaken to establish the numbers that are two-element representation of the index. The calculations are carried out based on formulas (3) and (4).

Calculated values were normalized to remove their units and to bring the scale of values to a uniform level. Normalization in case of presented procedure is made according to the formula (Nermend 2009):

$$x'_{ij} = \frac{A_j}{\sigma_j} \tag{5}$$

and the numerator can be defined by formula:

$$A_j = x_{ij} - \bar{x}_{ij} \tag{6}$$

where $x_{ij}$ is value of *j*-th variable for *i*-th object, and $\bar{x}_{ij}$ is mean value of *j*-th variable for *i*-th object.

Reference points for ranking creation are automatically determined on the basis of the first and the third quartiles (Kolenda 2006). As the coordinates of the reference point which is the pattern object third quartile for the stimuli and the first quartile for destimuli is adopted:

$$x'_{wj} = \begin{cases} x'_{k_{III}j} & \text{for stimuli} \\ x'_{k_I j} & \text{for destimuli} \end{cases} \tag{7}$$

where $x'_{wj}$ is value of *j*-th normalized variable for model object, $x'_{k_I j}$ value of *j*-th normalized variable for first quartile and $x'_{k_{III}j}$ — value of *j*-th normalized variable for third quartile.

In the case when the reference point is anti-pattern object procedure is inverse, anti-pattern object coordinates are equal to the first quartile for stimuli and third quartile for destimuli:

$$x'_{aw\,j} = \begin{cases} x'_{k_I j} & \text{for stimuli} \\ x'_{k_{III}j} & \text{for destimuli} \end{cases} \tag{8}$$

where $x'_{aw\,j}$ is value of *j*-th normalized variable for non-model object.

Values of the examined objects' variables in vector space are interpreted as coordinates of vectors. Each object determines a specific direction in space. The difference between pattern and anti-pattern object is also a vector representing a direction in space. Along this direction the value of the composite indicator for each object is calculated. This is schematically illustrated in Figure 9. This value is determined by the formula:

$$m_{a_i} = \frac{\sum_{j=1}^{M} \left( x'_{ij} - x'_{aw\,j} \right) \cdot \left( x'_{wj} - x'_{aw\,j} \right)}{\sum_{j=1}^{M} \left( x'_{wj} - x'_{aw\,j} \right)^2} \tag{9}$$

where: M is the number of variables, $m_{a_i}$ composite indicator's value, $x'_i$, $x'_w$ i $x'_{aw}$ vectors representing respectively *i*-th object, pattern and anti-pattern object. Performing the calculation procedure for the example described above, allowing generating two maps that are shown in Figure 10.

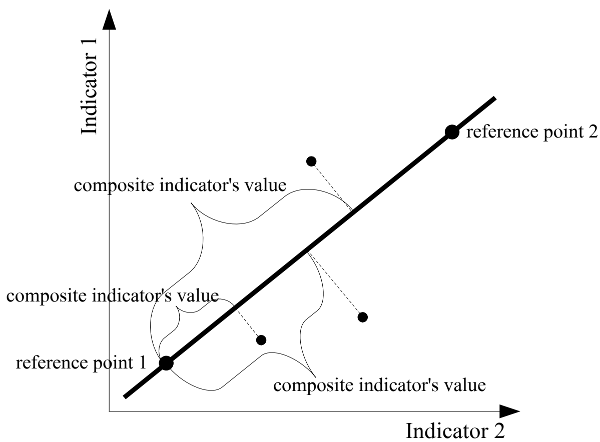



Figure 9. Calculating of vector composite indicator's value

Source: own elaboration.

The first map presents classification of examined regions and their division into four categories in terms of information society development. Countries that achieved the best result were assigned to the first category, the weakest – to the category number four. The second map shows the range of composite index variability in the considered period, which means the possible cross-category shift of regions over time. With the brightest colour on this map are marked the most stable regions, for which in the period considered the slightest fluctuation of indicators were observed.

For comparison, exemplary results obtained with the use of other methods including the dynamics and variability of phenomenon are presented. The maps representing classifications are shown in Figures 11, 12, 13, 14 and 15[1].

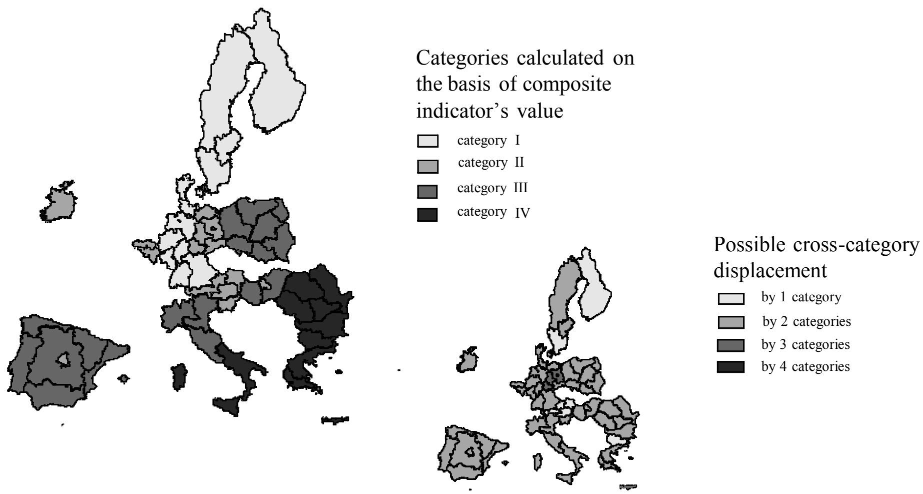



Figure 10. Classification of regions in terms of level of information society development

Source: own elaboration.

[1] Methods presented in (Tarczyński 2004) and (Pluta 1977) are designer to show overall result of all objects. Therefore, they results cannot be shown with the use of maps. This is the reason why these methods were omitted in the figures.

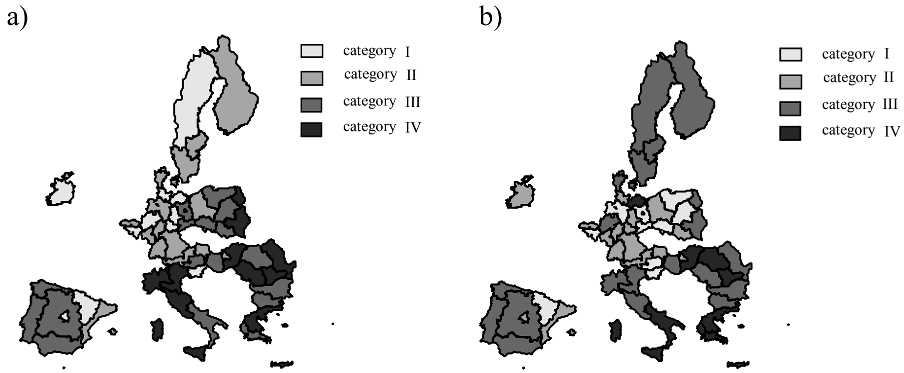



Figure 11. Classification of regions in terms of level of information society development – Dittmann & Pisz method; a) results between 2008 and 2009 b) results between 2009 and 2010

Source: own elaboration.

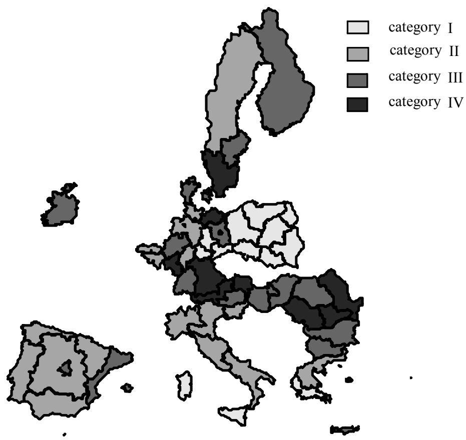



Figure 12. Classification of regions in terms of level of information society development – (Grabiński et al. 1989) method (linear trend)

Source: own elaboration.

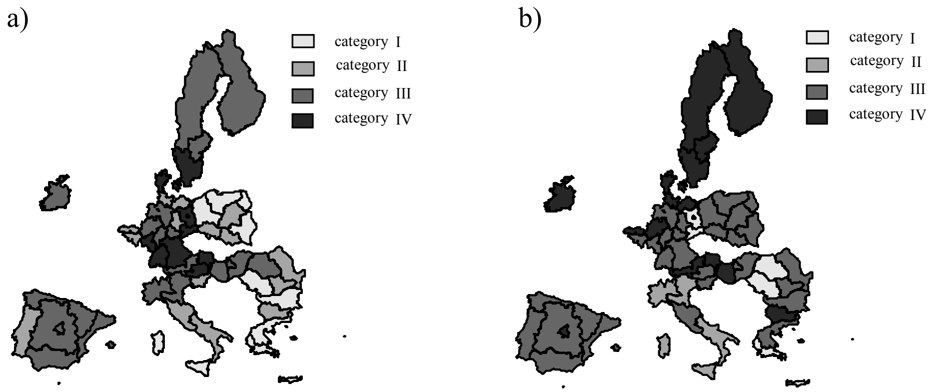



Figure 13. Classification of regions in terms of level of information society development – (Cherchye et al. 2007) method; a) results between 2008 and 2009 b) results between 2009 and 2010

Source: own elaboration.

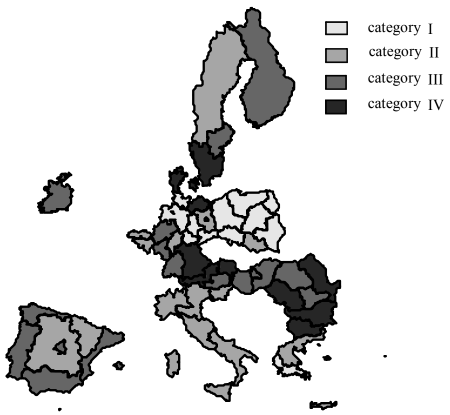



Figure 14. Classification of regions in terms of level of information society development – (Nowak 1990) method (linear trend)

Source: own elaboration.

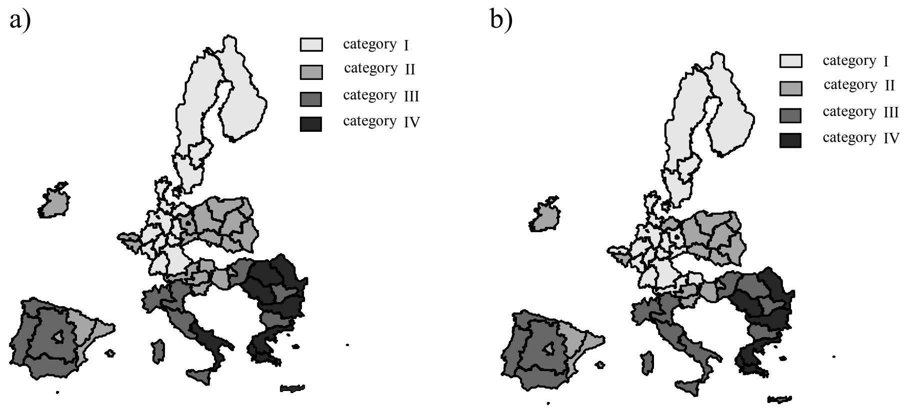



Figure 15. Classification of regions in terms of level of information society development – (Nermend 2009) method – reference point from 2008; a) 2009; b) 2010

Source: own elaboration.

## Conclusions

The introduction of additional information in the method based on interval arithmetic and vector calculus allowed in this case to determine the stability for the classification and determine which regions had the most harmonious development in terms of information society in the period considered (the volatility of phenomenon is considered). Comparing the results obtained, it can be stated that only in this one case, the construction of composite indicator allowed to obtain any additional information and calculate the value of an index itself. In case of other methods, mostly only dynamics was shown (Figures 11, 12, 13, 14). In these figures the more dynamic the object is, the brighter colour it has on the map. It may be observed that countries which already have a high level of development are mostly in the lowest category – it is hard for them to be "more developed" in that matter. Considering the fact, that results of these methods show different aspect of classification it is not possible to compare them with interval arithmetic method

The method presented in Figure 15 is based on vector calculus as well, so its results may be, to some extent comparable with results of the proposed method. As the classifications maps are taken into account, it may be observed that northern European countries are much more developed in terms of the level of information society than southern European countries. It can be also seen, that the newest countries in EU are quite weak in this field. It could be a very disappointing conclusion, however, as it is shown in the results of using other methods, their dynamics is high, so the development progresses fast.

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## METODY BUDOWY MIAR AGREGATOWYCH UWZGLĘDNIAJĄCYCH ZMIENNOŚĆ I DYNAMIKĘ BADANYCH ZJAWISK W ANALIZIE STOPNIA ROZWOJU SPOŁECZEŃSTWA INFORMACYJNEGO

### Streszczenie

Miary agregatowe od wielu lat są popularnym i często wykorzystywanym sposobem dokonywania pomiarów zjawisk, które nie mogą być wyrażone za pomocą pojedynczych wskaźników, przykładowo takich jak rozwój społeczno-gospodarczy, poziom życia czy stopień rozwoju społeczeństwa informacyjnego. Większość rankingów opartych na miarach agregatowych tworzona jest w regularnych odstępach czasu – co miesiąc, co kwartał lub co rok. Powszechnie stosowane podejście polega na tym, że za każdym razem, w momencie tworzenia rankingu jest on oparty jedynie na zaktualizowanych wartościach pojedynczych wskaźników, bez odniesienia do ich wartości w latach poprzednich, przez co nie jest uwzględniana dynamika i zmienność w dokonywanych pomiarach.

Celem artykułu jest zaprezentowanie metodologii budowy miar agregatowych proponowanych w literaturze krajowej i światowej, które biorą pod uwagę dynamikę i zmienność badanych zjawisk, wraz z ich wadami i zaletami oraz przedstawienie podstaw metodycznych alternatywnego podejścia do problemu. Artykuł prezentuje również metody pomiaru i porównywania stopnia rozwoju społeczeństwa informacyjnego oraz przykład wykorzystania opracowanej metody w odniesieniu do badania tego zjawiska.

**Słowa kluczowe:** społeczeństwo informacyjne, miara agregatowa, dynamika, zmienność