CONTRIBUTIONS TO ECONOMICS

Kesra Nermend

Vector Calculus in Regional Development Analysis

Comparative Regional Analysis Using the Example of Poland

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Contents

List of Variables and Notation

X	Matrix of objects describing variables
x_{ik}	Value of kth variable of ith object (first index – object number, second index – variable number)
w	Number of objects
n	Number of variables
z_{ik}	Standardized value of kth variable of ith object
s_k	Standard deviation of kth variable
$\bar{x}_k$	Mean value of kth variable
v_k	Variability level measure of kth variable
S_i	Standard deviation of ith object's variables
I	Stimulants set
K	Destimulant set
L	Nominants set
P_i	Point representing ith object
P_o	Point representing the standard
d_{ij}	Similarity measure between ith and jth objects
$d(P_i, P_j)$	Similarity measure between ith and jth points
m_i	Development measure of ith object
$\bar{m}$	Mean measure of development of all objects
s_m	Standard deviation of synthetic measure
wg_k	Weight of kth variable
r_k	Coefficient of object's scale change along kth variable
Δ_k	Coefficient of object's translation along kth variable
$\vec{A}$	Designation of vector
g_{ij}	Metric tensor
gr_{ij}	Border between classes
$odl_{i\,jk}$	Distance of ith object from the border between class jth and class kth
$odl\_wzgl_{i\,jk}$	Percentage distance of ith object from the border between class jth and class kth
pas	Coefficient controlling width of border belt
$\overline{szer\_klas}$	Mean width of class
$pp_{i\,j}$	Percentage reliability of ith object membership of jth class

$roz_{\vec{A}\vec{B}}$	Similarity between two objects represented by two vectors $\vec{A}$ and $\vec{B}$ calculated as length of their vectors difference
$\frac{\vec{A}}{\lvert\vec{A}\rvert}$	Unit vector along vector $\vec{A}$
$c_{\frac{\vec{A}}{\lvert\vec{A}\rvert}\frac{\vec{B}}{\lvert\vec{B}\rvert}}$	Projection of unit vector $\frac{\vec{A}}{\lvert\vec{A}\rvert}$ onto unit vector $\frac{\vec{B}}{\lvert\vec{B}\rvert}$
reg_k	Value at point P_k of regular grid
$nreg_i$	Value at point P_i of irregular grid
l_klas	Number of classes

Introduction

Methods used for regional development analysis are employed mainly to make forecasts and comparisons. Forecasting models of various types (e.g. econometric models) are usually used for forecasting. Recently, vector-autoregressive models (VAR) have become popular. These models were proposed by Sims in 1980. On the contrary, taxonomic methods (that are in the center of attention as far as the present publication is concerned) are most often employed to make comparisons. Linear ordering methods, including standard methods, are the most popular among taxonomic methods. They are based on different distance and similarity measures, which leads to the fact that they do not always provide reliable information. When, for example, one construes the standard for a base year and then compares it with data for other years, it may turn out that the measure determined will have worse values than the standard for a real object (region, micro region) although this object is better from the standard. Hence, one must look for new methods employed in regional development analysis or improve hitherto existing ones in such a way so that information obtained reflects the reality to a larger extent.

The main aim of the present publication is to work out methodological basis for regional development analysis based on vector calculus together with assumptions about computer system supporting the implementation of the method suggested.

In the context of the present discussion, the following three statements have been adopted as research hypotheses:

1. Methods hitherto used for regional development analysis do not meet requirements of objective assessment of regions and micro regions both for the purpose of science and economic practice.
2. Author's system of regional development assessment (made with the use of vector calculus) presented in the publication describes in detail the quality of socio-economic and environmental processes in the area examined and hence it could be useful in making economic and investment decisions.
3. Adaptation of regular and irregular grids from the systems of spatial information for the purpose of spatial correlation analysis may make decision makers aware of the influence that particular groups of factors have on socio-economic development.

In order to verify the first mentioned research hypothesis, the analysis of classical methods used for examining regional development has been carried out. This analysis will allow to indicate premises that these methods should meet, which will make it possible to achieve the aim of the present publication. In order to verify the second mentioned hypothesis, empirical research has been conducted with the use of both classical synthetic measures as well as taxonomic vector measure of regional development proposed by the author. The empirical research relates to Polish counties as a case-study. The presented in the work measure can be used in wide variety of regional studies.

At the same time, the application of standards construed not on the basis of maximal and minimal values of variables but on the basis of quartiles is a novelty here. Furthermore, in order to simplify the procedure for putting the approach suggested into practice, assumptions about computer system were made and the prototype of this system was developed. The system discussed has been equipped with a module enabling to examine spatial relations among groups of variables, which was possible thanks to author's adaptation of regular and irregular grids from systems of spatial information for the purpose of spatial correlation analysis.

The layout of the present publication was determined by the research purpose and hypotheses. The publication consists of five chapters preceded by introduction and succeeded by conclusion.

In the *first chapter*, the notion of "regional development" was analyzed together with factors determining this development. Moreover, the importance of regional data monitoring in the procedure for regional development examination was highlighted. Finally, indicators taken into account in the research were discussed.

In the *second chapter*, issues relating to methodology of regional development analysis were raised paying special attention to classical methods. Furthermore, reasons behind looking for new methods or improving the existing ones (in order to make the research apparatus more precise) were presented.

While discussing the issues raised in the first and second chapters, the author employed elementary analysis method with the use of which the subject matter of research was divided into several parts and discussed individually. Causal analysis was used for determining the relationship between phenomena under examination, and deduction method – for discussing the questions important as far as the fulfillment of the main aim of the present publication was concerned. Discussion made in these chapters have deductive-logical and review character. The main method of justification is logical argumentation.

In the *third chapter*, methodical basis of regional development analysis (with the use of vector calculus methods) was presented. Particular stages of research procedure based on the method suggested were described. Moreover, the author also indicated features of the method thanks to which measures (obtained with the use of this method) were more accurate than classical measures. The possibility of presenting the results of analysis in 3D space was discussed as well.

The *fourth chapter* includes the description and results of research conducted by means of the method suggested. The research was carried out for NUTS IV level, i.e. for 314 Polish counties and at the same time, 42 diagnostic variables were taken into account. The research results were collated with analogical results received with the use of classical methods in order to present advantages of the method suggested. In this sense, the fourth chapter formed a basis for verifying the research hypothesis formulated.

Finally, in the *fifth chapter*, the author had presented assumptions about computer system supporting the regional development analysis that was supposed to provide computer environment for the implementation of the method suggested. This method is based on a complex mathematical apparatus and hence, can be difficult for persons who deal with shaping regional policy. In order to make it available to a wider circle of not only theoreticians, researchers and professionals dealing with regional analyses, but also practitioners, decision makers and politicians, one must create a computer system equipped with a friendly interface that could be used by persons who are not IT specialists. Additional advantage of the system is the possibility of scaling it, i.e. using objects at different levels of spatial hierarchy, namely in communes, counties and voivodships, etc. for the analysis. Apart of the concept of the system discussed, its functioning had also been presented quoting the example of particular analyses.

In the last part, the author has presented the most important general conclusions from theoretical discussion and the research conducted. Furthermore, practical possibilities of using regional development analysis method devised as well as plausible directions of work on improving computer system created particularly for the purpose of this method have been presented.

Chapter 1
Regional Development: Economic Perspective

1.1 Notion and Factors Determining Regional Development

Region is a notion used in many spheres of life. Its meaning is generally similar in economy, science, politics and every-day life. Analyzing the sense of "region", one should notice that this notion has different connotations in each of the aforementioned spheres.

The word region derives from Latin *regio*, *regionis* that has two meanings in a direct translation. The first sense refers to a movement in a certain direction, whereas the other one refers to the direction outlining the space (in other words, surroundings, land, district). The last-mentioned sense, relating to area, has acquired more and more profound significance and become widely accepted over the course of time. As a result, the word region is found in many languages and countries.[1]

Polish economist Ponikowski highlights the polysemy of the notion discussed. He presents two premises that form a basis for creating the definition of a region. The first one has a central character, i.e. it describes region as area connected with a big city and treats interrelation and gravity force between center and surroundings as crucial elements of a region. The other one (zonal) treats region as a cohesive and at the same time homogenous area outlined on the basis of certain features determining its profile. Definitions offered by Ponikowski emphasize borders between regions in relation to its surroundings. Such an approach results in administrative division that plays a profound role in the way one comprehends regional phenomena, which may contribute to concentration or artificially reduce the actual intensity of occurring phenomena.[2]

Parteka, architect and urban planner, understands "region" as a material area that is a part of space usually used by people, i.e. a fragment of a larger whole. It is

[1]Korenik S.: *Development of Economic Region quoting the example of Dolny Śląsk*. [In Polish] Wyd. Akademii Ekonomicznej we Wrocławiu, Wrocław 1999., p. 9.

[2]Ponikowski H.: *About Properties of Regional Phenomena Space*. In: *Local and Regional Economy in Theory and Practice*. [In Polish] Red. D. Strahl. Prace Naukowe Akademii Ekonomicznej we Wrocławiu nr 1124. Wrocław 2006, p. 194.

K. Nermend (ed.), *Vector Calculus in Regional Development Analysis*,
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not easy to outline and name this area. In spatial economy (just as in geography), region is an area in which the character of particular elements of spatial relations make up a homogenous and cohesive whole. This whole has been isolated from a larger area by means of specific criteria and is homogenous or cohesive only in the scope of these criteria.[3] As there is no uniform and commonly accepted definition of a "region",[4] objective and criterion are the most important while outlining the part of the space. Parteka, although does not specifically mention elements of a region, expends this notion via establishing criteria on the basis of which it is possible to isolate a particular area and form a homogenous whole known as a region. Parteka, just as Ponikowski, pays attention to demarcation lines between regions. The difference between views held by the authors quoted is fundamental. The first-mentioned author states that borders are established in an explicit way, while the last-mentioned author claims they are natural and it is not plausible to mark them clearly.

Taken the character of the present publication into account, one should fully analyze differences in comprehending natural region (i.e. physical-geographical) and economic region. Economic region is understood as a set of elementary spatial units which constitutes a part of a larger whole, clearly stands out from this whole in geographical terms and shares certain common or complementary features. Furthermore, it can be treated as a clearly developed or just developing economic agreement the elements of which are connected with one another and with natural environment by means of co-existence and interdependence relations, and with external environment by means of intense interdependence relations.[5]

In the literature, economic region is classified in many different ways, for instance Kuciński divides economic region in the following way[6]:

1. Zonal region (surface, homogenous) that is homogenous in certain respects;
2. Central region (nodal), i.e. area of gravities or economic links with a center of a region;
3. Extensive region, i.e. manufacturing complex of a certain production-service specialization.

It is also worth mentioning the typology of economic region proposed by Korol who, having adopted the specialization of a region as a basis for division, distinguished the following types of economic regions[7]:

– Industrial, further divided by specialization (taken particular types of production into account),

[3]Cf. Domański R.: *Spatial Development*. [In Polish] Wyd. Naukowe PWN, Warszawa 2002, p. 109.

[4]T. Parteka: *Regional Development Strategy*. In: *Regions*. [In Polish]. Red. Z. Brodecki. Lexis Nexis, Warszawa 2005, p. 63.

[5]See: R. Domański: *Shaping Open Economic Regions*. [In Polish] PWN, Warszawa 1972, p. 7.

[6]K. Kuciński: *Economic Geography*. [In Polish] SGH, Warszawa 2004, p. 175.

[7]J. Korol: Indicators showing Sustainable Development in Regional Processes Modelling. [In Polish] Wyd. Adam Marszałek, Toruń 2007 p. 15.

– Agricultural (can be divided further as well),
– Industrial-agricultural,
– Agricultural-industrial, depending on promotion between main production departments,
– Tourist-recreational.

This typology is in accordance with what Kuciński has proposed. Types of specialist regions coincide with zonal, central and extensive regions.

Discussion on the notion of economic region is relevant in the context of defining regional development. It is difficult to determine the essence and specificity of regional development.[8] The notion of development is based on such categories as change and structure. Development is a kind of chain of directed and irreversible changes occurring in the structure of complex objects, i.e. systems.[9] Borys believes that this notion is not only polysemous and has not been defined yet but also that it is not possible to define it (and hence, it is a primary notion).[10] As aptly noticed by Piontek, the notion of "development" is used very widely. *Dictionary of Polish Language* defines development as a progression from a simpler or lower to a more advanced, mature, or complex form or stage.[11] However, it has not

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[8]Regional development process is the subject of a large number of research work whose authors show difficulties connected with defining the specificity and essence of the notion under consideration, e.g. M. Pięta: *Factors and Determinants Shaping the Development of Economic Region*. [In Polish]. Prace Naukowe Akademii Ekonomicznej we Wrocławiu nr 938. Wrocław 2002; K. Secomski: *Theory about Regional Development and Planning*. [In Polish] PWE, Warszawa 1987; T. Kudłacz: *Regional Development Programming*. [In Polish] Wyd. Naukowe PWN, Warszawa 1999; J. Chądzyński, A. Nowakowska, Z. Przygodzki: *Region and its Development in Globalization Conditions*. [In Polish] CeDeWu, Warszawa 2007; Kudłacz T.: *Programming Socio-economic Development at a Local Level*. [In Polish] Wyd. Akademii Ekonomicznej w Krakowie, Kraków 1993; K. Gawlikowska-Hueckel: *Regional Development Processes in the European Union*. [In Polish] Wyd. Uniwersytetu Gdańskiego, Gdańsk 2003; S. Korenik: *Disproportions in the Development of Polish Regions – Chosen Aspects*. [In Polish] Wyd. Akademii Ekonomicznej we Wrocławiu, Wrocław 2003; *Development, Regional and Local Policy in Poland*. [In Polish] Red. J. Kaj, K. Piech. SGH, Warszawa 2005; A. Jewtuchowicz: *A Territory and Contemporary Dilemma over its Development*. [In Polish] Wyd. Uniwersytetu Łódzkiego, Łódź 2005; J. Adamiak, W. Kosiedowski, A. Potoczek, B. Słowińska: *Management of Regional and Local Development, Theoretical and Practical problems*. [In Polish] Wyd. Dom Organizatora, Toruń 2001; B. Winiarski: *Regional Policy*. [In Polish] PWE, Warszawa 1976.

[9]Cf. Z. Szymla: Determinants of Regional Development. [In Polish] Akademia Ekonomiczna w Krakowie, ZNiO, Kraków 2000, p. 33; W. Krajewski: The Notion of Development and Progress. [In Polish] In: Theoretical Assumptions in the Research on Historical Development. [In Polish] Red. J. Kmita. PWN, Warszawa 1977, p. 26.

[10]T. Borys: *Axiological Foundations of Development*. [In Polish] In: *Humanistic, Economic and Environmental Aspects of Development*. [In Polish] Red. F. Piontek i J. Czerny. Zeszyty Naukowe nr 40. WSEiA, Bytom 2005, after B. Piontek: *Contemporary Determinants of Socio-economic Development*. [In Polish] Akademia Techniczno-Humanistyczna w Bielsku-Białej, Wyd. ATH, Bielsko-Biała 2006, p. 16.

[11]*The Free Dictionary by Farlex*. Available on the Internet: http://www.thefreedictionary.com/development (accessed November 08, 2008).

been explicitly specified who is supposed to gain benefit from it or what criteria must be met.[12]

In order to define regional development, one should understand the notion "development" first. In the literature on the subject, one may come across many definitions of the notion under consideration. In general, development is treated as both product and process. Employment, wealth, investments, standard of living and working conditions (i.e. matters important to people who live, work and invest in particular regions, and to be more precise – increase or improvement in these indicators) are products associated with economic development. On the other hand, industry support, infrastructure, labour force and market development (that are dealt with by economists and planners) are processes.

Unfortunately, it is very often difficult to combine intended results connected with economic development and processes employed. This may pose a dilemma for persons responsible for economic development management as well as development and improvement of strategies and plans aiming at achieving the conformity between intended results of a product and appropriate and acceptable economic processes.

Strahl treats regional development as a starting point for discussion on economic policy, systemic transformation, regional policy, regional development programming, problem of European integration as well as globalization.[13] On the other hand, Markowska states that regional development is socio-economic development occurring in a region that is treated as the development of economic potential of a region characterized by sustained improvement in its competitiveness as well as improvement in people's standard of living. Hence, it is a process of positive quantitative and qualitative changes occurring in a region in the scope of economic, cultural and social activity as well as in the scope of interaction in socio-production sphere and political sphere.[14] Kudłacz defines regional development in alike manner and claims that regional development implies a steady increase in the standard of living of residents and economic potential in a certain territorial unit.[15] The aforementioned definition stems from changes in the following components:

– Economic potential,
– Economic structure,
– Natural environment,
– Infrastructure development,
– Spatial order,
– Inhabitants' standard of living,
– Land development.

[12]B. Piontek: *Contemporary Determinants* ... [In Polish] p. 16.

[13]*Regional Development Assessment Methods*. [In Polish] Red. D. Strahl. Wyd. Akademii Ekonomicznej we Wrocławiu, Wrocław 2006, p. 13.

[14]M. Markowska: *Regional Development Determinants*. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu nr 939. Wrocław 2002, p. 20.

[15]T. Kudłacz: *Regional Development Programming*. [In Polish] ..., p. 15.

The author under discussion stresses that it is too complicated to define the development with the use of more operational expressions. The identification and measurement of regional development should consist in the choice of two or more states of development of the aforementioned components and the identification, description and assessment of qualitative differences between these components made with the use of quantitative criteria and measures of development of particular components. Furthermore, it ought to involve the assessment of the degree to which regional development (i.e. stemming from the development of components under analysis) is advanced.[16]

Klasik defines regional development as sustainable development of three elements, namely economic potential of regions, their competitive force and inhabitants' standard of living.[17] It ought to be highlighted that what the author means is sustainable development contributing to the development of the entire national community. In order to expand his definition, Klasik has distinguished the following components of regional development:

– Economic growth and employment,
– Rising prosperity and standard of living,
– Growing investment attractiveness of regions,
– Innovative processes and diversification of economic structure of regions,
– Eco-development and improvement of living conditions in regions,
– Development of social services and human capital,
– Development of identity and regional integration processes.

Therefore, determining the stage of regional development in empirical way consists in the identification and measurement of changes in its components.[18]

As stated by Szymla, research into socio-economic development on a regional (local) scale is complicated as each sphere develops not as autarchic[19] element but as integral element of national economy. Every theory of regional development holds that interregional differences exist and are something objective. At the same time, it is assumed a priori that these differences should not exist.[20]

Blakely defines regional economic development as a process in which local organizations, deriving from self-governments and communities, are involved in stimulating and maintaining business activity and/or employment. The main aim of regional economic development is to create employment opportunities in

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[16]Ibidem.

[17]A. Klasik: Concepts of Regional Development in Poland vs. Regional Differences. Stenographic record from a seminar entitled Regional Development of Poland as an element of European integration. [In Polish] Sejm RP, 22.04.1997, after Regional Development Assessment Methods. [In Polish] . . ., p. 13.

[18]Ibidem, p. 14.

[19]The sense of the notion "autarchic" derives from the word "autarchy" that refers to economic self-sufficiency of a country or group of countries, and also a situation in which society isolates from others since it believes it is self-sufficient. See: *Dictionary of Polish Language . . .*

[20]Z. Szymla: *op.cit.*, p. 35.

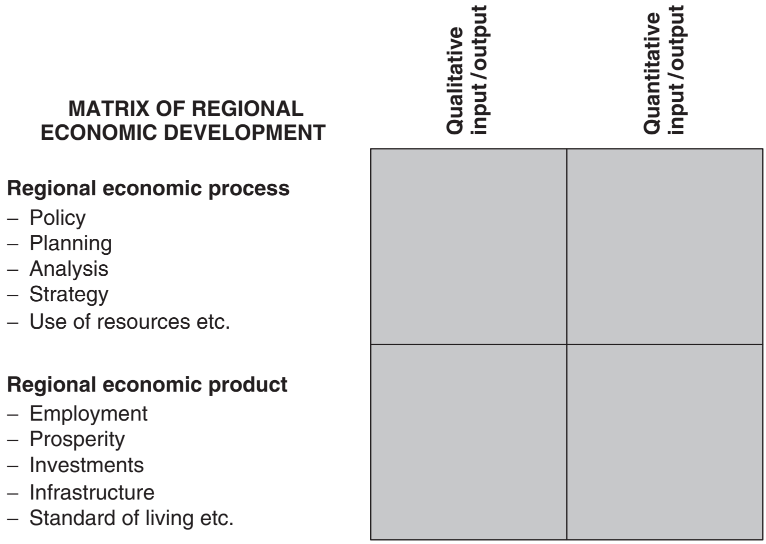

Fig. 1.1 Regional economic development as a matrix of qualitative and quantitative variables as well as development processes and products
Source: R.J. Stimson, R.R. Stough, B.H. Roberts: Regional Economic Development Analysis and Planning Strategy. Springer-Verlag, Berlin-Heideberg 2006, p.7

sectors that improve community via existing human, natural and institutional resources.[21] This definition introduces a new dimension of economic development in which more than labour, capital, prices and production is taken into account. It also covers the mobilization of social capital.

Regional development may be understood as a matrix of results that a product or service may reach for a particular region. Results that stem from acceptable development processes determined by qualitative and quantitative variables (see Fig. 1.1).

Stimson, Stough and Roberts state that regional economic development may be defined as the use of economic processes and resources available in a region, which results in sustainable development of a region and produces intended results. Regional economic development occurs in accordance with values and meets expectations from business, inhabitants as well as people visiting the region.[22]

Strahl claims that regional development is a process understood as social and economic transformation taking place in a regional space and resulting from the following three groups of factors: endogenous, exogenous and factors determining endogenous ability to respond to changes in macro environment.[23]

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[21]E.J. Blakely: *Planning Local Economic Development. Theory and Practice*. Sage Publications, Thousands Oaks, CA 1994, s. XV.

[22]R.J. Stimson, R.R. Stough, B.H. Roberts: *op.cit.*, p. 6.

[23]Regional Development Assessment . . ., p. 16.

Endogenous factors are responsible for regional development. This group encompasses factors determining the ability of resources (in particular fields of regional development) to develop. These resources are among other things age structure of population, educational status and qualifications acquired by people inhabiting a region, their entrepreneurship and innovativeness, degree to which local community is integrated in social organizations, participation in regional power, components and resources of natural environment, spatial order, state of pollution, ecological awareness, technical infrastructure and its potential for development, amount of regional budget, structure of regional markets, employing the concept of regional marketing.

Exogenous factors cover changes in macro environment of a region that are either a positive or negative impulse for particular fields of regional development. These factors stem from among other things globalization processes, European integration processes, changing macroeconomic conditions, political changes (e.g. decentralization of a state), changing economic situation, political situation and interregional policy pursued by a state. As an impulse for development, exogenous factors contribute to development and innovative transformation of endogenous factors, as well as create new resources and institutions connected with the location of new devices, technologies and jobs in a region.

Factors determining the ability of a region to respond to changes in macro environment result from different reactions to exogenous chance or danger to regional development. Endogenous regional reaction to changes in macro environment occurring as a result of exogenous factors depends mainly on the following factors:

– Flexibility of economy structure in a region,
– Internal capital potential,
– Activity and openness of regional policy,
– Competence and qualifications of regional and local authorities,
– Activity of community, infrastructure and intellectual resources, etc.

The first and third groups of factors produce centrifugal development, which implies that sources of regional development can be found in internal potential as well as initiative and creativity of regional community. The second group of factors initiates the process of development determined externally, which means that the reason behind regional development are benefits accruing from spatial differentiation of production cost.[24]

According to Klasik, strategic approach and thinking make it necessary to examine regional development from many dimensions. The environment, economy, space, technical infrastructure and socio-cultural dimension are planes mentioned most often[25] (cf. Table 1.1). Each of the aforementioned planes covers a set of

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[24] Ibidem, p. 16.

[25] A. Klasik, F. Kuźnik: *Strategic Planning for Local and Regional Development*. [In Polish] In: *Functioning of Local Self-governments – Experience and Prospects*. [In Polish] Red. S. Dolata. Wyd. Uniwersytetu Opolskiego, Opole 1998, after M. Markowska: *Regional Development*..., p. 24.

Table 1.1 Factors determining regional development in the context of strategic planning

Item number	Regional development dimensions	Factors determining regional development
1.	Socio-cultural	Population and its education, professional qualification, integration of community, living conditions, social institutions and services
2.	Environmental	Natural environment components and resources. State of environmental pollution and devastation, environmental infrastructure, environmental awareness
3.	Infra-technical	Local, regional and supraregional technical infrastructure, organization of infrastructure sectors, infrastructural gap, infrastructural reserves, infrastructural investments
4.	Economic	Economic resources, business activity by trades, sectors, economic functions, local and regional markets, economic base of cities and regions, external benefits, social cost, common goods and facilities, competitiveness of cities and regions
5.	Spatial	Land development, functional-spatial arrangements, spatial availability, spatial order and arrangement, spatial value

Source: Markowska M.: *Regional Development Determinants* [In Polish] . . ., p. 25

factors determining the level of regional development. These factors measure regional development on particular planes, due to which once assessments from each plane have been collected, the state of regional development is presented.

Bagadziński presents the description of factors determining regional development arranged by various aspects of socio-economic activity.[26] He assumes that positive phenomena initiated in the course of development processes translate into positive results that are a starting point for further development processes. Such an approach allows to treat them as factors determining another stages of development. The most significant effects, entailed by the development, have been distinguished in each group, namely

1. Economic factors including capital growth, demand growth (also changes in its structure), earnings received by population, profits generated by enterprises, employment, investment outlays, work output and specialization as well as creation of modern management;
2. Social factors including consumption increase and changes in its structure, rate and character of urbanization, changes in regional awareness, promoting entrepreneurial attitudes, improvement in the functioning of self-governments as well as increase in educational status and activity;
3. Technical and technological factors, i.e. development of technical and research base, introduction of technical and product innovations, improvement in

[26] S.L. Bardziński: Local Economic Policy during the Period of Systemic Transformation. [In Polish] UMK, Toruń 1994.

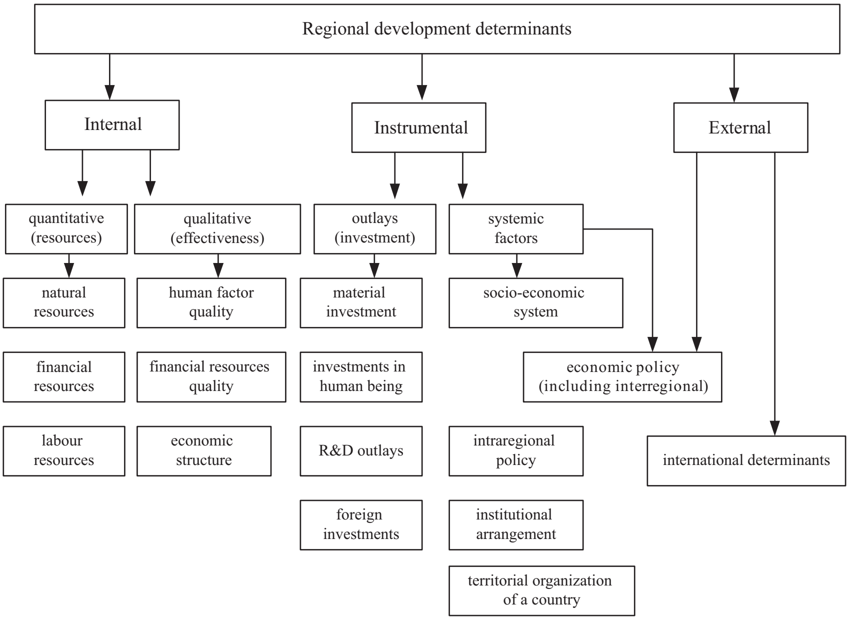

Fig. 1.2 Factors determining the development of regions
Source: J. Kudełko: *op.cit*., p. 79

production quality, improvement in technical infrastructure, modernization of material structure of manufacturing apparatus;
4. Environmental factors, namely progress in the environmental protection, rationalization of resources management, implementation of closed cycles;
5. Political factors, i.e. character of power, competence and rights, way of exercising power, degree to which society accepts authorities.

According to Kudełko, analyzing the notion of "regions' development", one should remember that regions are not isolated socio-economic entities but are strongly connected with their environment and refer to the character of their internal determinants. This means that regional development is determined by the following three factors: internal determinants of a region, external environment determinants as well as influence of public authorities and various economic and social institutions. Hence, the author has presented the division of factors into internal, instrumental and external (Fig. 1.2).[27]

Internal factors are connected with the right use of region's economic potential and social potential. These are also factors resulting indirectly from socio-economic situation of a region, its internal determinants and the use of socio-economic potential.

[27] J. Kudełko: *Level of Socio-economic Development of Polish Voivodships*. [In Polish] Zeszyty Naukowe Akademii Ekonomicznej w Krakowie nr 651. Kraków 2004, pp. 78–81.

Instrumental factors encompass actions influencing the shape and use of quantitative and qualitative factors distinguished. In fact, development outlays play a crucial role among instrumental factors as they indirectly contribute to enriching socio-economic potential of a region.

External factors are not affected by a particular region and do not depend on economic situation of regions or the effectiveness of regional policy pursued in these regions (cf. Fig. 1.2).

Markowska emphasizes that in the era of globalization, local and regional development are processes that practically cannot be isolated. They occur inside a country but on two different planes, and the border is determined by the degree to which development processes are complex and synergic effect possible to reach. Factors determining the development of a region on a local scale may be investigated in the context of functional assets namely

1. Factors influencing the level of assets of resources determining the possibilities and easiness of receiving all the necessary production factors (natural resources, personnel, production traditions, objects, land and infrastructural development standards);
2. Factors influencing the level assets of demand (market absorption, availability of external markets, demand structure);
3. Factors determining the attractiveness of arrangement to potential inhabitants and institutions (spatial development state, access to services, natural environment state, social security, etc.).[28]

The idea of sustainable growth is strictly connected with the notion of "regional development". The first mentioned concept was introduced with the degradation of the environment, demographic expansion and growing disproportion in socio-economic development occurring in particular sides of the world as well as depleting natural resources. With the development of this concept, it was more and more evident that there was a need for change in the hitherto existing idea of world development (the idea shaped in accordance with economic theory and development).[29] In one of first definitions formulated in the 3rd Section of United Nations Environment Programme (UNEP) in 1975, sustainable development was described as inevitable and desired economic development that would not disturb human environment profoundly and irreversibly, that would not result in biosphere degradation and combine natural and economic laws with culture.[30]

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[28] M. Markowska: *Regional Development . . .*, pp. 25–26.

[29] Por. J. Korol: *op.cit.*, p. 23; M. Kistowski: *Model of Sustainable Development and Environmental Protection in Poland and Strategies toward Development of Voivodships*. [In Polish] Bogucki, Wyd. Naukowe Uniwersytetu Gdańskiego, Gdańsk–Poznań 2003, p. 15.

[30] Cf. M. Sej-Kolasa, A. Zielińska: Comparative Analysis of Communes in Dolnośląskie Voivodship on the basis of Selected Indicators Showing Sustainable Development. [In Polish] In: Taxonomy 9. Data Classification and Analysis. Theory and Applicatopns. [In Polish] Red. K. Jajuga, M. Walesiak. Akademia Ekonomiczna we Wrocławiu, Wrocław 2002, p. 12; S. Kozłowski: Is the Transformation of Polish Economy Aimed at Sustainable Development. [In Polish] In: Mechanisms and Determinants of Eco-development. [In Polish] Vol. I. Wyd. Politechniki Białostockiej, Białystok 1996, p. 97.

The definition of sustainable development, quoted the most often, comes from the report of Bruntland Commission *Our Common Future*.[31] The Commission has placed concepts of sustainable development and future in international programme and defined it as the development that satisfies the needs of present generations without putting future generation at risk of losses so that they could meet their needs as well. This development is not a permanent state of harmony but rather a process of change during which resource exploitation, trends in investments and technological development as well as institutional change are in accordance with future and present needs.[32] The aforementioned definition refers to a particular type of further and future development of society aware of the fact that this development is connected with the exploitation of resources and hence resources should be managed in such a way so that future generations could use them as well.[33]

The statement issued by Bruntland Commission was criticized by some as it did not take a major difference between development and growth into account. Development is very often equated with growth and these notions are used interchangeably, which is a mistake as they are not synonyms. For instance, Kozłowski and Hill state that development is the attainment of certain social and economic goals that may require stabilization, growth, reduction, change in quality or even the exclusion of existing elements. At the same time, achievement of goals may require the creation of new elements. It should be noticed that in each of the aforementioned cases, development, occurring via certain changes, is supposed to lead to progress reflected mainly in improvement in common interests of communities involved in this process.[34]

Better results achieved by a region do not necessarily have to result from economic growth (usually described as GDP per capita growth or gross regional product per capita growth), and lack of growth does not entail that development has not occurred. Nevertheless, followers of sustainable development believe that it is vital to state that a need for economic progress goes hand in hand with development though such development should minimize costs (economic, social and environmental) and maximize profits. This is a compromise and, at the same time, a challenge.

Jacobs believes that sustainable development allows to provide all the members of a particular community with basic environmental, social and economics services

[31]Bruntland Commission: *Our Common Future*. World Commission on Environment and Development, New York 1987.

[32]R.J. Stimson, R.R. Stough, B.H. Roberts: *op.cit*., p. 43.

[33]H.N. van Lier: Land Use Planning in Perspective of Sustainability. An Introduction. In: Sustainble Land Use Planning, ISOMUL Developments in Landscape Management and Urban Planning. Red. A.J. de Buck, C.R. Jurgens, Jaarsma, H.N. van Lier. Elsevier, Amsterdam 1994, pp. 1–12.

[34]J. Kozlowski, G. Hill: Towards Planning for Sustainable Development. A Guide for UET Method. Aldershot, England 1993, p. 4.

and does not threaten the implementation of natural, created and social systems on which providing the services depends.[35] Pearce et all suggest that sustainability implies that the environment should be protected in such conditions and to such extent so that its capabilities (capability of the environment to fulfill various functions) could be maintained for a long time and at a level sufficient to provide future generations with opportunity to take advantage of the environment to a comparable degree.[36]

According to Maastricht Treaty on European Union from 1992 (article 2), sustainable development is believed to improve the quality of life as long as this life is capable of supporting the ecosystems. The 5th European Community Environment Programme (from 1993) called for treating sustainable development as harmonized development of economic activity that did not cause inflation and respected the environment. Local Governments for Sustainability (ICLEI) perceive sustainable development as constant economic and social development harmless to national resources on which the quality of human activity and further development depend.

Sustainability may also be defined as continuation without reduction and hence sustainable community or region may be considered as looking for and improving economic, environmental and social qualities of a particular area in such a way so that members of this community could live in a healthy, creative and pleasure way. Development can be understood as improving or leading to a more advanced state. Therefore, sustainable development may be perceived as development improving the economy but not weakening the environment or society.

There are several factors contributing to sustainable development, namely capability to create and absorb innovations, improve human capital and knowledge, professional organization of human resources and creation of effective structural arrangements of human and material resources of a region allowing the commercialization of regional product.[37]

Sustainable development is also very often called long-lasting development or eco-development. It is a concept of permanent use of capital or resource. It defines permanence in economic terms, i.e. as maintaining the natural capital.[38] Natural capital is the entire natural environment that is a resource of production means such as soil, air, forests and water, thanks to which goods and services provided can be

[35] M. Jacobs: The Green Economy: Environment, Sustainable Development, and the Politics of the Future. Pluto Press, London 1991.

[36] D. Pearce, A. Markandya, E.B. Barbier: *Blueprint for a Green Economy*. Earthscan, London 1989.

[37] M. Sobocińska: *Using Marketing in Regional Development – Selected Issues*. [In Polish] In: *Marketing and Activity of Regions*. [In Polish] Red. J. Karwowski. Uniwersytet Szczeciński, Szczecin 2006, p. 60.

[38] J. Śleszyński: *Introduction to Issues relating to Sustainable Development Indicators*. [In Polish] In: *Markets and Regulation. Poland at the close of 1990's*. [In Polish] Materiały z konferencji Wydziału Nauk Ekonomicznych Uniwersytetu Warszawskiego. WNEUW, Warszawa 1998, p. 359.

recycled or not recycled and launched or not on the market. It should be stressed that methods for acting should allow to marinate natural resources or at least do not reduce benefits accruing from these resources.[39]

Piontek defines sustainable development as continued improvement in the quality of life of present and future generations via shaping the right proportions in using three types of capital, namely economic, human and natural capital.[40]

Gil and Śleszyński also mention three elements of sustainable development, i.e. economic, social and environmental. Economic element makes one aspire to economic growth that leads to real prosperity and enables him/her to avid short-sighted policy resulting in long-term impoverishment. Societies must optimize income stream and at the same time maintain basic resources of their capital as well as optimize social and environmental costs connected with the production and distribution of goods. Social element refers to satisfying fundamental needs by members of a society and providing equal opportunities for development. Finally, environmental element implies that natural goods and services should be used in such a way so that, on the one hand, complex ecosystem relationships are not disturbed, and on the other hand, the contribution that goods and services have made to human prosperity is not lessened.[41]

The above discussion on the notion of "regional development" allows to draw certain general conclusions. In fact, regional development refers to a certain space (territorial unit) and may be treated not only in terms of a product but also from the perspective of a process and hence it is vital to analyze it in a temporal dimension. Regional development is determined by many factors both qualitative and quantitative in nature. Furthermore, it cannot be analyzed in isolation from the concept of sustainable development. Thus, the examination and assessment of regional development are extremely complex tasks.

1.2 Data Monitoring for Regional Development Assessment

Proper and reliable assessment of regional development cannot be made without access to extensive source of diverse yet comparable information items. Any flaws or gaps in this scope hinder the assessment and limit the possibilities of carrying it out in a comprehensive and objective way.[42] The examination of a current situation

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[39] S. Gil, J. Śleszyński: *Lasting Economic Prosperity Indicators.* [In Polish] In: *Economist*. [In Polish] Warszawa 2000, pp. 608–609.

[40] B. Piontek: *Determinants of Socio-economic Development in Contemporary Economy*. [In Polish] In: *Economy and Environment no 1(27).* [In Polish] Fundacja Ekonomistów Środowiska i Zasobów Naturalnych, Białystok 2005, p. 25.

[41] Cf. S. Gil, J. Śleszyński: *op.cit*., pp. 608–609; J. Śleszyński: *op.cit*., p. 362.

[42] The notion "assessment" is understood as determination of the value and importance of something (*Popular Dictionary of Polish Language.* [In Polish] Red. B. Dunaj. Wyd. Wilga, Warszawa 2000), which in the context of regional development assessment entails a diagnosis of region's state. Regional development assessment understood in such a way is in accordance with the majority of publications concerning this subject matter (e.g. *Regional Development* ..., p. 34 et al).

in a region, possibility of predicting the future course of phenomena via the projection of historical data, dynamic analyses or interregional comparison are plausible only thanks to proper resources of databases.[43]

In this context, regional monitoring is of profound importance.[44] "Regional monitoring" is understood as a process of consistent collection of reliable information concerning a region in order to observe changes occurring in this region. It is about both quantitative information (that enables one to identify the level at which an explicitly defined measure is achieved) and qualitative information. In other words, regional monitoring consists in a long-term or permanent observation of certain phenomena occurring in particular dimensions of regional development (cf. Table 1.1) that allows to get to know their response to certain actions. As a result of these observations, certain information pieces regarding the state of a region are collected (database). Such information is used, among other things, by local authorities for decision-making.[45] Understood in such a way, monitoring is a key element in programming and managing of regional development (taken sustainable development principles into account).[46] Programming and managing of regional development are impossible without the support from information collected and complemented during the process of monitoring.

The system of regional monitoring should be analyzed on the following planes:

– Institutional – organizational,
– Information – functional.

Institutional – organizational structure of monitoring system consists of the following units: statistical offices, statistical service of local government and government administration, and other units obliged to register changes occurring in a region.

The main unit dealing with the collection of statistical information, that may be used for assessing the regional development, is Central Statistical Office (GUS), i.e. one of central bodies of public administration obliged to make data widely available in the light of legal regulations (Public Statistics Act and Statistical Research

[43]To find more consult the following sources: M. Obrębalski: *Urban audit – Attempt to Measure the Standard of Living in Selected European Cities*. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu nr 979. Wrocław 2003, p. 448; M. Markowska: *Databases of Regions as an Element Supporting Regional Management*. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu nr 979. Wrocław 2003, pp. 102–03.

[44]"Monitoring" is understood here as a system involving long-term or recurrent observation of a certain type made with reference to phenomena of specific type or response to these phenomena (*Dictionary of Foreign Words*. Red. I. Kamińska-Szmaja. Wyd. Europa, Warszawa 2001). The notion is defined similarly by *Popular Dictionary...*: constant observation, taking continuous and systematic measurements.

[45]Cf. M. Obrębalski: *Public Statistics as a Means for Supporting Local Authorities in Decision-making*. [In Polish] In: *Strategic Decisions in Regional Economy*. [In Polish] Red. R. Krupski, E. Tyszkiewicz. I-BIS, Wrocław 1996, pp. 204–31.

[46]W. Toczyski: System for Monitoring Sustainable Development in Northern Poland. [In Polish] In: Sustainable Development – Polish and European Experience. [In Polish] Red. S. Czaja. Biblioteka "Ekonomia i Środowisko" nr 23. Nowa Ruda 2005.

Programme announced every year). Access to data is at present relatively easy as it is published on websites of Central Statistical Office in the form of Regional Database (BDR).[47]

Regional database, functioning since 1995, is the largest arranged set of information about socio-economic, demographic and social situation as well as the environment made available on the Internet in Poland. On the main website, one may browse a list of information available as well as its catalogue which is presented in the form of features (indicators) describing the units of territorial division in Poland and consists of many items arranged by fields. The number of items is different in consecutive years and depends on the scope of research conducted and gradual extension of database. So far, GUS has collected about 1,800 features in the following categories:

territorial division (surface area of a county, number of villages and towns),

- Local self-government (councilors by sex, age, occupational group),
- Population (population state and natural movement, migrations for permanent residence),
- Surface area and use of arable land (farmlands, other arable land and wastelands),
- Transport and communications (county, local and city roads, post offices, telephone subscribers),
- State of the environment and environmental protection (municipal sewage treatment plants, air pollution emission, industrial waste, natural and landscape protection, greens),
- Communal economy (water system, sewage system, gas mains in cities, power industry, public transport routes),
- Trade (shops, market places),
- Tourism (tourist accommodation, accommodation places by categories),
- Pre-school education (number of institutions, places, children, teachers),
- Education (number of institutions, departments, pupils/students, teachers, graduates),
- Health protection and social security (hospitals, health care in spas, clinics, pharmacies, health service, crèches, social security institutions),
- Culture and art (libraries, cinemas, theaters),
- REGON, i.e. National Economy Register (units registered in sectors and sections of EKD,[48] i.e. European Classification of Business Activity),
- Income and expenditure in the district budget (income and expenditure in the district budget by sources and purposes).

The above information refers to voivodships, counties and communes as subjects in the system of social and administrative organization of a country, as

[47]The address of Regional Database website is as follows: http://www.stat.gov.pl/bdr/.

[48]European Classification of Business Activity (Polish EKD) has been carried out on the basis of the project carried out by Statistical Bureau of European Community EUROSTAT. It has a subject character and is a systematized set consisting of types of socio-economic activities in national economy.

well as regions and sub regions that are elements of Nomenklatura Jednostek Terytorialnych do Celów Statystycznych (NTS).[49] NTS divides Poland into hierarchically related territorial units at five levels. Three levels are regional whereas the remaining two – local ones. Regional level includes:

1. level 1 – the area of a region (on May 1, 2004, 6 regions were outlined each of which included from two to four voivodships),
2. level 2 – voivodships,
3. level 3 – sub regions (groups of counties).

Local level encompasses level 4 (counties) and level 5 (communes). Levels 2, 4 and 5 are in keeping with the system of identifiers and nomenclature of units of administrative division that is a part of National Register of Official Territorial Division of a Country (TERYT).

A Polish voivodship meets the following two criteria established in the delimitation of EU regions: region is the largest unit in the administrative division of a country (administrative criterion) and has elective authorities, legal subjectivity and its own budget (political criterion). It is also in compliance with the definition of a region accepted by the Assembly of European Regions that puts an emphasis on political criterion (region is a territorial unit that occupies a position directly below central government and has its own political representatives elected).[50]

NTS nomenclature has been worked out on the basis of European Nomenclature of Territorial Units for Statistics (NUTS) that is in operation in EU Member States. It is used for collecting and harmonizing data on regional statistics of Member States as well as making it available. Furthermore, the nomenclature in question is also employed while shaping the regional policy in EU Member States and essential for analyzing the degree to which regions have developed socio-economically, paying special attention to the assessment of regional diversity and working out regional development programmes.[51]

NUTS distinguishes the following categories[52]:

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[49]NTS description has been presented, among other things, on the website: *Nomenklatura NTS*. GUS, http://www.stat.gov.pl/bdrpl/slowniki.nts_info (accessed October 9, 2007).

[50]T. Borys, P. Rogala et al.: Final Report on Work carried out: Devising the Implementation Model of Sustainable Development at the level of Voivodships as a part of Regional Database. [In Polish] Regionalny Ośrodek Ekorozwoju Fundacji Karkonoskiej, Jelenia Góra–Warszawa 2003, pkt 2.1.1 (the text is also available on the Internet: http://mos.gov.pl/2materialy_informacyjne/raporty_opracowania/synteza1.pdf).

[51]See: Regulation (EC) NO 1059/2003 of the European Parliament and of the Council (dated May 26, 2003) on the establishment of common classification of territorial units for statistics (NUTS). DzU L 154 dated June 21, 2003, p. 1.

[52]To find more about NUTS consult the following sources: J. Żebrowska-Cielek: *Nomenclature of Territorial Units for Statistics*. [In Polish] PARR, Warszawa 2001, available on the Internet: http://eupolicy-jeanmonnet.sggw.waw.pl/publikacja/5.3.pdf (accessed August 7, 2007); M. Rozkrut: *Investigation of Economic Development of Polish Counties in the context of Division into Territorial Units NUTS 1*. [In Polish] In: *Taxonomy 13. Data Classification and Analysis, Theory and Applications*. [In Polish] Red. K. Jajuga, M. Walesiak. Prace Akademii Ekonomicznej we Wrocławiu nr 1126. Wrocław 2006, pp. 343–344; *Division of Poland into Statistical Units NUTS*, http://www.zyrardow.pl/ue,podzial (accessed August 8, 2007).

1. NUTS I – the largest unit inhabited by from 3 to 7 million people, corresponds to, e.g. States of Germany and to level 1 in the aforementioned NTS nomenclature;
2. NUTS II – enabling to present socio-economic issues in a region-country arrangement in a comprehensive way, corresponding to, e.g. French or Spanish regions inhabited by from 800,000 to 3 million citizens and to level 2 (voivodships) in NTS nomenclature;
3. NUTS III – areas that are too small to conduct comprehensive regional analyses (from 150,000 to 800,000 inhabitants), correspond to, e.g. French departments or German counties and to level 3 in NTS (groups of counties);
4. NUTS IV – category defined only in certain countries, e.g. British counties, corresponding to level 4 in NUTS (counties);
5. NUTS V – basic units, i.e. communes (level 5 in NTS).

Figure 1.3 shows the map of Poland with units corresponding to NUTS I, i.e. to level 1 NTS (numbers refer to the number of inhabitants). The following regions have been marked on the map:

– region I (central) covering Mazowieckie and Łódzkie voivodships,
– region II (southern) with Małopolskie and Śląskie voivodships,
– region III (eastern) covering Podlaskie, Lubelskie, Podkarpackie and Świętokrzyskie voivodships,
– region IV (north-western) encompassing Wielkopolskie, Lubuskie and Zachodniopomorskie voivodships,
– region V (south-western) covering Dolnośląskie and Opolskie voivodships,
– region VI (northern) encompassing Pomorskie, Kujawsko-Pomorskie and Warmińsko-Mazurskie voivodships.

Regional Database, organized in accordance with the aforementioned NTS nomenclature, provides users with a permanent and friendly access to current statistical information as well as enables them to make multidimensional statistical analyses in regional and local arrangements. Apart from RD, statistical office has also established demographic database referring to many aspects of population mobility which presents (in a free of charge and partly paid form) indicators that, once selected carefully, may reflect the potential of a region in the context of, among other things, human capital quality.[53]

From a number of publications presenting the description of regions in a numerical form, one may also mention statistical yearbooks and bulletins[54] as

[53]Base is available on the Internet on the following website: http://www.stat.gov.pl/demografia/index.html.

[54]Central Statistical Office publishes among other things the following yearbooks: Small Statistical Yearbook of Poland, Demographic Yearbook, Statistical Yearbook of Voivodships, Statistical Yearbook of Industry, Statistical Yearbook of Agriculture and Rural Areas, Statistical Yearbook of the Republic of Poland [All the above in Polish]. Data useful in regional monitoring is also presented in various types of bulletins, journals and collective studies published by Central Statistical Office such as e.g. Information on socio-economic situation in the country; Information on socio-economic situation of Voivodships; Polish Counties etc. [All the above in Polish]. Complete list of GUS (Central Statistical Office) publications has been presented on the following website: http://www.stat.gov.pl/gus/zws_PLK_HTML.htm.

Fig. 1.3 Division of Poland into NUTS regions
Source: own elaboration based on J. Zimny, J. Sokołowski, R. Kozłowski: *NUTS – another partition of Poland?* [In Polish] Instytut Studiów nad Rodziną UKSW, http://www.isnr.uksw.edu.pl/aktual/2005/nutsy.htm (accessed August 8, 2007)

well as other papers[55] providing him/her with information on socio-economic situation of voivodships (paid data on labour market, remuneration, pensions and retirement pensions, housing construction, economic entities, industrial production and construction, financial results of enterprises, agriculture, income and expenditure made by local self-government units). Furthermore, Regional Statistics Center (Polish CSR),[56] functioning since 1994, is developing the methodology of regional research. Internet Panorama of Cities, Communes and Regions functions as a part

[55]Monographs published by The Gdańsk Institute for Market Economics to, among other things, *Developmental Success of Polish Voivodships.* [In Polish] Red. T. Kalinowski. IBnGR, Gdańsk 2006.

[56]More information concerning the activity of the Center is presented on the following website: http://www.ae.poznan.pl/pages/i/1/1208.php.

of CSR and is aimed at supporting the local democracy, mainly in local self-governments, in terms of information.

Discussing the sources of data used for regional development assessment, one should also mention InfoBase system that has been developed by Acxiom corporation.[57] It is an integrated system of databases made up of the following sources: Regional Database of Central Statistical Office (GUS), Data from General Census 2002, PESEL MSWIA and Acxiom bases based on Polish questionnaire on products and services. Particular data sets describe different units, namely persons, buildings, statistical regions, communes. Table 1.2 shows general information concerning the level of data aggregation, its source and scope.

Database of EU Member States regions, i.e. Eurostat Regio (a part of New-Cronos base) is a useful source of information that may be employed in the system of regional monitoring. Eurostat, functioning since 1972, deals with making statistical forecasts and analyses mainly with reference to the European Union. They are of major importance to decisions made by community authorities who cope with coordinating and monitoring of work carried out by statistical offices in order to standardize the research methods used and consolidate national statistics in Member States.[58]

The quality of regional monitoring system depends on information-functional structure of available sources. Unfortunately, due to a diversity of tasks accomplished by institutions and organizations, data collected by them is not always cohesive. Hence, while making spatial-temporal analysis, a researcher very often comes across information barrier resulting from the lack of comparable statistical data. This fact hinders, or at best makes it difficult to assess the state of a region accurately, due to which it is not possible to identify a problem and, as a consequence, take measures that would provide harmonious and sustainable

Table 1.2 Organization of InfoBase system

Aggregation level	Data source	Information scope
Commune	Regional Data Bank GUS; General Census 2002	Urbanization, infrastructure, development of areas (migrations, investments), education
Statistical regions (400 households)	Operational data GUS, Acxiom base	Population size and density, lifestyle patterns
Building	PESEL base	Type of building, structure of age and sex of persons registered
Individual characteristics of consumer/household	Acxiom base	Age, sex, place of residence

Source: Infobase, Acxiom, http://www.acxiom.pl/CustomerInformation/Infobase/index.html (accessed October 17, 2007)

[57]Website of the corporation: http://www.acxiom.pl/.

[58]Regional Development Assessment . . ., p. 49.

development. The quality of research subjects covered, possibility of making comparison and effectiveness of scientific analyses depend on the quality of sources. Sources should be reliable, stable and comprehensive.[59] These postulates ought to be taken into account while shaping the system of regional monitoring. Information needs of this system result from the analysis of major processes in social, environmental (natural-cultural) and economic systems, having adopted sector, integrated and spatial perspectives.

In the literature on the subject, attention is paid to the fact that information-functional structure of regional monitoring system should allow, among other things, the analysis of increase in the number of new jobs, development of new markets, launching new production and new types of services, improvement in management effectiveness, technological progress, improvement in professional qualifications of the employed, and improvement in relations among economic entities as well as between inhabitants and the environment. All the aforementioned elements are of major importance while pursuing regional strategy. They reflect socio-economic phenomena occurring in a region and consequently are a point of reference in the assessment of results of actions taken in a region, i.e. successes and failures.[60]

1.3 Regional Development Indicators

It is vital to indicate areas that require observation and select appropriate indicators so that the monitoring is effective.[61] Apart from measuring the degree to which objectives have been fulfilled and keeping trace of changes in factors determining this process, these indicators are also used for mobilizing the participants in control process in the scope of programming and to carry out actions as well as adjust the behavior to management goals identified.

Construing the system of indicators, it is necessary to specify the criteria to be met by them. On the basis of experience gained while creating systems of indicators for the UN and OECD, the following three criteria can be mentioned[62]:

- Usefulness to a certain policy,
- Analytical and perceptual clarity for all the participants in monitoring system,
- “Technical” feasibility, possibility of taking measurement in particular.

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[59] M. Markowska: *Databases . . .* [In Polish], p. 107.

[60] L. Wojtasiewicz: *Strategy for Voivodship Development. Socio-economic Aspects*. [In Polish] In: *Spatial Information in Regional Economy*. [In Polish] Instytut Geodezji i Kartografii, Warszawa 1999, pp. 89–101.

[61] Indicator is understood as a measure determining the level of occurrence of a certain phenomenon and at the same time defining the degree to which objectives established have been achieved.

[62] GUS (Central Statistical Office) website, http://www.stat.gov.pl/gus/opis_wskaznikow_2891_PLK_WAI.htm (accessed September 15, 2007).

On the basis of the above criteria, one can prepare a detailed set of features by which regional development indicators should be characterized. These indicators should:

– Present a representative view of the system observed and conditions of environment,
– Show tendencies,
– Provide a well-founded basis for responding to occurring changes,
– Be related to systems recognized internationally, provide basis for making international, national and regional comparisons,
– Allow the assessment and interpretation of indicator value also via referring to standard values,
– Refer to functioning socio-economic models (development and control), decision-making models, models for forecasting and informing,
– Be based on available information that is well proven and of recognized quality,
– Have a comprehensible construction, and results of measurement should be relatively easy to interpret,
– Be updated.

The role of indicators in the assessment of regional development, factors determining it and its results is extremely crucial as it enables one to compare countries and regions. Without such a comparability, indicators loose their importance because they make it impossible to make relative references and assess changes as well as their rate.

Formulating the system of indicators, one should remember that it ought to be adjusted to the role and needs identified by particular groups of users, as well as types of problems faced in a certain region. For instance, in order to create a system for informing politicians and wide social circles, that would allow to make comparisons on a national scale and international scale, one can draw on the aggregation of detailed indicators. By doing so, one obtains so-called synthetic measures[63] used for decision-making. One may also use a method involving the selection of key indicators from all existing ones. However, they must be relevant to the group of objectives and problems that a particular indicator is supposed to reflect. Construing the system of indicators aimed at informing a wider community, one should pay attention to the fact that it should exert a profound influence in terms of social engineering. Indicators should reflect the reality and be weighed (as far as the scope and expressions are concerned) in such a way so that knowledge could be acquired

[63]K. Nermend: *A Synthetic Measure of Sea Environment Pollution*. “Polish Journal of Environmental Studies” 2005, Vol. 14, No 4b; D. Strahl: *Using Classification Methods for Identifying the Level of Regional Development*. [In Polish] Prace Akademii Ekonomicznej we Wrocławiu nr 979. Wrocław 2003, pp. 76–83; W. Tarczyński: *Discriminatory Analysis on the Stock Exchange*. [In Polish] “Przegląd Statystyczny” 1996, R. XLIII, z. 1–2; *idem*: *Capital Markets*. Vol. I. WNT, Warszawa 1997, p. 266; M. Oparło: *Regional Development Measures*. [In Polish] PWE, Warszawa 1972.

easily and make particular users act. Figure 1.4 shows a general hierarchy of the system of indicators adjusted to particular groups of receivers.

It is very hard to specify indicators characterizing regional development as it is determined by many different factors at different levels (corresponding to, e.g. NTS system). Some factors are common, while the others can be found and exert influence only in certain places and at certain moments. Many authors claim that regional development is determined by the location of a given region, resources and natural environment conditions, rank and character of agriculture, demographic situation and unemployment rate, occupational composition and qualifications gained by labor force, effectiveness of rural institutions (including the activity of self-governments and local authorities in communes), property relationship and capital endowment, activity of rural community, structure of economy, infrastructure state.[64]

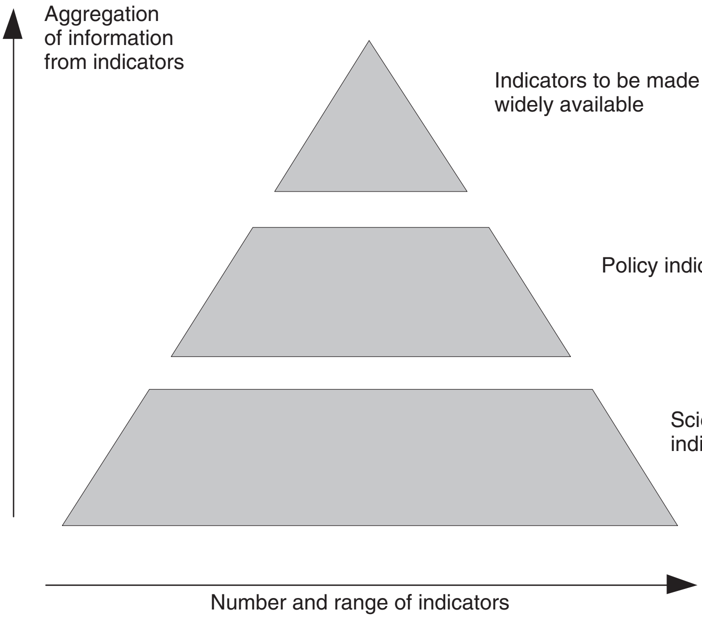

Fig. 1.4 Aggregation of indicators depending on the way they are used
Source: elaboration based on R. Coenen, H. Paschen: Untersuchung zu einem integrativen Konzept nachhaltiger Entwicklung: Bestandsaufnahme, Problemanalyse, Weiterentwicklung. Institut für Technikfolgenabschätzung und Systemanalyse, Karlruhe 1999, p. 4

[64]Cf. T. Kudłacz, M. Grzebyk: *Diversity of Communes with reference to Socio-economic Development Level in Rzeszowski Region*. [In Polish] Zeszyty Naukowe Akademii Ekonomicznej w Krakowie nr 588. Kraków 2002, p. 89; K. Duczkowska-Małysz: *Development of Rural Areas. Report*. [In Polish] MRiGŻ, Warszawa 1996, pp. 22–33; J.J. Parysek: *Local Economy Fundamentals*. [In Polish] UAM, Poznań 1997, pp. 73–120.

All the indicators taken into account in regional development analysis can be divided into the following groups:

– Demographic variables,
– Socio-economic variables,
– Environmental variables,
– Variables characterizing the degree to which socio-economic infrastructure has developed.

The group of demographic variables is of major importance as regions function in certain social, political and economic environment and hence their assessment should take demographic situation into consideration. The quality and quantity of human resources in a region as well as their inflow and outflow have a profound influence on regional development. It does matter if a region encourages new settlers to arrive and settle or rather to leave and if the structure of settlers' age is important in the context of formulating the strategy of regional development. Strategies implemented in areas inhabited by elderly people and in regions where people of working age live should be different as both groups have different expectations and requirements. Among the group of demographic variables, the following may included: birth rate, population density, number of women for every 100 men, population of pre-working age for every 100 inhabitants of working age, population of working age for every 100 of population, population of post-working age for every 100 inhabitants of working age, total of married couples for every 100 persons, total population influx for every 1,000 persons, total population outflow for every 1,000 persons. Selecting the indicators from this group, one should bear in mind the fact that in order to asses demographic situation of a region, it is necessary to employ many indicators as each of them individually may distort the real situation. For instance, birth rate may be negative (which is unfavorable) even when the number of births is large in a region (which is particularly favorable to a region).

Socio-economic indicators characterizing a given region form another group of variables of major importance. In the literature, one may come across the following indicators: industrial production sold per capita, personal income tax for every 1,000 of population, county investment income for every 1,000 of population, other county income for every 1,000 of population, special subsidies and grants for every 1,000 of population, total per capita income, total personal income per capita, total expenditure on education and upbringing for every 1,000 of population, total expenditure on health service for every 1,000 inhabitants, total expenditure on public safety and fire safety for every 1,000 of population, total per capita expenditure, number of firms for every 1,000 of population, number of firms in public sector to total of firms in per cent, number of firms in private sector to total of firms in per cent, surface area of arable land to surface area of a county in per cent, surface area of forests and wooded land to surface area of a region in per cent, total of working population for every 100 of population of working age, number of working women to total of working population in per cent, unemployed registered for every 100 inhabitants of working age, unemployed who have not worked yet, higher education institutions graduates to total of unemployed in per cent, unemployed women who have not worked yet, higher education institutions graduates to total of unemployed graduates who have not worked yet (in per cent), average gross monthly remuneration.

The group of socio-economic indicators is of profound importance to the research on regional development as these indicators provide information concerning human resources in a region. For example, indicator referring to the number of people of working age (from the group of demographic variables) has a whole different sense in comparison with indicators showing the total number of employed for every 100 of population of working age, number of working women to the total of employed in per cent, unemployed registered for every 100 inhabitants of working age or number of firms for every 1,000 of population. The quality and activity of human resources as well as economic background area of a region form the basis for initiatives and investments planned as well as strategic decisions.

Environmental variables form another group that include the following indicators: sewage channeled for every 100 inhabitants, sewage purified in municipal sewage treatment plants to sewage channeled in per cent, population served by sewage treatment plants in per cent, sewage channeled for every 100 firms, sewage purified in industrial sewage treatment plants to sewage channeled in per cent, emission of particulate pollutants for every 100 firms, emission of gaseous pollutants for every 100 firms, particulate pollutants blocked or neutralized to pollutants emitted in percent, gaseous pollutants blocked or neutralized to pollutants emitted in percent.

The aforementioned indicators inform about environmental conditions in which inhabitants of a particular region live. These indicators are important for at least two reasons. First of all, they reflect the influence that the environment has on an inhabitant and hence make conclusions about his/her condition and willingness to stay in a region. Secondly, they reflect the attitude of regional authorities toward creating as good environmental conditions in the area that comes within their jurisdiction as possible.

The last group of indicators used for regional development analysis are variables referring to the degree to which socio-economic infrastructure has developed. These variables form a basis for assessing regional infrastructure with the use of such indicators as among other things length of water supply system for every 100 km, length of sewage system for every 100 km, number of flats per one occupant, average floor surface of a flat per one occupant, county hard surface roads for every 100 km^2, improved county hard surface roads for every 100 km^2. It was legitimate to employ these indicators as they not only describe the conditions offered by a region to its inhabitants but are also a valuable source of information for potential investors.

Indicators employed in regional analyses enable one to asses the state of a region and level of regional development as well as to compare regions. Certain standards, that should be met by regions so that they do not diverge from the others unfavourably, are shaped thanks to indicators under consideration.

Summing up the discussion on indicators that can be taken into account in regional research, it is worth presenting a set of indicators that are used most often and referred to in European interregional comparisons, namely[65]

– GDP, GDP per capita, GDP dynamics,
– Regional unemployment rate (total, by sexes, among population up to 25 years old),
– Economic activity of population, employed, employment (by sex and age, in economic sectors),
– Population migrations, birth rate, population density,
– Structure of households, agricultural production,
– Wages and salaries in industry,
– Transport infrastructure, transport system, railway system and others,
– Science and technology (patents, doctorates, R&D outlays, employment in high-tech sector, share in education),
– Health service, mortality, doctors, hospital beds,
– Water system, communal waste stockpile, afforestation rate,
– City statistics.

In practice, various sets of indicators are used for regional analysis depending on the research purpose and methods employed in the research (to which the next chapter is devoted).

[65] T. Borys, P. Rogala et al: *op.cit*.

Chapter 2
Methodological Dilemma Over Regional Development Analysis

2.1 Organization of Analytical Processes in Regional Development Investigation

The main purpose of analytical processes involved in the investigation of regional development is to diagnose and evaluate region's state with respect to demographical, socio-economic, environmental and infrastructural aspects. As a result, information useful in decision-making is collected.

As far as decision-making process is concerned, two components that are stages in this process can be distinguished. The first one is called analytical and involves decision preparation procedures, and second one refers to making the right decision.[1] Procedures for preparing and making decisions have been schematically illustrated in Fig. 2.1.

Pre-decision actions, included in decision preparation procedure, involve a detailed analysis of information needs, collection and processing of data (textual and spatial) and structuring of information, i.e. conversion into the form of decision-making variants.

Decision-making is a conscious choice of decision-making variant made by persons entitled to make a decision and proceeded by reflection and consideration.[2] In such a case, decision means a deliberate and specific choice of one of many variants based on the analysis of optional actions.[3] Experience has taught that final decision is taken as a result of the confrontation of preferences expressed by participants in decision-making process that take place during interaction among them in the scope of their influence.[4] While carrying out regional development

[1]E. Radosiński: op.cit., pp. 14–15; K. Nermend, M. Borawski: Using Artificial Neural Networks for Decision Support in Long-term Planning in Local Self-governments. [In Polish] In: Organization Support Systems, SWO 2005. [In Polish] Ustroń 2005, pp. 443–450.

[2]J. Kozielecki: *Decision-making*. [In Polish] PWN, Warszawa 1992, p. 155.

[3]J. Rudniański: *Before a Decision*. [In Polish] PWE, Warszawa 1965.

[4]B. Roy: *Multi-crtieria Decision Support*. [In Polish] PWN, Warszawa 1990, pp. 18–19.

K. Nermend (ed.), *Vector Calculus in Regional Development Analysis*, Contributions to Economics,
DOI: 10.1007/978-3-7908-2179-6_2, © Springer Physica-Verlag Berlin Heidelberg 2009

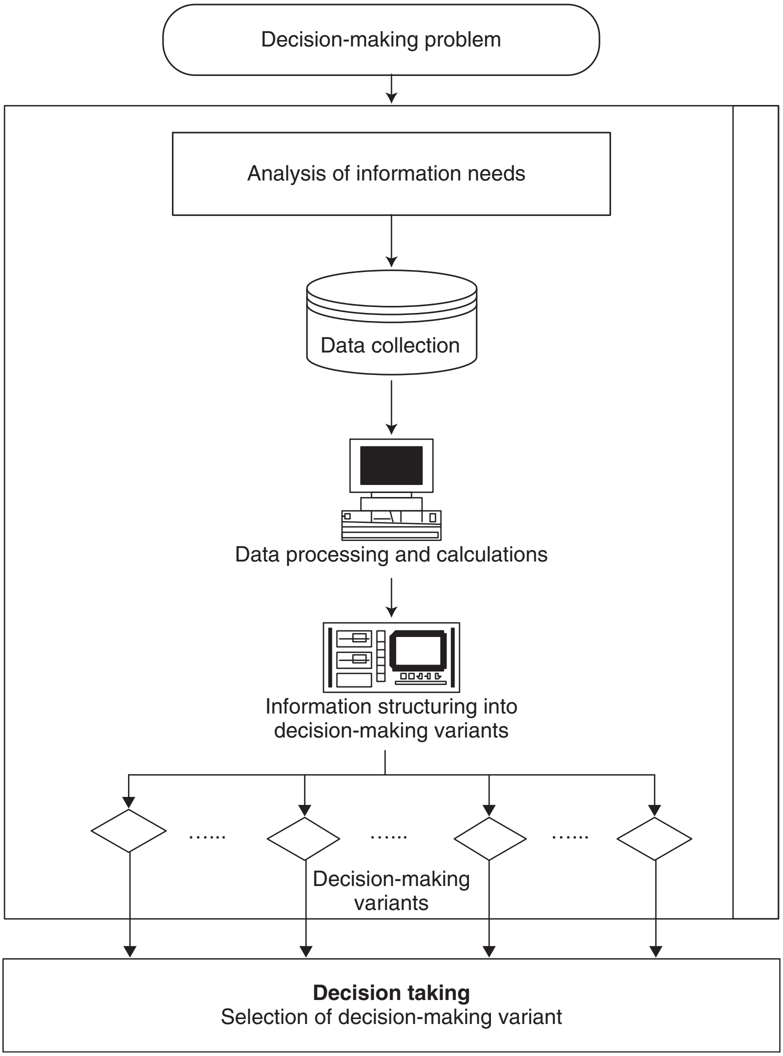

Fig. 2.1 Components of decision-making process and their interactions
Source: elaboration based on E. Radosiński: *Computer Systems in Dynamic Decision Analysis*. Wyd. Naukowe PWN, Warszawa–Wrocław 2001, p. 15

analysis, one may come across many different suggestions about achieving a goal connected, for example with the selection of set of indicators, applying other methods for classifying the objects or modelling the decision-making variants.

Setting about investigating the problem of regional development in the context of obtaining decision-making variants, one should begin with a detailed analysis of information needs, i.e. specify their scope and tasks. This analysis can be qualitative or quantitative.[5] The former centers on organisational, psychological and social aspects, while the latter concerns the determination of quantities analyzed and their specific values, as well as indicators determining the quality of analysis. Analytical stage of decision-making process comes down to actions connected with distinguishing the main factors of this process and defining its goals on the basis of information needs identified by users. The analysis of these needs can be understood as a set of actions identifying the problem, which can be presented in a formal way, namely.[6]

$$An = \{Pd, Ce, Wr, Mt, Hp\}\,, \tag{2.1}$$

where:
An – analysis,
Pd – set of decision-making subjects, i.e. organisations and persons whose information needs are to be satisfied,
Ce – set of goals, requirements and their interrelation,
Wr – set of external and internal conditions in which the analysis is conducted, e.g. economic, technical,
Mt – set of methods and techniques that allows to identify goals and relations between them, e.g. various heuristic methods or advanced techniques of computer simulation,
Hp – set of hypotheses, mainly in the form of coefficient of probability of specific situation occurrence or state of its surroundings.

Decision-making subject, whose information needs are satisfied in the course of decision-making process, is usually one of intervening persons, so-called decision-maker. In such a situation, decisions are not supported globally but are based on preferences of a decision-maker and are adjusted to his/her determinants. Acquiring the decision-making variants must also take opinions held by other participants in decision-making process into account, and can take place in different, often adverse conditions, e.g. imprecise information, uncertainty and risk.[7] The following groups can be rated among subjects of decision-making process in the sphere of regional development analysis:

– Authorities and persons employed in local and regional self-governments,
– Central authorities,
– Research and development institutions,

[5] Z. Bubnicki: *IT Foundations of Management Systems*. [In Polish] Wyd. Politechniki Wrocławskiej, Wrocław 1993; K. Nermend: *Introduction to Document Management in Enterprise*. [In Polish] Studia Informatica no. 17. Szczecin 2003, pp. 55–62.

[6] J. Kisielnicki, H. Sroka: Computer Systems in Business. Informatics for Management. [In Polish] Agencja Wydawnicza Placet 1999, pp. 47–50; K. Nermend: Methods for Discovering Regularities in Information Bases of Enterprise. [In Polish] In: Information – good or bad news. [In Polish] Ed. A. Szewczyk. Szczecin 2004, pp. 285–294.

[7] W.T. Bielecki: *Informatics in Management*. [In Polish] PWE, Warszawa 2000, pp. 66–74.

– Domestic and foreign investors,
– People inhabiting the regions.

Each of these groups, and even individuals from these groups, who has an influence on decision-making process, can strive after achieving many various goals in accordance with operation strategy adopted. Goals are characterized by different coefficients showing the relevance and possibility of their achievement. In many cases, these goals have a form of hierarchical tree (primary, secondary goals) and models, e.g. relational or object, representing the relationship between them. Goals to be achieved by decision-making subjects in the scope of regional data analysis can be as follows:

1. Comparative analysis of regions with regard to their economic potential, development of local infrastructure, etc;
2. Selection of regions meeting the criteria of investors to the largest extent;
3. Offering the best conditions for investment by providing access to economic indicators and ordered information about a region;
4. Improvement in development planning and land development;
5. Effective expending of budgetary funds on investment activities.

Specifying the set of conditions for carrying out analytical work, one should take into account the fact that internal conditions are frequently shaped by external factors coming from the surroundings of a region under consideration. External conditions may have a profound influence on situation analyzed and constrain it. Considering the issues relating to regional development, one should remember that decisions are not only economic but also political in nature. This means that various conditions resulting from current political situation may have a major influence on economic decisions. Decisions taken at governmental level about investments (located in particular regions) of strategic importance to a country can be quoted as an example of such influence. Such actions can enhance the attractiveness of these areas regardless of situation preceding such decisions.

Using the methods or techniques of analysis, it is possible to take various identification and deductive actions, for example the evaluation of information needs identified by participants (subjects) in decision-making process.[8] For this purpose, one can use formal methodical apparatus or so-called common sense methods.

Decision-making process is dynamic, i.e. it is not plausible to explicitly define the content of individual subsets (decision-making subject, goals, conditions, as well as methods and techniques), and therefore different hypotheses about the content of these sets are made. Next steps at analytical stage refer to practical data acquisition and processing as well as preparation of decision-making variants. Taking a decision, decision-maker usually does not have access to complete data and therefore to complete(ideal) information. Yet, he/she should take many complex conditions into account. Differences between information gathered and

[8]These issues were explored by E. Kolbusz: *Analysis of Information Needs in Enterprises – Methodological Basis*. [In Polish] Wyd. Naukowe Uniwersytetu Szczecińskiego, Szczecin 1993.

complete information indicate that there is an information gap that can be minimized by improving the process of information acquisition, form of information itself (quality, quantity) and the selection of right methods and techniques for its processing. In practice, it comes down to the acquisition of necessary information which can have, e.g. economic character and which forms a basis for undertaking analytical work in the scope of regional development analysis. Then, it is possible to talk about data, events, facts and economic phenomena occurring in particular environments,[9] e.g. data about the amount of grants, education spending in particular regions of the country or financial outlays on environmental protection. At this stage, one makes use of sets of indicators that have a direct influence on assessing and forecasting the actions taken. Furthermore, standard objects are created and object classification methods as well as statistical and econometric models are selected. The examples of data (indicators) that is subject to processing at the stage of decision preparation are as follows:

1. Demographic indicators, e.g. birth rate, number of contracted marriages, influx and outflow of population in a particular region;
2. Socio-economic indicators, for example the amount of personal income tax and corporate income tax, per capita income, expenditure on health protection and education;
3. Environmental indicators, for example amount of sewage channeled or treated, emission of particulate and gaseous pollutants;
4. Socio-economic infrastructure indicators, for example length of working water supply system, sewage system, floor surface of flats, length of roads.

Level of regional development is determined on the basis of correct identification and determination of changes in components of regions under analysis. Hence, this development can be perceived as a set of possible variants of the development of services or products determined by many factors both quantitative and qualitative. The phenomenon of regional development itself is interdisciplinary, which hinders making effective decisions.

In order to achieve goals defined by participants in decision-making processes, it is necessary to anticipate, describe and control decision-making processes as well as apply many sophisticated methods that support decision-making actions such as, for example data classification and analysis.[10] This allows to make economic assessment, classify the regions according to different criteria and establish favourable, neutral and unfavourable relations among objects[11] or investigate the level of economic potential of particular communes, counties and voivodships. The problem with adjusting

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[9]J. Czermiński: *Decision Support Systems in Corporate Management*. [In Polish] Dom Organizatora, Toruń–Gdańsk 2002, pp. 14–16.

[10]W. Flakiewicz: Semantic Aspects of Information and Decision-making Process. [In Polish] “Prakseologia” 1976.

[11]The object is understood as as any territorial unit (region, sub-region, voivodship, county, commune) in accordance with Nomenklatura Jednostek Terytorialnych do Celów Statystycznych (NTS; EU NUTS).

methods to a certain situation is the more serious, the larger the number of methods is available and the more stringent requirements are imposed on applications, effectiveness for various data sets (size of objects operated, diversity of data types), structure of classificators, etc. From the perspective of decision-making process effectiveness, it is necessary to conduct detailed investigation of methods used for regional development analysis, to which next sections have been devoted.

2.2 Review of Methods Used for Regional Development Analysis

Methods used for regional development analysis are employed mainly for two reasons, namely to forecast and compare. Various forecasting models are usually employed in this case. Econometric models may be cited as an example.[12] Recently, vector-autoregressive models (VAR), proposed by Sims in 1980, have become more and more popular.[13] They are used for making dynamic weather forecasts, investigating the relationship between variables, co-integration, etc.[14]

In regional development analysis, it is very often necessary to compare various economic objects. In order to do so, taxonomic models are employed most often.[15]

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[12]Possibilities of econometric model applications are presented among other things in the following publications: M. Markowska: *Application of Econometric Models in Regional Research*. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu no. 950. Wrocław 2002, pp. 42–51; E. Sobczak: *Possibilities of Assessing Regional Development on the basis of Econometric Models*. [In Polish]. Prace Naukowe Akademii Ekonomicznej we Wrocławiu no. 939. Wrocław 2002, pp. 54–61; M. Markowska, E. Sobczak: *Methods for Identification of Regional Development Determinants*. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu, no. 939. Wrocław 2002, pp. 34–41; E. Sobczak: *Spatial-Temporal Models in Regional Benchmarking*. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu no. 1083. Wrocław 2005, pp. 74–83. Practical applications of econmetric models can be found, e.g. in the following publications: M. Markowska: *Attempt to Use Discriminatory Analysis for Regional Development Assessment*. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu no. 978. Wrocław 2003, pp. 56–62; E. Sobczak: *Modelling the Relationship between Gross Domestic Product and its Determinants with the use of Factor Analysis*. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu no. 979. Wrocław 2003, pp. 112–123; K. Nermend: *Object Recognition Using Fourier Transform, Histogram, and Logical Product*. "Polish Journal of Environmental Studies" 2005, Vol. 14, pp. 50–52.

[13]C.A. Sims: *Macroeconomics and Reality*."Econometrica" 1980, No 48, pp. 1–48.

[14]E. Kusideł: *Application of VAR Models in Regional Development Assessment*. [In Polish] Prace Naukowe AE we Wrocławiu no. 939. Wrocław 2002, pp. 43. Such models were used for the investigation of regional development, e.g. for private sector analysis. *Ibidem*, pp. 42–53. Extended description and examples of other research can be found in E. Kusideł: *VAR Models – Methodology and Applications*. [In Polish] Absolwent, Łódź 2000.

[15]Possibility of taxonomic method applications are presented in details among other things in the following publications: A. Witkowska, M. Witkowski: *Classification of Communes in Wielkopolskie voivodship by Socio-economic Potential*. [In Polish]. In: *Taxonomy 10. Data Classification and Analysis*. [In Polish] Eds. K. Jajuga, M. Walesiak. Wrocław 2003, pp. 562–571; U. Gierałtowska, E. Putek: *Classification of Rural Communes in Zachodniopomorskie Voivodship*.

The most popular methods for linear ordering of elements are as follows[16]: method of a sum of standardized values, prime common factor and standard method. The idea of the first method is based on the calculation of the standardized sum of features values for each object. This method can be applied, among other things, for construing relative development indicator.[17] In rank method, constituent variables are made comparable and additive via attaching a rank to each variable. Ranks are ascribed to objects on the basis of certain features. As a result, one obtains a vector defining the order of objects.

Standard methods form a large group. It was Hellwig who had developed their methodological foundations.[18] He proposed a concept of so-called taxonomic measure of development understood as the arrangement of units investigated depending on their distance from a certain artificially construed point, called the standard establishing the development pattern. Taxonomic measure of development is an aggregate (synthetic measure) and a resultant of all variables defining the elements (units) of community under examination. Thus, it is used for linear ordering of elements of a given community.

In order to assess taxonomic measure of investment attractiveness (TMAI), Tarczyński uses a set of such features as a relation of hypothetical profit to net profit, dynamics of net profit, rate of return on shares, rate of return risk, beta coefficient, current liquidity ratio, fast liquidity ratio, profitability, debt ratio, receivables rotation, stock rotation, rotation of payables, fixed assets efficiency,

[In Polish] In: *Taxonomy 10…*, [In Polish] pp. 448–455; K. Lewandowska: *Investigation of Foreign Investment Inflow to Poland with the use of Multidimensional Comparative Analysis Methods*. [In Polish] In: *Taxonomy 14. Data Classification and Analysis*. [In Polish] Eds. K. Jajuga, M. Walesiak, pp. 376–384; D. Strahl, M.Markowska: *Structure of Employed in the EU by Sectors as basis for the Classification of Regional Space*. [In Polish] In: *Taxonomy 13. Data Classification and Analysis*. [In Polish] Eds. K. Jajuga, M. Walesiak. Wrocław 2006, pp. 308–315; M. Rozkrut: *op.cit.*, pp. 343–352.

[16] J. Pociecha, B. Podolec, A. Sokołowski, K. Zając: *op.cit.*, pp. 66–72; K. Nermend, M. Borawski: *Method for Minimizing Distances within Classes (MOWK)*. [In Polish] Akademia Ekonomiczna, Bydgoszcz 2003.

[17] B. Podolec, A. Sokołowski, M. Woźniak, K. Zając: *Methods for Investigating the Compatibility between Levels of Demographic and Economic Development*. [In Polish] Z Prac Zakładu Badań Statystyczno-Ekonomicznych GUS no. 113. Warszawa 1980.

[18] Z. Hellwig: Application of Taxonomic Method for Typological Division of Countries on Account of their Development Level and Structure of Qualified Human Resources. [In Polish] „Przegląd Statystyczny" 1977, z. 2; K. Nermend, M. Borawski: Classification of Communes in Zachodniopomorskie Voivodship with the Use of Method for Minimizing Distances within Classes (MOWK). [In Polish] In: Taxonomy 11. Data Classification and Analysis. [In Polish] Eds. K. Jajuga, M. Walesiak. Wrocław 2004, pp. 365–372; K. Nermend: Application of Artificial Neural Networks in the Prediction of the Zachodniopomorskie Voivodship's Communes' Income. In: Organization Support Systems. [In Polish] Ustroń 2006, pp. 567–574; idem: Using Average-Variance Representation for Supporting the Classification of Communes. [In Polish] In: New Technologies in Distance Learning. [In Polish] Koszalin–Osieki 2006, pp. 233–239.

and rate of return on equity capital. This has made it possible to create a portfolio of securities based on criterion resulting from synthetic measure.[19]

Another example of synthetic measure application is a method for determining the standard of living in European countries presented by Grabiński.[20] Measure used in this method is calculated on the basis of seven diagnostic variables in the scope of demography, economy and technical infrastructure with the application of linear ordering method. The measure allowed to define a gap between Poland and other European countries in the years 1960, 1970, 1980 and make forecast for the year 1990.

Table 2.1 presents a collation of methods used for regional development analysis. It turns out that linear ordering method is used the most frequently and vector calculus – the least frequently and mainly for predictive modelling.

From the analysis of the literature, it turns out that standard methods based on synthetic measures are most often used for comparing and classifying objects in regional development analysis. The process of calculation consists of a few stages. First and the most important stage, determining the correctness of final results, consists in the determination of elements in observation matrix on the basis of data collected. Data should include parameters characterising the objects under investigation that are called variables. Variables should describe the properties of objects that will determine their position in the classification. Depending on the aspect from which objects will be examined, particular variables can be recognized as influencing the assessment of object or as totally neutral. The latter variables should be rejected. All relevant variables are grouped and form observation matrix that can be presented in the following way[21]:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1k} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2k} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{i1} & x_{i2} & \cdots & x_{ik} & \cdots & x_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{w1} & x_{w2} & \cdots & x_{wk} & \cdots & x_{wn} \end{bmatrix}, \tag{2.2}$$

where:
w – number of objects $(i = 1, \ldots, w)$,
n – number of variables $(k = 1, \ldots, n)$,
x_{ik} – value of *k'th* variable on *i'th* object.

[19] W. Tarczyński: *Fundamental Portfolio of Securities*. [In Polish] PWE, Warszawa 2002, pp. 101–111; *idem*: *Discriminatory analysis..* [In Polish]; *idem*: *Capital markets…,* [In Polish] vol. I, p. 266; K. Nermend: *A Synthetic Measure…* [In Polish]

[20] T. Grabiński: *Selected Problems of Dynamic Multidimensional Comparative Analysis*. [In Polish] "Ruch Prawniczy, Ekonomiczny i Socjologiczny" 1985, z. 2.

[21] W. Pluta: Multidimensional Comparative Analysis in Economic Research. [In Polish] PWE, Warszawa 1977, p. 23.

Variables describing objects are as a rule heterogeneous because they describe various parameters of objects, are expressed in different units of measure, and have different scales, which results in the fact that data saved in such a way is incomparable. Hence, it is necessary to convert data into comparable form. The next step in construing the development measure is the standardization of variables during which measurement units are removed and scale of values becomes more or less uniform. Therefore, the standardization of variables can be carried out by means of the following formula[22]:

$$z_{ik} = \frac{x_{ik} - \bar{x}_k}{s_k}, \tag{2.3}$$

in which:

$$\bar{x}_k = \frac{1}{w}\sum_{i=1}^{w} x_{ik}, \tag{2.4}$$

$$s_k = \sqrt{\frac{1}{w}\sum_{i=1}^{w}(x_{ik} - \bar{x}_k)^2}, \tag{2.5}$$

where:

$$k = 1,\ 2,\ 3, \ldots,\ n,$$

x_{ik} – value of *k'th* variable on *i'th* object,
$\bar{x}_k$– arithmetic mean of *k'th* variable,
s_k – standard deviation of *k'th* variable,
z_{ik} – standardized value of *k'th* variable on *i'th* object.

In the next step, standardized values are used for the creation of the standard establishing the development pattern. It is a point of reference for all the objects investigated. For each variable in the set of objects under analysis, one can determine maximal and minimum values. If one needs the maximal value of a particular variable (stimulus), he/she adopts its maximal value as a coordinate of the standard, and when the smallest value (destimulus) is needed, one takes its minimum value. Some variables can have no influence on the assessment of object or this influence is ambiguous. Such variables are called nominants. Increasing the values within some range can have a positive effect on the object in the case of some variables, and a negative influence in the case of other ones. This kind of nominants should be converted into stimulants or destimulants, and the way of conversion is discussed in detail in the literature. Some nominants have one particular value or range of values that can be called optimal. If values of such nominants approach this range, the assessment of object is improving, and if they

[22] *Ibidem,* pp. 35.

Table 2.1 Methods used for regional development analysis

Author	Classical methods				Data classification and analysis				Forecasting models			
	DM	SA	STA	LO	FC	NN	SM	VC	VC	EM	NN	FM
1	2	3	4	5	6	7	8	9	10	11	12	13
B. Bal-Domańska[a]				+								
C. Biott, T. Cook[b]	+											
Z. Brodecki[c]	+											
K. Chudy, M. Wierzbińska[d]							+					
M. Gazińska[e]	+		+	+			+		+			
M. Grzebyk, L. Kaliszczak, Z. Kryński, K. Szara[f]				+								
G. Jianquan[g]	+		+									
J. Kacprzyk[h]												+
J. Korol[i]	+		+				+			+	+	
J. Kudełko[j]				+								
E. Kusideł[k]									+			
D. Krawczyk[l]				+								
M. Markowska[m]										+		
W. Nelec, A. Prusek[n]				+								
B. Piontek[o]	+											
Ch. Shi, Z. Guo[p]											+	
E. Sobczak[q]				+				+		+		
D. Strahl[r]	+	+	+	+			+		+	+		
A. Tatuśko[s]				+								
T. Tokarski, W.Stępień, J. Wojnarowski[t]				+								
A. Vasilakos, D. Stathakis[u]						+						
B. Woś[v]	+											

DM descriptive methods, *SA*SWOT analysis, *STA* statistical analysis, *LO* linear ordering, *FC* fuzzy classification and rough sets, *NN* neural networks, *SM* statistical methods, *VC* vector calculus, *EM* econometric models, *FM* fuzzy models

Source: own elaboration

[a]B. Bal-Domańska: Application of Mahalanobis Distance in the Analysis of the Structure of Budgetary Revenues in Counties. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu nr 950. Wrocław 2002, pp. 52–60; idem: Classification of Counties by Budgetary Revenues Levels and Structure. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu no. 1023. Wrocław 2004, pp. 324–331.

[b]C. Biott, T. Cook: Local Evaluation in a National Early Years Excellence Centres Pilot Programme. Integrating Performance Management and Participatory Evaluation.“Evaluation” 2000, No 6 (4), pp. 399–413.

[c]*Regions*. [In Polish] Ed. Z. Brodecki. LexisNexis, Warszawa 2005.

[d]K. Chudy, M. Wierzbińska: *Taxonomic Analysis of Socio-economic Development in Podkarpackie Voivodship*. [In Polish] “Wiadomości Statystyczne” 2001, no. 2, pp. 77–83.

[e]M. Gazińska: *Demographic Potential of a Region. Quantitative Analysis*. [In Polish] Wyd. Naukowe Uniwersytetu Szczecińskiego, Szczecin 2003.

[f]M. Grzebyk, L. Kaliszczak, Z. Kryński, K. Szara: *Assessment of Socio-economic Development in some Voivoships*. [In Polish] “Wiadomości Statystyczne” 2003, no. 2 (501), pp. 37–48.

[g]G. Jianquan, T. Bingyong, B. Shi, Y. Jianzheng: *Forecast of the Regional EC Development Through an ANN Model with a Feedback Controller*.“Modelling and Simulation” 2006, vol. 43.

[h]J. Kacprzyk: Towards Percepetion-Based Fuzzy Modeling. An Extended Multistage Fuzzy Control Model and its use in Sustainable Regional Development Planning. In: J. Kacprzyk, Z. Nahorski, D. Wagner: Application of System Research in Science, Technology and Economics. [In Polish] Exit, Warszawa 2005.

[i]J. Korol: *op.cit*., Toruń 2007.

[j]J. Kudełko: *op.cit*., pp. 75–90.

[k]E. Kusideł: *op.cit*., p. 43.

[l]G. Krawczyk: *Disproportions in Socio-economic Development of Communes in Lubuskie voivodship*. [In Polish] “Wiadomości Statystyczne” 2007, no. 3 (550), pp. 55–66.

[m]M. Markowska: *Attempt to Use*... [In Polish] pp. 56–62; *idem*: *Application of Econometric Models*... [In Polish] pp. 42–51.

[n]W. Nelec, A. Prusek: *Dynamic Analysis of Socio-economic Development of Counties in Podkarpackie Voivodship and their Classification*. [In Polish] Zeszyty Naukowe Akademii Ekonomicznej w Krakowie no. 669. Kraków 2005, pp. 111–133.

[o]B. Piontek: Contemporary Determinants ...

[p]Ch. Shi, Z. Guo: Application of Artificial Neural Network in Complex Systems of Regional Sustainable Development.“Chinese Geographical Science” 2004, No 1.

[q]E. Sobczak: Methods of Multidimensional Comparative Analysis in the Quantification of Competitiveness of Regions. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu no. 885. Wrocław 2001, pp. 19–33; idem: Suggestion as to Segmentation on the basis of the Concept of Chains of Objectives and

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[r]D. Strahl: *Using Classification Methods...* [In Polish] pp. 76–83; *idem*: *Classification of Regions with Median*. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu no. 950. Wrocław 2002, pp. 11–18; M. Obrębalski, D. Strahl: *Concept of Method for Assessing the Activity of Communes*. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu no. 669. Wrocław 1994, pp. 69–80; J. Prudzienica, D. Strahl: *Study into Development Prospects of a Region. Methodological Suggestions*. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu no. 669. Wrocław 1994, pp. 9–15; D. Strahl: *Structural Measure of Regional Development*. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu no. 1075. Wrocław 2005, pp. 224–235; *idem*: *Diversification of Regional Development in Poland*. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu no. 885. Wrocław 2001, pp. 34–41; *idem*: *Innovativeness of Polish Regions vs. European Regional Space on the account of Development of Service Sector*. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu no. 1124. Wrocław 2006, pp. 27–36.

[s]A. Tatuśko: *Ways of Measuring the Competitiveness of Cities*. [In Polish] Prace Naukowe Akademii Ekonomicznej we Wrocławiu no. 939. Wrocław 2002, pp. 119–136.

[t]T. Tokarski, W. Stępień, J. Wojnarowski: *Diversification of Levels of Socio-economic Development of Voivodships*. [In Polish] "Wiadomości Statystyczne" 2006, no. 7/8 (542/543), pp. 87–105.

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[v]B. Woś: *Development of Regions and Regional Policy in the European Union and Poland*. [In Polish] Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2005.

move away, the assessment is becoming worse and worse. The way in which this measure can be calculated for this kind of nominant will be presented in the next part of this chapter.

Let point P_0 be the standard with coordinates $z_{01},\ z_{02},\ ...,\ z_{0n}$ and at the same time[23]:

$$z_{0k} = \max_i z_{ik},\ \text{if } k \in I, \tag{2.6}$$

$$z_{0k} = \min_i z_{ik},\ \text{if } k \in K\ (k = 1,\ 2, \ldots, n), \tag{2.7}$$

where:
I– set of stimulants,
K– set of destimulants,
z_{ik}– standardized value of *k'th* variable on *i'th* object.

In order to determine the degree of similarity between object and the standard (point P_0, one can calculate the similarity measure with the use of the following formula[24]:

$$d_{i0} = \sqrt{\sum_{k=1}^{n} (z_{ik} - z_{0k})^2},\ \left(i = 1, \ldots, w\right). \tag{2.8}$$

For a variable belonging to set L (nominants) for which optimum range of values belongs to range $(z_{0d},\ z_{0g})$, similarity measures are determined as follows[25]:

$$d_{i0} = 0,\ \text{if } z_{ik} \text{ belongstorange } \left\langle z_{0d}, z_{0g} \right\rangle, \tag{2.9}$$

$$d_{i0} = \sqrt{\sum_{k=1}^{n} \left(z_{ks} - z_{0g}\right)^2},\ \text{if } z_{ik} > z_{0g}, \tag{2.10}$$

$$d_{i0} = \sqrt{\sum_{k=1}^{n} (z_{ik} - z_{0d})^2},\ \text{if } z_{ik} > z_{0d}. \tag{2.11}$$

Similarity measures determined in such a way are used for calculating the measure determining how “good” a given object is. This measure is very frequently called development measure[26]:

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[23] *Ibidem,* p. 24.

[24] *Ibidem,* p. 25.

[25] Ch. Lis: Statistical Analysis of Joint-stock Companies quoted on the Stock Exchange in Warsaw. Macro- and microeconomic problems with the functioning of economy. [In Polish] Wyd. Naukowe Uniwersytetu Szczecinskiego, Szczecin 2000, p. 41.

[26] W. Pluta: *op.cit.,* pp. 25–26; K. Nermend, M. Borawski: *Using Average variance Number System in Calculation of a Synthetic Development Measure.* “Polish Jounal of Environmental Studies” 2006, Vol. 15, No 4C, pp. 127–130.

$$m'_i = \frac{d_{i0}}{d_0}, \tag{2.12}$$

where:

$$d_0 = \bar{d}_0 + 2 \cdot S_0 \tag{2.13}$$

$$\bar{d}_0 = \frac{1}{w} \sum_{i=1}^{w} d_{i0}, \tag{2.14}$$

$$S_0 = \sqrt{\frac{1}{w}(d_{i0} - \bar{d}_0)^2}. \tag{2.15}$$

Values of development measure m'_i indicate the degree to which object has developed. The closer to zero this value is, the better developed the object, and the closer to one it is, the less developed the object. This way of interpreting the development measure is counter-intuitive. As a rule, the more developed the object, the higher the value of this indicator. Hence, development measure is usually presented in the following form[27]:

$$m_i = 1 - \frac{d_{i0}}{d_0}. \tag{2.16}$$

Measure m_i can be interpreted as follows: the closer to one this measure is, the better developed the object, and the closer to zero it is, the less developed the object. Table 2.2 shows similarity measures used most frequently for determining the extent to which objects are similar. In economic sciences, these measures are used mainly for clustering (grouping) and construing synthetic measures. Due to their comparative nature, the measures should satisfy the following strong premises:

1. There must be a value determining maximal similarity that may occur only when the object is compared with itself;
2. Similarity between objects A and B should be the same as between object B and A (symmetry).

If the first premise is not met, lines or curves along which similarity measure is zero appear. Then, similarity measure should be well adjusted to the nature of objects compared. In this case, it is possible to make comparison but similarity measure must be created especially for a particular type of objects or one must adjust it to objects through fitting certain parameters. It is a very difficult task and measures are not universal.[28]

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[27] *Ibidem*, p. 27.

[28] Measure of this kind is used in relativity theory. In Riemann Space, used in contemporary physics, there are similarity measures that allow even negative values.

Table 2.2 Basic similarity measures

Name of similarity measure	Similarity measure d_{ij}		
	uniform weights	weighted variables	weighted partial distances
Minkowski (for $p \geq 1$)	$\sqrt[p]{\sum_{k=1}^{n} \lvert z_{ik} - z_{jk} \rvert^p}$	$\sqrt[p]{\sum_{k=1}^{n} wg_k^p \lvert z_{ik} - z_{jk} \rvert^p}$	$\sqrt[p]{\sum_{k=1}^{n} wg_k \lvert z_{ik} - z_{jk} \rvert^p}$
Urban (for $p = 1$)	$\sum_{k=1}^{n} \lvert z_{ik} - z_{jk} \rvert$	$\sum_{k=1}^{n} wg_k \lvert z_{ik} - z_{jk} \rvert$	
Euclidean (for $p = 2$)	$\sqrt{\sum_{k=1}^{n} \lvert z_{ik} - z_{jk} \rvert^2}$	$\sqrt{\sum_{k=1}^{n} wg_k^2 \lvert z_{ik} - z_{jk} \rvert^2}$	$\sqrt{\sum_{k=1}^{n} wg_k \lvert z_{ik} - z_{jk} \rvert^2}$
Chebyschev (for $p \to \infty$)	$\max_k \lvert z_{ik} - z_{jk} \rvert$	$\max_k wg_k \lvert z_{ik} - z_{jk} \rvert$	
Square Euclidean distance[a]	$\sum_{k=1}^{n} \lvert z_{ik} - z_{jk} \rvert^2$	$\sum_{k=1}^{n} wg_k^2 \lvert z_{ik} - z_{jk} \rvert^2$	$\sum_{k=1}^{n} wg_k \lvert z_{ik} - z_{jk} \rvert^2$
Correlation	$\frac{\sum_{k=1}^{n} (z_{ik}-\bar{z}_i)(z_{jk}-\bar{z}_j)}{\sqrt{\sum_{k=1}^{n} (z_{ik}-\bar{z}_i)^2 \sum_{k=1}^{n} (z_{jk}-\bar{z}_j)^2}}$	$\frac{\sum_{k=1}^{n} wg_k^2 (z_{ik}-\bar{z}_i)(z_{jk}-\bar{z}_j)}{\sqrt{\sum_{k=1}^{n} wg_k^2 (z_{ik}-\bar{z}_i)^2 \sum_{k=1}^{n} wg_k^2 (z_{jk}-\bar{z}_j)^2}}$	$\frac{\sum_{k=1}^{n} wg_k (z_{ik}-\bar{z}_i)(z_{jk}-\bar{z}_j)}{\sqrt{\sum_{k=1}^{n} wg_k (z_{ik}-\bar{z}_i)^2 \sum_{k=1}^{n} wg_k (z_{jk}-\bar{z}_j)^2}}$
Canberra	$\sum_{k=1}^{n} \frac{\lvert z_{ik}-z_{jk} \rvert}{(z_{ik}+z_{jk})}$		$\sum_{k=1}^{n} wg_k \frac{\lvert z_{ik}-z_{jk} \rvert}{(z_{ik}+z_{jk})}$
Bray–Curtis	$\frac{\sum_{k=1}^{n} \lvert z_{ik}-z_{jk} \rvert}{\sum_{j=1}^{n} (z_{ik}+z_{jk})}$	$\frac{\sum_{k=1}^{n} wg_k \lvert z_{ik}-z_{jk} \rvert}{\sum_{k=1}^{n} wg_k (z_{ik}+z_{jk})}$	
Clark	$\sqrt{\frac{1}{n} \sum_{k=1}^{n} \left(\frac{z_{ik}-z_{jk}}{z_{ik}+z_{jk}}\right)^2}$		$\sqrt{\frac{1}{n} \sum_{k=1}^{n} wg_k \left(\frac{z_{ik}-z_{jk}}{z_{ik}+z_{jk}}\right)^2}$
Jeffreys–Matusita	$\sum_{k=1}^{n} \left(\sqrt{z_{ik}} - \sqrt{z_{jk}}\right)^2$	$\sum_{k=1}^{n} wg_k \left(\sqrt{z_{ik}} - \sqrt{z_{jk}}\right)^2$	
Marczewski and Steinhaus	$\frac{\sum_{k=1}^{n} \lvert z_{ik}-z_{jk} \rvert}{\sum_{k=1}^{n} \max\{x_{ik}, x_{jk}\}}$	$\frac{\sum_{k=1}^{n} wg_k \lvert z_{ik}-z_{jk} \rvert}{\sum_{k=1}^{n} wg_k \max\{x_{ij}, x_{jk}\}}$	

Source: own elaboration based on M. Walesiak: *Generalized Distance Measure in Statistical Multidimensional Analysis*. [In Polish] Wyd. Akademii Ekonomicznej we Wrocławiu, Wrocław 2002, p. 24; H.H. Bock: *Automatische Klassification*. Vandenhoeck & Ruprecht, Getynga 1974

[a]Description of the square of Euclidean measure can be found on the website of StatSoft Poland: http://www.statsoft.pl/download/help6.php?sortmodul (accessed Match 25, 2007).

It is plausible not to meet the second premise only if objects are assigned to given classes (when the standard is imposed in advance). In the case of clustering algorithms, in which division into groups is automatical, this can lead to assigning the objects to groups depending on the sequence of its processing by algorithm. Besides, in order to increase the agreement between similarity measures and intuition and hence facilitate the interpretation, one can impose two weak premises:

1. Measure should be a metric;
2. Increase in the difference between any coordinates should always result in declining similarity between objects, and vice versa.

The construction of synthetic measures consists in the creation of a certain comparison indicator which informs about the degree to which objects have developed. It is based on comparison with a certain standard. However, the goal is not to compare it with the standard but to compare objects themselves. This assumption leads to the fact that premises concerning synthetic measures will change. It is impossible to define strong premises as such because all objects are compared only with the standard which is not subject to change during the investigation. We can list a few weak premises:

1. Increase in the difference between any coordinate of objects should always bring about the fact that the measure indicates slighter similarity between objects, and vice versa;
2. Measure can be bounded neither from below nor from above;
3. Change in the scale of objects compared should have no influence on the value of measure;
4. Measure should not impose limitations on the values of object coordinates.

The first premise must be met only when one is interested in values of co-ordinates and not in their ratios. The object under consideration is a very small county for which the value of variable ‘surface area’ is 400 km^2, and population is 50,000. It is compared with a much larger county with the surface area of 1,600 km^2, and population amounting to 200,000. It is clear that despite big differences in values of coordinates, they are very similar because population density is identical. In this case, one is interested not in the values of coordinates themselves but in their ratios.

The second premise is a contradiction of a strong premise concerning similarity measures. It results from the fact that the nature of standard is slightly different. Standard is a unit of measure just as the standard of meter. Value of similarity measure of the standard itself is a border dividing the objects into better and worse than the standard. In taxonomic methods, operations are made on known and unchangeable observation matrix and therefore measures are bounded from below and above. Hence, one knows that none of objects can be better than the standard. Adding a new object to the matrix requires the calculation of the standard from the beginning. Possibility of adding the object from outside the sample to the matrix is very desirable in many cases. The example can be the comparison between the development level of regions in a given country and the standard created on the basis of data derived from another region (also outside a given country) characterized by development level to which one wants to equal. In such a situation, one can never be certain if there is an object worse than the worst object known so far, or better than the best object known. Thus, measure should be bounded neither from below nor from above.

Variables used for the creation of synthetic measure have different scales of values, e.g. a surface with the area of the order of thousands of square kilometers, and population of the order of hundreds of thousands. The third premise stems from the above. If it is not met, variables with high values prevail. Measures satisfying this premise are not so prone to this dominance.

Measures should not impose limitations on possible values of variables because this limits their application with reference to certain problems. Obviously, it is possible to reduce variables to a desirable range but this can cause a change in the scale of values and shift the level of mean value. In certain cases, this can influence the results of subsequent comparisons.

Figure 2.2 shows the dependence of urban similarity measure on the distance from the standard. Curves show the lines of constant value of increase in comparison coefficient. This measure belongs to the group of measures called Minkowski distances. The remaining ones (Euclidean and Chebyschev) are shown in Figs. 2.3 and 2.4. These measures satisfy both strong and weak premises concerning similarity measures and allow easy interpretation of results obtained. However, they do not meet all the premises discussed. They are bounded from below – minimal value of a measure is always zero, which leads to the fact that the standard must always be the best. This substantially lessens the possibility of creating the standards.

In all the measures presented, r-time increase in all the variables of objects compared has resulted in r-time change in the value of measure. Not all measures have this property. Multiplying all the variables of objects compared by r for the square of Euclidean measure:

$$\sum_{k=1}^{n} (rz_{1k} - rz_{2k})^2 = r^2 \sum_{k=1}^{n} (z_{1k} - z_{2k})^2 = r^2 d_{01}, \tag{2.17}$$

results in r-time increase in all coordinates and r^2-time increase in this measure. Thus, this measure is very sensitive to big differences in the values of variables of objects compared, and not sensitive to small differences (see Fig. 2.5). The application of this measure in the classification of objects can lead to the creation of class with single elements. This phenomenon could be observed while classifying the objects among which there are several objects in the case of which coordinate of one object will be very different from the coordinates of other objects.

Let's change values of all variables by translation coefficients Δ_k:

$$\sum_{k=1}^{n} (z_{1k} + \Delta_k - z_{2k} - \Delta_k)^2 = \sum_{k=1}^{n} (z_{1k} - z_{2k})^2 = d_{01}. \tag{2.18}$$

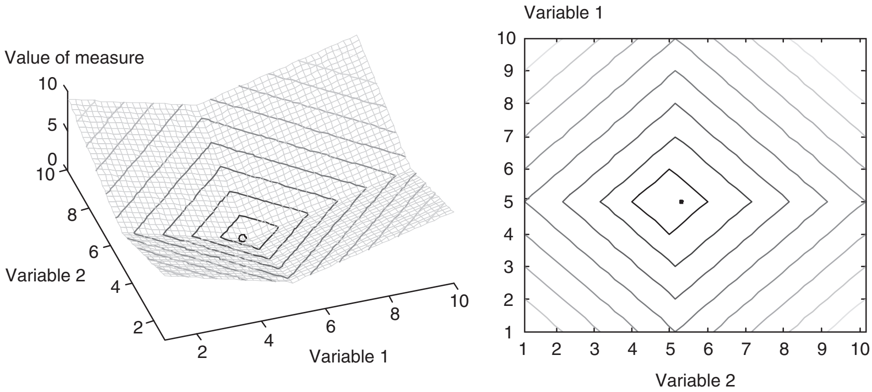

Fig. 2.2 Values of urban similarity measure depending on position relative to the standard located in point $P_0(5,\ 5)$
Source: own elaboration

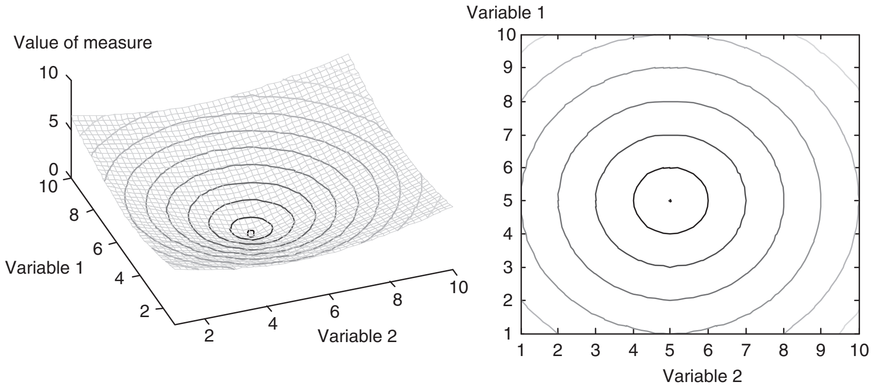

Fig. 2.3 Values of Euclidean similarity measure depending on position relative to the standard located in point $P_0(5,\ 5)$
Source: own elaboration

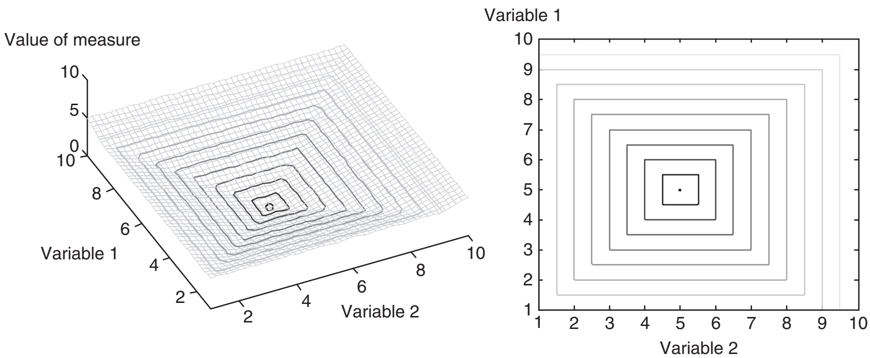

Fig. 2.4 Values of Chebyschev similarity measure depending on position relative to the standard located in point $P_0(5,\ 5)$
Source: own elaboration

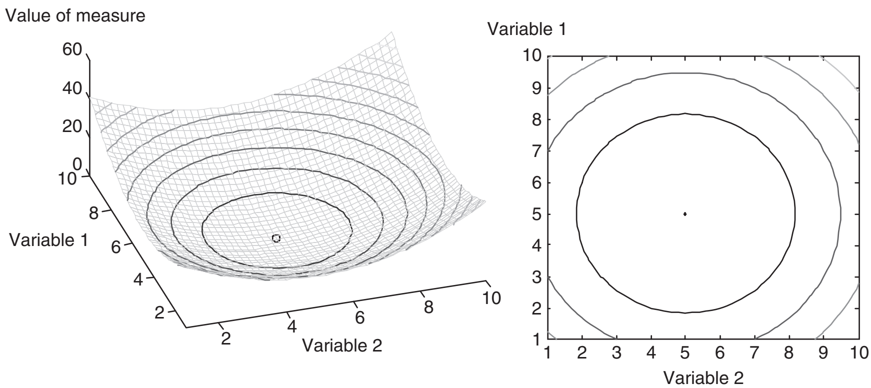

Fig. 2.5 Values of the square of Euclidean similarity measure depending on position relative to the standard located in point $P_0(5,\ 5)$
Source: own elaboration

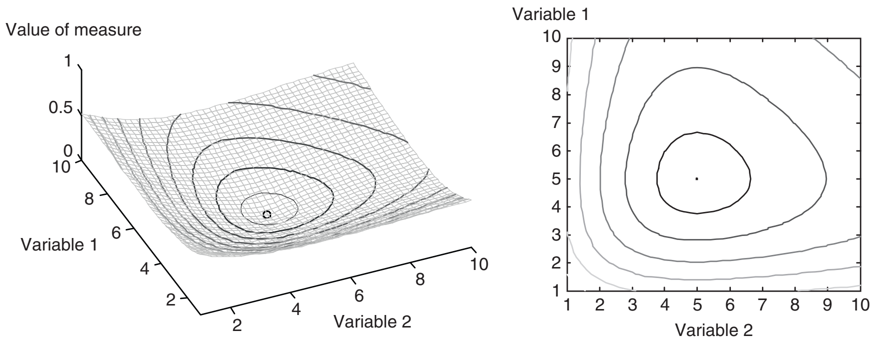

Fig. 2.6 Values of Clark's similarity measure dependending on position relative to the standard located in point $P_0(5,\ 5)$
Source: own elaboration

It can be noticed that the value of measure does not depend on the location of objects in space but on their relative positions. This measure is not a metric (triangle inequality is not satisfied).

Clark's measure is similar to the square of Euclidean measure (Fig. 2.6). Its value depends on the scale of objects. It is not a metric as triangle inequality is not satisfied.

In order to find a value with which the measure attains maximal dissimilarity between object and the standard, one should calculate the measure at $\pm\infty$. To do so, he/she calculates the limit at which one of variables approaches $\pm\infty$. Let $P_0(z_{01},\ z_{02})$ be a point in which the standard is located and with which other points are compared. Value of Clark's measure in point $P_1(t,\ z_{12})$, when t approaches ∞ is as follows:

$$\lim_{t\to\infty} d_{01} = \lim_{t\to\infty} \sqrt{\frac{1}{2}\left[\left(\frac{z_{01}-t}{z_{01}+t}\right)^2 + \left(\frac{z_{02}-z_{12}}{z_{02}+z_{12}}\right)^2\right]}$$
$$= \lim_{t\to\infty} \sqrt{\frac{1}{2}\left[\left(\frac{\frac{z_{01}}{t}-1}{\frac{z_{01}}{t}+1}\right)^2 + \left(\frac{z_{02}-z_{12}}{z_{02}+z_{12}}\right)^2\right]}, \quad (2.19)$$

thus

$$\lim_{t\to\infty} d_{01} = \sqrt{\frac{1}{2}\left[1 + \left(\frac{z_{02}-z_{12}}{z_{02}+z_{12}}\right)^2\right]} = \sqrt{\frac{1}{2} + \frac{1}{2}\left(\frac{z_{02}-z_{12}}{z_{02}+z_{12}}\right)^2}. \quad (2.20)$$

If both values of coordinates approach infinity, Clark's measure approaches one. This observation can be generalized to any number of dimensions. Regardless of the number of dimensions, if all coordinates approach infinity, Clark's measure approaches one. Likewise, if all coordinates approach minus infinity, Clark's measure also approaches one.

One should consider the case in which birth rate is negative. Then, zero can appear in the denominator. Function limit is calculated in the point where zero – $(-z_{01})$ can appear. Let $P_0(z_{01},\ z_{02})$ be a point with which other points are compared. Value of Clark's measure in point $P_1(t,\ z_{12})$, with t approaching $-z_{01}$ on the right side, is the following:

$$d_{01} = \sqrt{\frac{1}{2}\left[\left(\frac{z_{01}-t}{z_{01}+t}\right)^2 + \left(\frac{z_{02}-z_{12}}{z_{02}+z_{12}}\right)^2\right]}, \quad (2.21)$$

$$\lim_{t\to -z_{01}^+} d_{01} = \lim_{t\to -z_{01}^+} \sqrt{\frac{1}{2}\left[\left(\frac{z_{01}-t}{z_{01}+t}\right)^2 + \left(\frac{z_{02}-z_{12}}{z_{02}+z_{12}}\right)^2\right]}, \quad (2.22)$$

because

$$\lim_{t\to -z_{01}^+} \left(\frac{z_{01}-t}{z_{01}+t}\right)^2 = \left(\frac{2z_{01}}{0^+}\right)^2 = +\infty, \quad (2.23)$$

thus

$$\lim_{t\to -z_{01}^+} d_{01} = +\infty. \quad (2.24)$$

When t approaches $-z_{01}$ on the left side, then

$$\lim_{t \to -z_{01}^{-}} d_{01} = \lim_{t \to -z_{01}^{-}} \sqrt{\frac{1}{2}\left[\left(\frac{z_{01}-t}{z_{01}+t}\right)^2 + \left(\frac{z_{02}-z_{12}}{z_{02}+z_{12}}\right)^2\right]} = +\infty, \tag{2.25}$$

because

$$\lim_{t \to -z_{01}^{-}} \left(\frac{z_{01}-t}{z_{01}+t}\right)^2 = \left(\frac{2z_{01}}{0^{-}}\right)^2 = +\infty. \tag{2.26}$$

While making comparison between objects and the object with $P_0(z_{01},\ z_{02})$ coordinates, the minimal value is in point $P_{01}(z_{01},\ z_{02})$. Maximal value is infinity and can be reached by approaching point $P_0(-z_{01}, t)$ or $P_{01}(t, -z_{02})$ on the left or right side. If all values of coordinates approach plus or minus infinity, Clark's measure equals one.

After multiplying all the variables of objects compared by r_k, value of Clark's measure will amount to:

$$\sqrt{\frac{1}{n}\sum_{k=1}^{n}\left[\frac{r_k z_{1k} - r_k z_{2k}}{r_k z_{1k} + r_k z_{2k}}\right]^2} = \sqrt{\frac{1}{n}\sum_{k=1}^{n}\left[\frac{r_k(z_{1k} - z_{2k})}{r_k(z_{1k} + z_{2k})}\right]^2}$$
$$= \sqrt{\frac{1}{n}\sum_{k=1}^{n}\left[\frac{(z_{1k} - z_{2k})}{(z_{1k} + z_{2k})}\right]^2} = d_{01}. \tag{2.27}$$

Thus, Clark's measure is invariant to object scale and values of individual variables. Its chief asset is that it does not require the standardization of variables, and its drawback is that in the case of negative values of coordinates, it equals infinity (Fig. 2.7). That is why, Clark's measure is used only for positive values of coordinates.

Having changed all the variables by factor Δ_k

$$\sqrt{\frac{1}{n}\sum_{k=1}^{n}\left[\frac{z_{1k} + \Delta_k - z_{2k} - \Delta_k}{z_{1k} + \Delta_k + z_{2k} + \Delta_k}\right]^2} = \sqrt{\frac{1}{n}\sum_{k=1}^{n}\left[\frac{z_{1k} - z_{2k}}{2\Delta_k + z_{1k} + z_{2k}}\right]^2}. \tag{2.28}$$

This measure is not invariant in relation to the translation of objects. Similar limitation as to the allowable range of variables can be found in the case of Jeffreys–Matusita measure (Fig. 2.8). This limitation is a result of the square root of variable value present in this formula. Unlike Clark's measure, there is no limitation in relation to upper value of this measure. If at least one variable approaches plus infinity, value of measure also approaches plus infinity. Once the values of all variables of objects compared have been multiplied, value of Jeffreys–Matusita will be as follows:

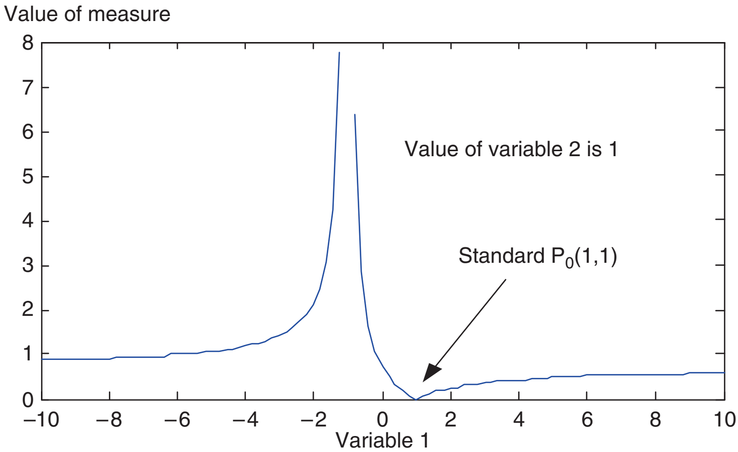

Fig. 2.7 Value of Clark's similarity measure depending on position relative to the standard located in point $P_0(1, 1)$ with variable 2 equal one
Source: own elaboration

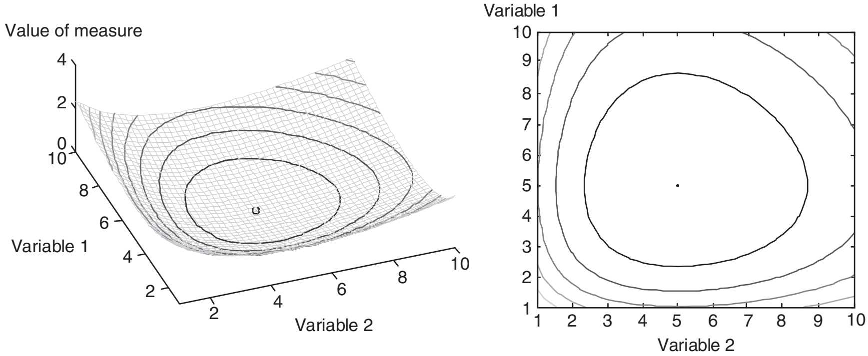

Fig. 2.8 Values of Jeffreys–Matusita similarity measure depending on position relative to the standard located in point $P_0(5,\ 5)$
Source: own elaboration

$$\sum_{k=1}^{n} \left(\sqrt{rz_{ik}} - \sqrt{rz_{jk}}\right)^2 = \sum_{k=1}^{n} r\left(\sqrt{z_{ik}} - \sqrt{z_{jk}}\right)^2 = rd_{01}. \tag{2.29}$$

As it arises from this formula, r-time increase in values of all variables of objects compared leads to r-time increase in the value of this measure.

From a change in the value of all variables by factor Δ_k:

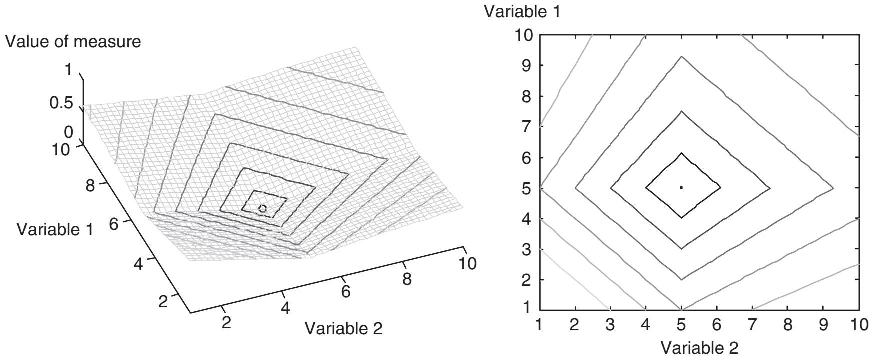

Fig. 2.9 Values of Marczewski and Steinhaus similarity measure dependening on position relative to the standard located in point $P_0(5,\ 5)$
Source: own elaboration

$$\sum_{k=1}^{n}\left(\sqrt{z_{ik}+\Delta_k}-\sqrt{z_{jk}+\Delta_k}\right)^2=\sum_{k=1}^{n}\left(z_{ik}-2\sqrt{z_{ik}+\Delta_k}\sqrt{z_{jk}+\Delta_k}+z_{jk}+2\Delta_k\right), \tag{2.30}$$

it follows that this measure is not invariant with regard to translation.

Clark's measure and Jeffreys–Matusita measure have the shape of lines with constant values of measure that resemble distorted Euclidean measure. The shape of a line with identical values of Marczewski and Steinhaus measure resembles metric measure (Fig. 2.9).

Let $P_0(z_{01},\ z_{02})$ a point with which other points are compared. If the value of Marczewski and Steinhaus measure at $P_1(t,\ z_{12})$, where t approaches ∞, is:

$$\begin{aligned}\lim_{t\to\infty} d_{01} &= \lim_{t\to\infty}\frac{|z_{01}-t|+|z_{02}-z_{12}|}{\max\{z_{01},t\}+\max\{z_{02},z_{12}\}}\\ &= \lim_{t\to\infty}\frac{|z_{01}-t|+|z_{02}-z_{12}|}{t+\max\{z_{02},z_{12}\}},\end{aligned} \tag{2.31}$$

then

$$\lim_{t\to\infty} d_{01}=\lim_{t\to\infty}\frac{\frac{|z_{01}-t|}{t}+\frac{|z_{02}-z_{12}|}{t}}{1+\frac{\max\{z_{02},z_{12}\}}{t}}=\lim_{t\to\infty}\frac{\frac{\left|t\left(\frac{z_{01}}{t}-1\right)\right|}{t}+\frac{|z_{02}-z_{12}|}{t}}{1+\frac{\max\{z_{02},z_{12}\}}{t}}, \tag{2.32}$$

t is positive, thus:

$$\lim_{t\to\infty} d_{01} = \lim_{t\to\infty} \frac{\left|\frac{z_{01}}{t} - 1\right| + \frac{|z_{02}-z_{12}|}{t}}{1 + \frac{\max\{z_{02}, z_{12}\}}{t}} = \frac{|-1|}{1} = 1. \tag{2.33}$$

If at least one coordinate approaches infinity, Marczewski and Steinhaus measure approaches one.

Let $P_0(z_{01},\ z_{02})$ be a point with which other points are compared. Value of Marczewski and Steinhaus measure in point $P_1(t, z_{12})$ when t approaches $-\infty$, is:

$$\begin{aligned}\lim_{t\to-\infty} d_{01} &= \lim_{t\to-\infty} \frac{|z_{01} - t| + |z_{02} - z_{12}|}{\max\{z_{01}, t\} + \max\{z_{02}, z_{12}\}} \\ &= \lim_{t\to-\infty} \frac{|z_{01} - t| + |z_{02} - z_{12}|}{z_{01} + \max\{z_{02}, z_{12}\}},\end{aligned} \tag{2.34}$$

because $|z_{01} - t| \underset{t\to\infty}{\longrightarrow} \infty$

$$\lim_{t\to-\infty} d_{01} = \infty. \tag{2.35}$$

Therefore, increase in Marczewski and Steinhaus measure is the same for positive and negative values. If one of coordinates approaches plus infinity, value of

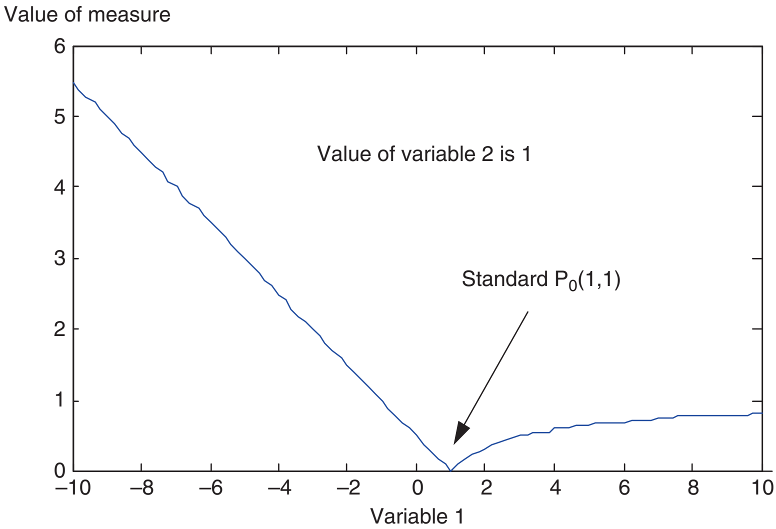

Fig. 2.10 Values of Marczewski and Steinhaus similarity measure depending on position relative to the standard in point $P_0(1,\ 1)$ with variable 2 equal one
Source: own elaboration

measure approaches one. By contrast, if one of coordinates approaches minus infinity, value of this measure approaches infinity (Fig. 2.10). Consequently, this measure can be used only for variables with positive values. Additionally, it has another disadvantage, i.e. it is linear for values of variables lower than variables of objects with which it is compared, and it is nonlinear for higher ones, i.e. takes the scale of the standard into account.

Value of Marczewski and Steinhaus measure, after multiplying all the variables of objects compared by $r>0$, amounts to:

$$\frac{\sum_{k=1}^{n}|rz_{ik}-rz_{jk}|}{\sum_{k=1}^{n}\max\{rz_{ik},rz_{jk}\}}=\frac{r\sum_{k=1}^{n}|z_{ik}-z_{jk}|}{r\sum_{k=1}^{n}\max\{z_{ik},z_{jk}\}}=d_{01}. \tag{2.36}$$

Hence, this measure is invariant in relation to the scale of object but not to the scale of values of particular variables.

By changing values of all variables by factor Δ_k:

$$\frac{\sum_{k=1}^{n}|z_{ik}+\Delta_k-z_{jk}-\Delta_k|}{\sum_{k=1}^{n}\max\{z_{ik}+\Delta_k,z_{jk}+\Delta_k\}}=\frac{\sum_{k=1}^{n}|z_{ik}-z_{jk}|}{\sum_{k=1}^{n}\max\{z_{ik},z_{jk}\}+\Delta_k}, \tag{2.37}$$

one can observe that this measure is not invariant with regard to translation.

Similar shape of the line with identical values of measure is found in the case of Bray–Curtis measure (Fig. 2.11).

Let $P_0(z_{01},\ z_{02})$ be a point with which other points are compared. Value of Bray–Curtis measure in point $P_1(t,\ z_{12})$, when t approaches ∞, is:

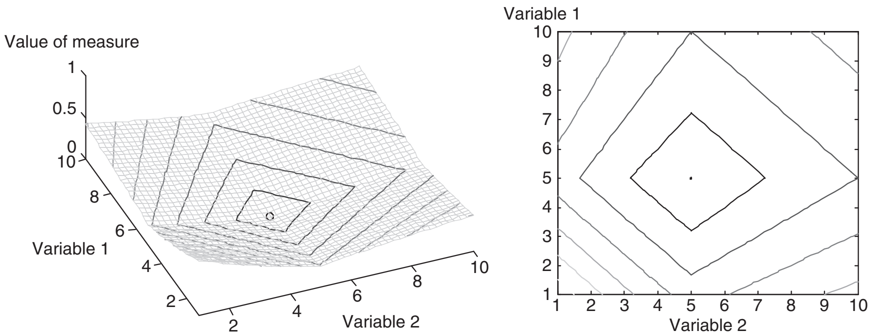

Fig. 2.11 Values of Bray–Curtis similarity measure (non-metric coefficient) depending on position relative to the standard located in point$P_0(5,\ 5)$
Source: own elaboration

$$\lim_{t\to\infty} d_{01} = \lim_{t\to\infty} \frac{|z_{01}-t|+|z_{02}-z_{12}|}{z_{01}+t+z_{02}+z_{12}} = \lim_{t\to\infty} \frac{\frac{1}{t}|z_{01}-t|+\frac{1}{t}|z_{02}-z_{12}|}{\frac{z_{01}}{t}+\frac{t}{t}+\frac{z_{02}}{t}+\frac{z_{12}}{t}}, \tag{2.38}$$

t is positive, thus

$$\lim_{t\to\infty} d_{01} = \lim_{t\to\infty} \frac{\left|\frac{z_{01}}{t}-\frac{t}{t}\right|+\left|\frac{z_{02}}{t}-\frac{z_{12}}{t}\right|}{\frac{z_{01}}{t}+\frac{t}{t}+\frac{z_{02}}{t}+\frac{z_{12}}{t}} = \frac{|-1|}{1} = 1. \tag{2.39}$$

If at least one coordinate approaches infinity, Bray–Curtis measure approaches one.

Let $P_0(z_{01},\ z_{02})$ be a point with which other points are compared. Value of Bray–Curtis measure in point $P_1(t, z_{12})$, when t approaches $-\infty$, is:

$$\lim_{t\to-\infty} d_{01} = \lim_{t\to-\infty} \frac{|z_{01}-t|+|z_{02}-z_{12}|}{z_{01}+t+z_{02}+z_{12}} = \lim_{t\to-\infty} \frac{\frac{1}{t}|z_{01}-t|+\frac{1}{t}|z_{02}-z_{12}|}{\frac{z_{01}}{t}+\frac{t}{t}+\frac{z_{02}}{t}+\frac{z_{12}}{t}} \tag{2.40}$$

$$= \lim_{t\to-\infty} \frac{\frac{1}{t}|z_{01}-t|+\frac{1}{t}|z_{02}-z_{12}|}{\frac{z_{01}}{t}+1+\frac{z_{02}}{t}+\frac{z_{12}}{t}} = \lim_{t\to\infty} \frac{\frac{1}{(-t)}|z_{01}+t|+\frac{1}{(-t)}|z_{02}-z_{12}|}{\frac{z_{01}}{(-t)}+1+\frac{z_{02}}{(-t)}+\frac{z_{12}}{(-t)}} \tag{2.41}$$

$$= \lim_{t\to\infty} \frac{\left|\frac{z_{01}}{t}+\frac{t}{t}\right|+\left|\frac{z_{02}}{t}-\frac{z_{12}}{t}\right|}{-\frac{z_{01}}{t}+1-\frac{z_{02}}{t}-\frac{z_{12}}{t}} = \lim_{t\to\infty} \frac{\left|\frac{z_{01}}{t}+1\right|+\left|\frac{z_{02}}{t}-\frac{z_{12}}{t}\right|}{-\frac{z_{01}}{t}+1-\frac{z_{02}}{t}-\frac{z_{12}}{t}} = \frac{1}{-1} = -1, \tag{2.42}$$

because $\left|\frac{z_{01}}{t}+1\right| \underset{t\to\infty}{\longrightarrow} 1$ *and* $\left|\frac{z_{02}}{t}+\frac{z_{12}}{t}\right| \underset{t\to\infty}{\longrightarrow} 0.$

If at least one coordinate approaches infinity, Bray–Curtis measure approaches minus one.

Let $P_0(z_{01},\ z_{02})$ be a point to which other points are compared. Value of Bray–Curtis measure in point $P_0(t, z_{12})$ when t approaches $-(z_{01}+z_{02}+z_{12})$ on the right side, is:

$$\lim_{t\to-(z_{01}+z_{02}+z_{12})^+} d_{01} = \lim_{t\to-(z_{01}+z_{02}+z_{12})^+} \frac{|z_{01}+t|+|z_{02}-z_{12}|}{z_{01}-t+z_{02}+z_{12}} = \infty, \tag{2.43}$$

because

$$\lim_{t\to-(z_{01}+z_{02}+z_{12})^+} (z_{01}-t+z_{02}+z_{12}) = 0^+. \tag{2.44}$$

Similarly when t approaches $-(z_{01}+z_{02}+z_{12})^+$ on the left side:

$$\lim_{t\to-(z_{01}+z_{02}+z_{12})^-} d_{01} = \frac{|z_{01}+t|+|z_{02}-z_{12}|}{z_{01}-t+z_{02}+z_{12}} = -\infty. \tag{2.45}$$

While making comparison between objects and object with $P_0(z_{01},\ z_{02})$ coordinates, the minimal value is in point $P_0(z_{01}, z_{02})$. Maximal value is infinity and is reached while approaching points $P_0(-(z_{01}+z_{02}+t)\,, t)$ or $P_0(t, -(z_{01}+z_{02}+t))$ on the right side. Minimal value is minus infinity when approaching the points $P_0(-(z_{01}+z_{02}+t), t)$ or $P_t(t, -(z_{01}+z_{02}+t))$ on the left side.

Once values of all variables of objects compared have been multiplied by r, value of Bray–Curtis measure will amount to:

$$\frac{\sum_{k=1}^{n}|rz_{ik}-rz_{jk}|}{\sum_{k=1}^{n}\left(rz_{ik}+rz_{jk}\right)}=\frac{r\sum_{k=1}^{n}|z_{ik}-z_{jk}|}{r\sum_{k=1}^{n}\left(z_{ik}+z_{jk}\right)}=d_{01}. \tag{2.46}$$

Therefore, this measure is invariant with regard to change in object's scale but not invariant to the scale of values of individual variables.

After changing the values of all variables by factor Δ_k:

$$\frac{\sum_{k=1}^{n}|z_{ik}+\Delta_k-z_{jk}-\Delta_k|}{\sum_{j=1}^{m}\left(z_{jk}+\Delta_k+z_{jk}+\Delta_k\right)}=\frac{\sum_{k=1}^{n}|z_{ik}-z_{jk}|}{\sum_{k=1}^{n}\left(z_{ik}+z_{jk}+2\Delta_k\right)}, \tag{2.47}$$

this measure is not invariant with regard to translation.

Bray–Curtis measure allows negative values (Fig. 2.12) and therefore is used only in the range of positive values of coordinates.

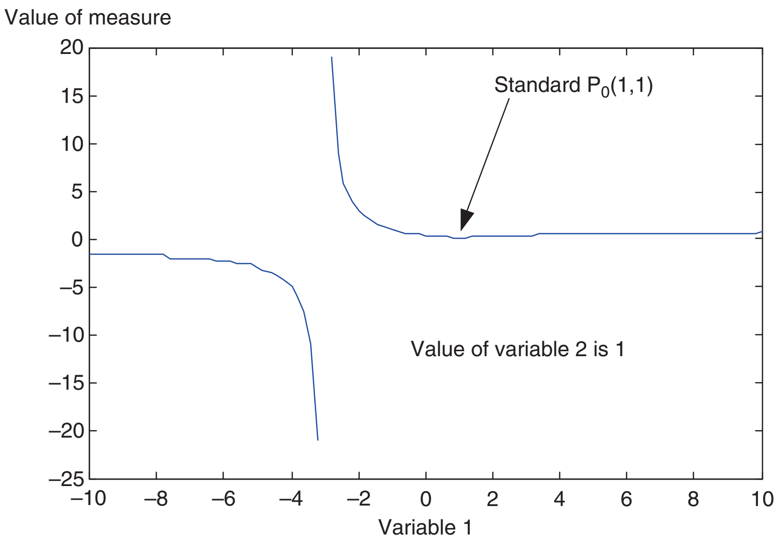

Fig. 2.12 Values of Bray–Curtis similarity measure depending on position relative to the standard located in point $P_0(1,\ 1)$ with variable 2 equal one. *Source:* own elaboration

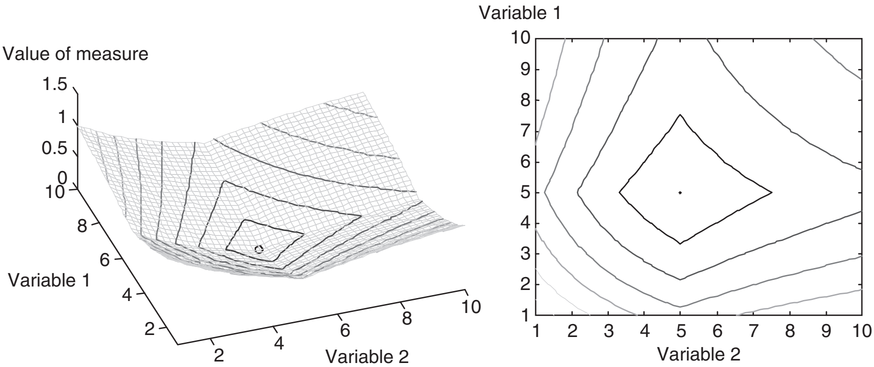

Fig. 2.13 Values of Canberra similarity measure depending on position relative to the standard located in point $P_0(5,\ 5)$
Source: own elaboration

Canberra measure has a character similar to last two measures (Fig. 2.13) but unlike these two measures, it is a metric.

Let $P_0(z_{01}, z_{02})$ be a point compared with other points. Value of Canberra measure in point $P_1(t, z_{12})$, when t approaches ∞, is:

$$\lim_{t\to\infty} d_{01} = \lim_{t\to\infty}\left[\frac{|z_{01}-t|}{z_{01}+t}+\frac{|z_{02}-z_{12}|}{z_{02}+z_{12}}\right] = \lim_{t\to\infty}\left[\frac{\left|\frac{z_{01}}{t}-1\right|}{\frac{z_{01}}{t}+1}+\frac{|z_{02}-z_{12}|}{z_{02}+z_{12}}\right]$$
$$= \frac{|z_{02}-z_{12}|}{z_{02}+z_{12}}+1. \tag{2.48}$$

If both values of coordinates approach infinity, Canberra measure approaches one, and when both coordinate values approach minus infinity, Canberra measure approaches minus one.

Let $P_0(z_{01}, z_{02})$ be a point compared with other points. Value of Canberra measure in point $P_1(t, z_{12})$, when t approaches $-z_{01}$ on the right side, is:

$$\lim_{t\to -z_{01}^+} d_{01} = \lim_{t\to -z_{01}^+} \frac{|z_{01}-t|}{z_{01}+t}+\frac{|z_{02}-z_{12}|}{z_{02}+z_{12}} = \infty, \tag{2.49}$$

because

$$\lim_{t\to -z_{01}^+} \frac{|z_{01}-t|}{z_{01}+t} = \left(\frac{2z_{01}}{0^+}\right)^2 = \infty \tag{2.50}$$

Similarly, when t approaches $-z_{01}$ on the left side:

$$\lim_{t \to -z_{01}^-} d_{01} = \lim_{t \to -z_{01}^-} d_{01} \frac{|z_{01} - t|}{z_{01} + t} + \frac{|z_{02} - z_{12}|}{z_{02} + z_{12}} = -\infty. \tag{2.51}$$

Once values of all variables of objects compared have been multiplied by $r_k > 0$, value of Canberra measure is:

$$\sum_{k=1}^{n} \frac{|r_k z_{ik} - r_k z_{jk}|}{r_k z_{ik} + r_k z_{jk}} = \sum_{k=1}^{n} \frac{r_k |z_{ik} - z_{jk}|}{r_k \left(z_{ik} + z_{jk}\right)} = d_{01}. \tag{2.52}$$

Hence, this measure is invariant in relation to the scale of object and scale of values of particular variables.

From a change in values of all variables by factor Δ_k:

$$\frac{\sum_{k=1}^{n} |z_{ik} + \Delta_k - z_{jk} - \Delta_k|}{\sum_{j=1}^{m} \left(z_{jk} + \Delta_k + z_{jk} + \Delta_k\right)} = \frac{\sum_{k=1}^{n} |z_{jk} - z_{jk}|}{\sum_{k=1}^{n} \left(z_{ik} + z_{jk} + 2\Delta_k\right)}, \tag{2.53}$$

it follows that it is not invariant with regard to translation (Fig. 2.14).

Unlike previous measures, measure of correlation is a direction measure. In this case, objects are interpreted as directions and not as points. This measure is sensitive to ratios of coordinates, but not to their scale. Once the values of all

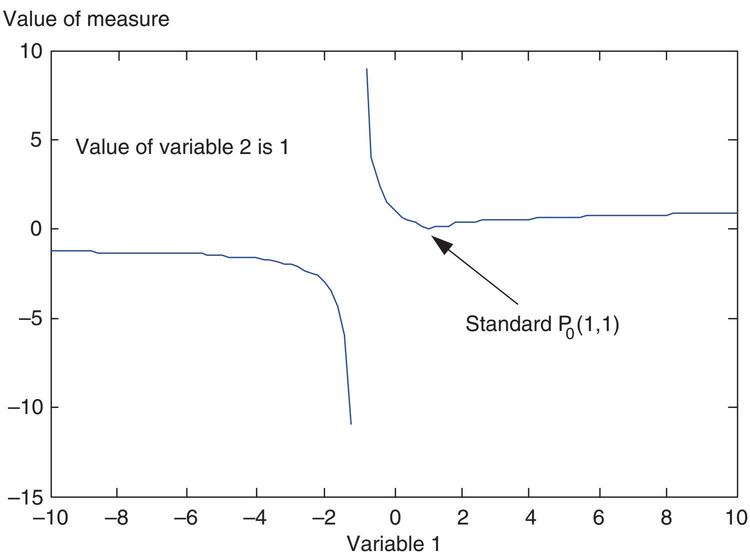

Fig. 2.14 Values of Canberra similarity measure depending on position relative to the standard located in point $P_0(1,\ 1)$, with variable 2 equal one. *Source:* own elaboration

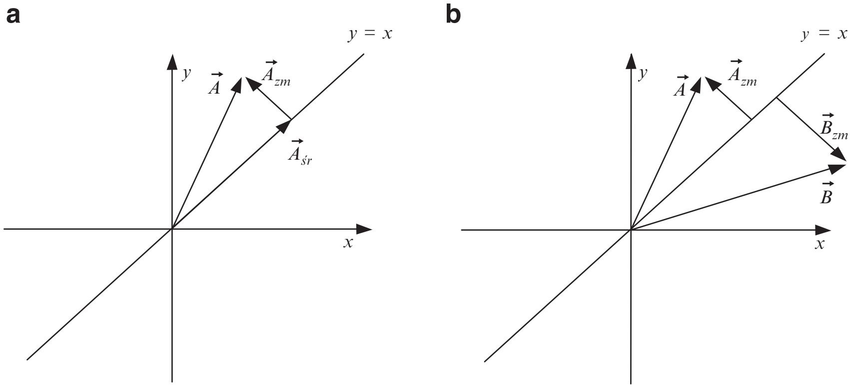

Fig. 2.15 Comparison between vectors with the aid of correlation (**a**) division of a vector into fixed and variable components, (**b**) comparison between two vectors in 2D space
Source: M. Borawski: *op.cit.*, p. 44; own elaboration

variables of objects compared have been multiplied by r, value of correlation measure amounts to:

$$\frac{\sum_{k=1}^{n}\left(rz_{ik}-r\bar{z}_i\right)\left(rz_{jk}-r\bar{z}_j\right)}{\sqrt{\sum_{k=1}^{n}\left(rz_{ik}-s\bar{z}_i\right)^2\sum_{k=1}^{n}\left(rz_{jk}-r\bar{z}_j\right)^2}}=\frac{r^2\sum_{k=1}^{n}\left(z_{ik}-\bar{z}_i\right)\left(z_{jk}-\bar{z}_j\right)}{r^2\sqrt{\sum_{k=1}^{n}\left(z_{ik}-\bar{z}_i\right)^2\sum_{k=1}^{n}\left(z_{jk}-\bar{z}_j\right)^2}}=d_{1,2}. \tag{2.54}$$

Thus, this measure is invariant in relation to the scale of object but not to the scale of values of particular variables.

Value of correlation equals one or minus one when objects are similar, and zero when they are not similar. Minus one value indicates that the direction is the same but senses of vectors are opposite. For time series, correlation compares vectors representing variable of data – see Fig. 2.15a ($\vec{A}_{zm}$ and $\vec{B}_{zm}$). Due to the fact that vectors representing the fixed parts of data are always vertical to vectors representing variable components of data,[29] dimension of space in which comparison is made is reduced by one dimension. As a consequence, correlation in 2D space can only reach one or minus one value because all vectors of variable's value always have the same direction and differ only with respect to their senses (Fig. 2.15b).

[29] M. Borawski: *Vector Calculus in Image Processing*. [In Polish] Wyd. Uczelniane Politechniki Szczecińskiej, Szczecin 2007, pp. 43–46.

2.3 Reasons Behind Using Vector Calculus in Regional Development Analysis

In taxonomic methods none of objects described in observation matrix can have higher level of development than the standard created on the basis of diagnostic variables. This imposes limitations on the application of this method. A situation in which the standard is taken outside the set investigated is impossible. The example is a situation in which one compares levels of development of Polish counties with corresponding territorial units of the best developed EU Member State. Having merged data derived from both countries into one observation matrix and formed a common standard, it is possible to make classification but a problem may arise and distort the results. If some variables of Polish regions have higher values than regions of the best developed EU country, this will cause the translation of standard location and, as a consequence, change in values of development levels obtained.

The way of calculating the standard, forced by the application of distance similarity measures, leads to another disadvantage of synthetic measures. In certain situations, objects, with one coordinate differing substantially from the remaining ones may occur. In practice, this type of coordinate for these objects can have a value even thousands times higher than coordinates of the remaining objects. As a consequence, maximal (or minimal) value of such a variable after standardization can be even ten times higher than maximal (minimal) values of other variables. Hence, this variable is prevailing and in extreme case it can bring about the fact that value of measure will practically depend only on this variable. In practice, there are only two possible solutions to this problem: application of special standardization method or change in the way of standard determination. Yet, the latter way is not possible when comparison measures based on distance are used. Thus, it turns out that one should seek other ways of synthetic measures creation. As in the case of synthetic measures it is direction indicated by the standard that is interesting and not the standard location itself, for the creation of the standard one can use not spaces with defined measures based on distance but vector calculus, which enables him/her to determine directions in the space and compare them.

Chapter 3
Methodology of Vector Calculus in Regional Development Analysis

3.1. Procedure for Applying Vector Calculus in Regional Development Analysis

In order to examine many phenomena that are subject to economic analysis, one can use methods based on different kinds of spaces. Figure 3.1 shows the best known kinds of spaces, and the ones frequently used in economic analyses are given in bold.

Spaces Space can be applied for economic analyses in two ways: for determining the position and direction. Notions of position and direction do not have to be closely related to geographic position and direction as they should be understood in a wider context. Talking about space, one can mean not only the geographical space but also economic space[1] in the case of which position resulting from certain variables characterizing economic objects is taken into account, instead of geographical position. Income, profit, and in the case of regions – population and length of roads can be such variables.

In socio-economic sciences, methods based on various kinds of similarity measures are frequently used. Similarity measures in spaces are called distance measures. Introducing distance measure into the space enables one to determine object's position[2] (Fig. 3.2), which allows easy and effective comparison between economic objects. One should remember that while defining the distance measure, he/she can determine the object's position in space, but not the direction. Of course, one can draw a system of coordinates for the sake of orientation but only for the sake of orientation and hence one should be very careful while interpreting the

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[1] K. Kuciński: *op.cit.*, pp. 15–22.

[2] Object is understood here as arbitrary territorial unit (region, sub-region, voivodship, county, commune) in accordance with Nomenklatura Jednostek Terytorialnych do Celów Statystycznych (NTS). In figures presented in this chapter, objects are identified with counties for the sake of simplification although the method proposed can be used at any level of NTS.

K. Nermend (ed.), *Vector Calculus in Regional Development Analysis*, Contributions to Economics,
DOI: 10.1007/978-3-7908-2179-6_3, © Springer Physica-Verlag Berlin Heidelberg 2009

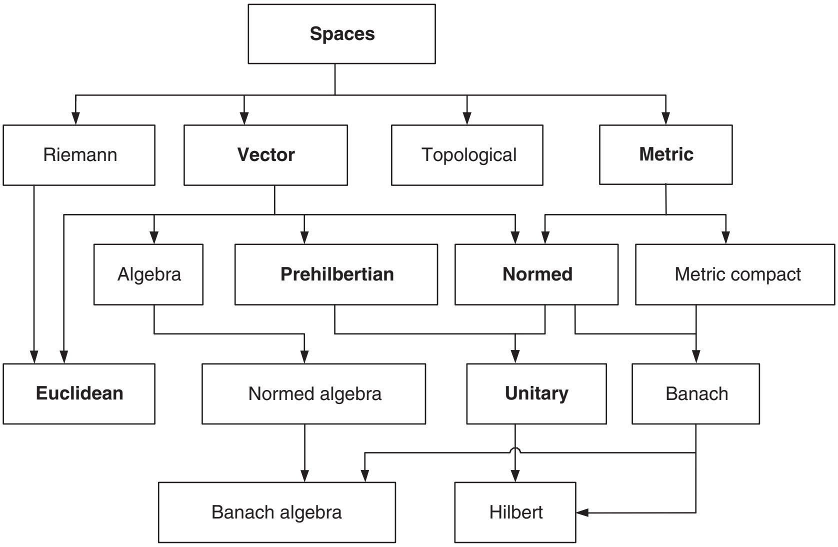

Fig. 3.1. Kinds of spaces
Source: own elaboration based on M. Borawski: *op.cit.*, p. 26

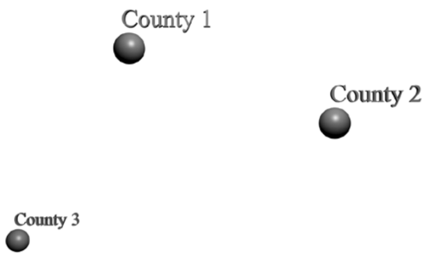

Fig. 3.2. Objects in space with distance measure
Source: own elaboration

results presented in such a coordinate frame. From algebraic point of view, one cannot create a coordinate frame in such a space.

Metric is a certain group of distance measures distinguished. Distance measure d is a metric between a pair of points P_1 and P_2 if the following conditions are satisfied[3]:

1. Nonnegativity:

$$d(P_1, P_2) \geq 0, \tag{3.1}$$

which means that distance measure cannot be negative.

[3] I.N. Bronsztejn, K.A. Siemiendiajew: Mathematics. Encyclopaedic Handbook. [In Polish] Wyd. Naukowe PWN, Warszawa 2003, p. 659.

2.

$$d(P_1, P_2) = 0 \Leftrightarrow P_1 = P_2. \tag{3.2}$$

Occurrence of zero distance measure between two points means that they occupy the same position in the space embedding these points.

3. Symmetry:

$$d(P_1, P_2) = d(P_1, P_2). \tag{3.3}$$

Distance does not depend on the fact that one measures distance from point P_1 to point P_2, or from point P_2 to P_1.

4. Triangle inequality:

$$d(P_1, P_2) \leq d(P_1, P_3) + d(P_3, P_2). \tag{3.4}$$

Distance between points P_1 and P_2 is the smallest, which means that while moving from point P_1 to P_2, one cannot find point P_3 and while moving through this point, the path will be shorter than while moving directly from point P_1 to P_2.

Space in which metric is defined is called metric space. Metric spaces are a very convenient tool for comparing different kinds of objects but sometimes the interpretation of results can be very difficult. There is no direction defined in this space, there are no assumptions as to the features of numbers used as co-ordinates and there is no additivity of objects, due to which it is not easy to transform the change in any coordinate of objects into the result of comparison.

Vector spacesXE Vector space allow the determination of directions in the space without the determination of position. Therefore, they are generally used in combination with distance measure. Every object under analysis is not a point in vector space but a vector (Fig. 3.3). Objects do not have their positions in the space because only direction is established and thus position is not a factor diversifying economic objects.

In vector space, two kinds of elements are distinguished, namely scalars and vectors. Scalars are simply the numbers associated with operations over vectors in vector space. The following conditions must be satisfied so that a space is a vector space[4]:

1. Set of numbers K with the operation of addition and multiplication must be a field (K, +, *), i.e. definite relationship between addition and multiplication must be established and the element inverse to addition and multiplication must be found. This makes it impossible to use natural numbers, integers and most kinds of fuzzy numbers.

[4]*Ibidem*, p. 343.

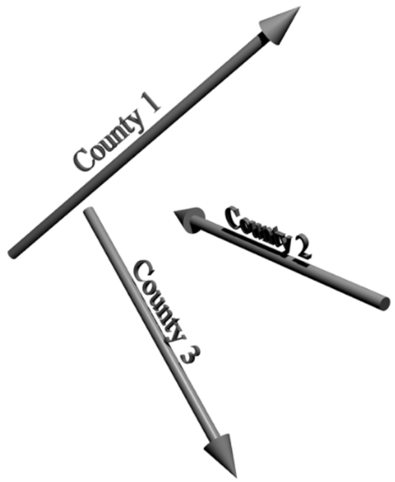

Fig. 3.3. Objects in vector space
Source: own elaboration

2. Set of elements of space V (vectors) with the operation of addition must be Abelian group $(V, +)$. This explicitly defines principles of adding the objects that are elements of this space and enables one to define the operation inverse to addition, i.e. subtraction (that is an exact inverse of addition).
3. One must define a two-argument operation between the element from a set of vectors and element from a set of scalars with result belonging to set of vectors. This operation is called the multiplication of scalar by vector.
4. Neutral element e of multiplication in the set of scalars K is a neutral element of multiplication of scalar by vector:

$$\forall \vec{A} \in V : e\vec{A} = \vec{A}. \tag{3.5}$$

This indicates that the multiplication of vector by a number that is a neutral element of multiplication does not change this vector.
5. Result of multiplying two scalars by vector does not depend on the order of operations:

$$\forall u, r \in K, \forall \vec{A} \in V : u(r\vec{A}) = (ur)\vec{A}, \tag{3.6}$$

which means that it is not important if one first makes a product of both scalars and then the result will be multiplied by vector or one of scalars will be first multiplied by vector and then the result will be multiplied by the second scalar. In both cases, the result must always be the same.
6. Result of adding two scalars and multiplying by vector does not depend on the order of operation:

$$\forall u, r \in K, \forall \vec{A} \in V : u\vec{A} + r\vec{A} = (u + r)\vec{A}, \tag{3.7}$$

which implies that it is not important whether two scalars will be added and the result will be multiplied by vector or if vector will be multiplied by the first scalar, then by the second scalar, and both results will be added. In both cases, results are always the same. This operation makes it possible to take the number outside the brackets.

7. Result of adding two vectors and multiplying by scalar does not depend on the order of operations:

$$\forall r \in K, \forall \vec{A}, \vec{B} \in V : r(\vec{A} + \vec{B}) = r\vec{A} + r\vec{B}. \tag{3.8}$$

This indicates that it is not important whether two vectors will be added and then multiplied by a number or if vector will be multiplied by the number and then the second vector will be multiplied by the same number and results will be added. Both procedures must always produce the same result. This operation allows to take vector outside the brackets.

Vector space itself enables one to determine only the direction without coordinates in the space and hence it is difficult to compare objects. Thus, economic analyses based on "pure" vector space do not give precise enough results. However, comparison based on metric can sometimes pose certain interpretation problems, due to which both spaces are very often merged, i.e. in vector space a metric is defined and another condition called homogeneity condition is added:

$$d(r\vec{A}) = rd(\vec{A}). \tag{3.9}$$

This means that a change in the absolute value of vector results in proportional change in distance measure. If a metric satisfies this additional condition, it becomes a norm. This leads to the creation of a normed space, which makes it possible to measure distance in the space and determine the direction. Hence, it is easier to interpret the results received. In such a space, one can also construct the coordinate systems, but only to some extent. In fact, having specified the coordinates of the object x_1, x_2, ..., x_n and coordinate system specified by vectors $\vec{A}_1, \vec{A}_2, \ldots, \vec{A}_n$, one can explicitly determine vector $\vec{B}$ in this system with the use of the following formula:

$$Y = \sum_{i=1}^{n} x_i X_i. \tag{3.10}$$

However, the inverse process is not possible, unless we introduce an additional element into the vector space. This element is a scalar product. Scalar product $(\vec{A}, \vec{B})$ of two vectors $\vec{A}$ and $\vec{B}$ is a two-argument functional, the arguments of which are vectors and the result is a scalar. This product must satisfy the following conditions[5]:

[5] *Ibidem*, p. 671.

1. Non-negativity:

$$(\vec{A},\vec{A}) \geq 0, \tag{3.11}$$

which means that scalar product of a vector with itself cannot be negative.
2.

$$(\vec{A},\vec{A}) = 0 \Leftrightarrow \vec{A} \text{ is zero vector}, \tag{3.12}$$

Existence of scalar product of a vector with itself means that it is a zero vector (all coordinates equal zero).
3.

$$(\vec{A},\vec{B}) = (\vec{B},\vec{A})^{*}, \tag{3.13}$$

where * – conjugate number.
4.

$$(\vec{A}+\vec{B},\vec{C}) = (\vec{A},\vec{C}) + (\vec{B},\vec{C}). \tag{3.14}$$

Scalar product of a sum of vectors $\vec{A}+\vec{B}$ and vector $\vec{C}$ equals the sum of scalar products of vectors $\vec{A}$ and $\vec{C}$ and $\vec{B}$ and $\vec{C}$.
5.

$$(r\vec{A},\vec{B}) = r(\vec{A},\vec{B}). \tag{3.15}$$

If vector $\vec{A}$ is multiplied by scalar r, then in the case of calculating the scalar product of vector $r\vec{A}$ by any other vector, scalar r can be taken before the scalar product.

Vector space with scalar product is called a prehilbertian space. Scalar product allows to determine coordinates of a vector in arbitrary coordinate system defined by base vectors. On the basis of scalar product, one can define the vector norm[6]:

$$\|\vec{A}\| = \sqrt{(\vec{A},\vec{A})}, \tag{3.16}$$

where $\|\vec{A}\|$ – norm of vector $\vec{A}$.

Definition of norm allows not only to determine the direction in space but also the absolute value of a vector, thanks to which it is possible to translate the vectors

[6] S. Lang: *Algebra*. [In Polish] PWN, Warszawa 1984, p. 352.

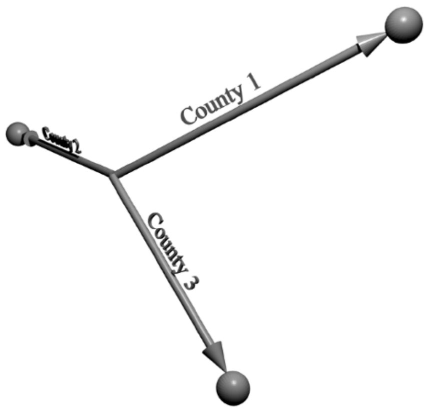

Fig. 3.4. Objects in unitary space. *Source:* own elaboration

in such a way so that their origins will touch (coincide) (Fig. 3.4). Their ends will indicate positions relative to their origins and their specific positions in space are known, which allows not only to compare their directions but also positions in space.

While preparing the data for analysis and interpreting the functioning of methods, one must take mathematical properties of the space into account. Calculations in vector space facilitate the interpretation of methods, which simplifies their modification. In another part of the chapter, conditions for the application of vector space and methods that make use of vector space shall be described together with their interpretations in such a space. Spaces described have been marked in grey in Fig. 3.1.

Vector calculus is closely connected with geometry. In the simplest way, a vector can be described as a segment that has a defined absolute value and direction[7]. From this perspective, the concept of vector, just as the concept of point, are simple terms defined indirectly.[8] Vector calculus can be developed from the definition of vector space based on field theory.[9] It is a very general approach as it allows to use vector calculus not only for geometrical but also non-geometrical objects, thanks to which while making operations on non-geometrical objects one can equate certain "parameters" with geometrical quantities, which in turn facilitates the interpretation of methods.

Definition of vector space is based on a number of axioms that indicate the assumptions underlying the vectors and scalars. Actually, such matters as what vectors and scalars are and what they should be are not discussed. Any object, that satisfies certain axioms (assumptions), can be a vector. This approach is well

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[7]I.N. Bronsztejn, K.A. Siemiendiajew: *op.cit*., p. 646.

[8]P.K. Raszewski: *Riemannian Geometry and Tensor Analysis.* [In Polish] PWN, Warszawa 1958, p. 7.

[9]I.N. Bronsztejn, K.A. Siemiendiajew, G. Musiol, H. Muhlig: *Contemporary Compendium of Mathematics.* [In Polish] Wyd. Naukowe PWN, Warszawa 2004, p. 343.

illustrated by an anecdote about Hilbert, who was asked, during the discussion on the foundations of geometry, if inkwells can be points and pens treated as vectors. He replied: “Yes, if inkwells and pens satisfy the system of geometry’s axioms”.[10]

Axioms are assumptions concerning given objects. From these assumptions, certain properties of objects are derived and methods allowing operations over objects are devised. Because one does not have precise information about the nature of objects but only certain assumptions about the objects are made, all properties derived from assumptions are true for all objects satisfying these assumptions. Similarly, all methods defined on the basis of these assumptions can be used for the analysis of all objects meeting these assumptions.

In order to treat economic objects as vectors, one should first select a proper set of numbers that must satisfy the axioms of the field. Taken the best known set of numbers (i.e. natural, integer, and rational, real and complex) into account, only last three meet relevant axioms. As square root cannot be found for all rational numbers, the application of this set would make it impossible to define unitary space further. Introduction of distance measure, belonging to a set of complex numbers, into the vector space could lead to the creation of distance measure for which points located in different positions could indicate zero value in certain conditions. This would hinder the interpretation of results. As far as the aforementioned sets are concerned, only the set of real numbers satisfies all axioms of the field, allows to operate in any space and omits spaces in the case of which interpretation would be difficult.

Economic research with the use of vector calculus can be limited by measurement scale applied.[11] Only values measured on ratio scaleXE Ratio scale could form a field. While data expressed with the aid of natural numbers or integers can be converted into real numbers for the purpose of calculations, it is not always possible to change the measurement scale.

Describing the economic objects as vectors, it is best to use one-dimensional table of real numbers, filled with as many data as the number of dimensions of the space. For such a table, addition can be defined as the addition of corresponding elements. Due to the fact that the set of real numbers and addition operation form Abelian group, addition of such tables will also form Abelian group. This enables one to add vectors.

The last stage of defining the vector space consists in finding the function-relating field of numbers with Abelian group of vectors. In the case under consideration, this is a product of real number and vector table. Multiplication consists in multiplying all the elements from the table by the real number. Multiplication must satisfy certain axioms that have been described at the beginning of this chapter. It can be easily shown that the product defined in such a way meets axioms mentioned. Elements of the field can be called scalars within the frame of vector

[10]A. Mostowski: *Mathematical logic.* [In Polish] Seminarium Matematyczne. Uniwersytet Wrocawski, Wrocław 1948, p. 230.

[11]Description of measurement scale can be found, e.g. in J. Jaworski: *Mathematical foundations of metrology.* [In Polish] WNT, Warszawa 1979, pp. 18–45.

space. The function defined, i.e. product of real number and vector, allows the expansion or shrinkage of the vector.

Data filling the vector-table must be properly arranged and linked in a specific way. Therefore, it admits a few possible ways of object representation with the use of the following vectors:

1. Vectors representing geographic location – define geographic location of economic objects;
2. Vectors representing parameters of economic objects – consist of different kinds of parameters describing economic objects such as profit, income, debt, etc; each number in the table of vector is a separate feature of this object and these features often have different measurement units (e.g. profit and population);
3. Vectors representing time series – each number in vector table represents separate point in time but all refer to the same feature of a given object.

The only possibility offered by vector space is the addition of vectors and their elongation as a result of multiplication by scalar. This limits the definition of methods in vector space and hence scalar product is often defined. Scalar product is a function evaluating the value of scalar on the basis of two vectors. Needless to say, this function must meet certain axioms. For a previously defined vector, the scalar product can be defined as follows[12]:

$$(\vec{A}, \vec{B}) = \sum_{k=1}^{n} a_k b_k, \tag{3.17}$$

where:

$\vec{A}, \vec{B}$ – vectors,
a_k, b_k – numbers describing the vectors,
n – number of space dimensions (that equal the number of variables),
$(\vec{A}, \vec{B})$ – scalar product of vectors $\vec{A}$, and $\vec{B}$,

Introducing scalar product into vector space result in the creation of prehilbertian space. Scalar product allows to compare directions of vectors, determine their linear independence and coefficient of vector projection onto another vector or group of vectors. When one has a group of linearly independent vectors and projects any vector onto this group, he/she can receive a set of coefficients that are the coordinates of that vector relative to vectors in this group, and the vectors in the group form a coordinate system. Thus, it is possible to talk about coordinates only in prehilbertian space.

Vectors representing geographical location (once the absolute value of vector has been defined) indicates the physical position of economic objects and other objects in the space. One should only define a point of reference. In general, it is

[12] A.I. Kostrikin: *Introduction to Algebra. Linear Algebra.* [In Polish] Wyd. Naukowe PWN, Warszawa 2004, p. 96.

position in 2D space that is vital in this case. In practice, the main problem is the curvature of the Earth surface, which results in the fact that parallel lines, proportionality of areas, distances and directions are not maintained. This fact stems from deformations of elements transformed from the sphere onto a plane. To compensate the influence of curvature, one must use curvilinear space. In practice, errors caused by incorrect calculation of distance are not significant. What is more, calculations become more and more complex and hence the Earth curvature can be omitted in justified cases.

Vectors representing economic parameters allow to make comparisons (with the use of geometrical methods) among objects described by values that do not have any geometrical meaning themselves. For the sake of making valid comparison between objects, it is necessary to scale their coordinates in measurement units which are not mutually related. In order to make analysis of data represented as vectors, data must be expressed in the same units. The manner in which this operation is carried out will influence the results of calculations. This is due to the fact that, as a consequence of this operation, one changes the ratios of values of vector's coordinates and thus its direction and absolute value.

In statistics, the operation involving the unification of units of axes is called standardization.[13] In order to compare economic objects, which is aimed at grouping or clustering them or establishing their membership of a particular group, classical standardization is used as a rule[14] (see formulas (2.3), (2.4) and (2.5)).

As a result, values of coordinates of all vectors for a particular dimension will have zero mean value and standard deviation will equal one.[15] Mean value is not taken into consideration because it does not diversify the objects clustered and thus does not allow to divide them into groups. Fluctuations of individual coordinates' differences are scaled in such a way so that their standard deviation equals one and magnitudes of fluctuations are more or less similar (Fig. 3.5).

Another way of the standardization of variables is their unitarization[16]:

$$z_{ik} = \frac{x_{ik} - \bar{x}_k}{\max\limits_j x_{jk} - \min\limits_j x_{jk}} \tag{3.18}$$

or zero unitarization[17]:

[13] K. Kuku-a: *Zero Unitarization Method.* [In Polish] Wyd. Naukowe PWN, Warszawa 2000, p. 60.

[14] Application of Quantitative Methods in Real Estate Management. Analyses, Assessments and Forecasts) Ed. J. Hozer. Wyd. Naukowe Uniwersytetu Szczecińskiego, Szczecin 2005, p. 105.

[15] A. Snarska: *Statistics, Econometrics, Forecasting. Exercise in Excel.* [In Polish] Wyd. Placet, Warszawa 2005, p. 69.

[16] K. Kuku-a: *op.cit.*, p. 79.

[17] M. Lasek: *Data Mining. Application in Analyses and Appraisal of Bank Customers)* Oficyna Wydawnicza "Zarządzanie i Finanse" Sp. z o.o., Warszawa 2002, p. 130.

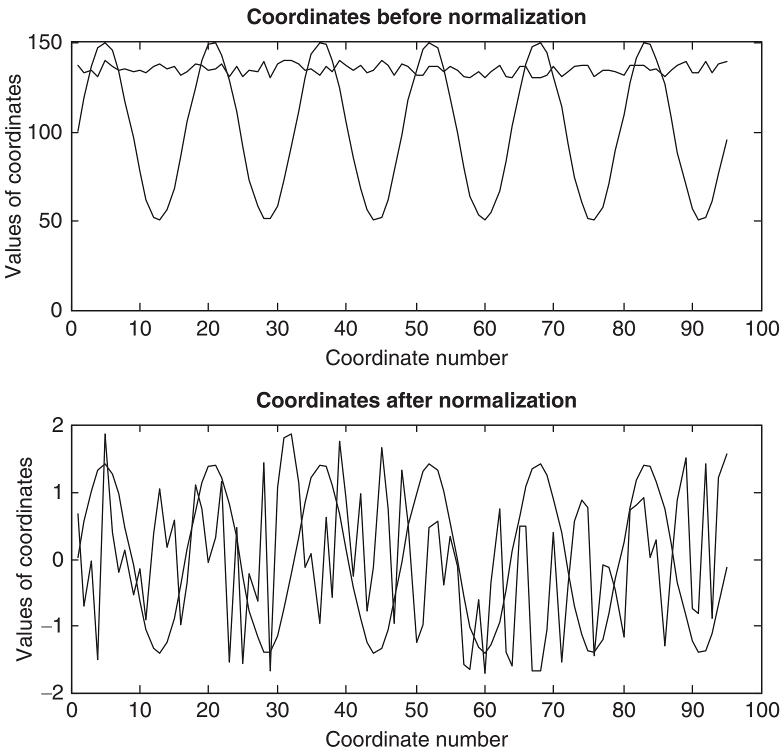

Fig. 3.5. Variable normalization
Source: own elaboration

$$z_{ik} = \frac{x_{ik} - \min_j x_{jk}}{\max_j x_{jk} - \min_j x_{jk}} \tag{3.19}$$

It is not always desired to reduce standard deviations to one level. Very small value of standard deviation (compared to mean value) can indicate that a particular coordinate is hardly relevant and it is necessary to eliminate it. In such a situation, one can define the measure of variability level[18]:

$$v_k = \frac{s_k}{\bar{x}_k}. \tag{3.20}$$

[18] E. Nowak: *Outline of Econometric Methods.* [In Polish] Wyd. Naukowe PWN, Warszawa 2002, p. 12.

If this measure is lower than pre-set coefficient, for example equals 0.1, one should eliminate this coordinate.[19]

Calculated weights of coordinates are taken into consideration while calculating the distance measures.[20] For unitary space, distance measure is defined on the basis of scalar product and therefore weights should be included in scalar product itself. For this purpose, one can use the definition of scalar product in Riemann space[21]:

$$(\vec{A},\vec{B}) = \sum_{i=1}^{n} \sum_{j=1}^{n} g_{ij} a_i b_j \tag{3.21}$$

where g_{ij} – metric tensor.

Weights for particular coordinates are located in the main diagonal of a tensor $g_{i,j}$.

3.2. Taxonomic Vector Measure of Regional Development

3.2.1. Interpretation of Data in Space

Right interpretation of data presented in every space is of profound importance. In space with distance measure, the only factor differentiating the objects is distance. The fact that the distance between two objects equals zero can indicate they can be identical but not necessarily. There are spaces in which it is possible to determine the line of zero distance along which distance between all objects equals zero. Only in metric spaces zero distance means that two objects, the distance between which equals 0, have identical features. Even in metric spaces, the metric indicates only the degree to which objects are similar but not the things that make them different. It is a well-known fact that there is a distance x between two objects but apart from the degree of similarity, it does not tell more. This difference can result from their size, i.e. from the fact that one is a copy of the other but in different scale, or from the fact that ratios of coordinates are not equal.

Relations between certain distance measures and arrangement of points in space can be counter–intuitive. This problem is shown in Fig. 3.6. For instance, when one uses polar measure, some points look apparently closer to each other than indicated by distance measure. Having analyzed Fig. 3.6a, it can be stated that the shortest way from point P_1 to P_3 is via point P_4 and that point P_1 is located closer to point P_3

[19] W. Tarczyński: *Fundamental Portfolio of Securities.* [In Polish] PWE, Warszawa 2002, p. 100.

[20] *Methods of Statistical Multidimensional Analysis n Marketing Research.* [In Polish] Ed. E. Gatnar, M. Walesiak. Wyd. Akademii Ekonomicznej we Wrocławiu. Wrocław 2004, p. 41.

[21] E. Karaśkiewicz: *Outline of Theory of Vectors and Tensors.* [In Polish] PWN, Warszawa 1976, p. 453.

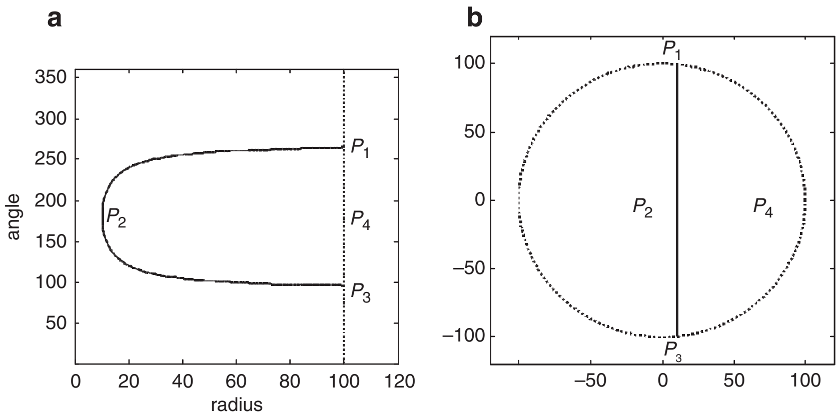

Fig. 3.6. Points in space with distance measure: (**a**) polar; (**b**) Euclidean
Source: own elaboration

than P_2. Distance measure indicates something quite different. The shortest way from P_1 to P_3 runs through P_2 and point P_2 is located in the middle of the distance between P_1 and P_3. This fact can be justified while making transformation from space with polar distance into space with Euclidean distance (Fig. 3.6b).

Using a given distance measure, one should known the specificity of space with which it is connected and data should be selected in such a way so that its character is in accordance with properties of the space. In the example discussed, data representing one of coordinates should be expressed in angular measure, otherwise the result is meaningless. If this specificity is not taken into account, one can receive results that do not correspond to reality at all. One should be particularly careful while using measures that are not metrics. He/she should remember that even the Euclidean distance between two points in n-dimensional space, say $P_1(z_{11}, z_{12}, \ldots, z_{1n}), P_2(z_{21}, z_{22}, \ldots, z_{2n})$, given by the following formula:

$$d(P_1, P_2) = \sqrt{\sum_{k=1}^{n} (z_{1k} - z_{2k})^2} \tag{3.22}$$

is a metric only if certain assumptions are made. A simple example can illustrate problems connected with this metric. Let's assume that there is a certain distance to cross. It is one unit long. It can be crossed in certain time which determines the speed. On this basis, one can define a 2D space in which one axis is the time and the other one – the distance travelled (Fig. 3.7a). Lines in this space determine the distance travelled by objects within a certain amount of time. Vertical line denotes body at rest, i.e. the one that travelled no distance despite the passage of time. The smaller the angle between line describing the body and axis of the road is, the greater the speed of a body is. Looking at the graph, it may seem that the speed will be infinite for horizontal line.

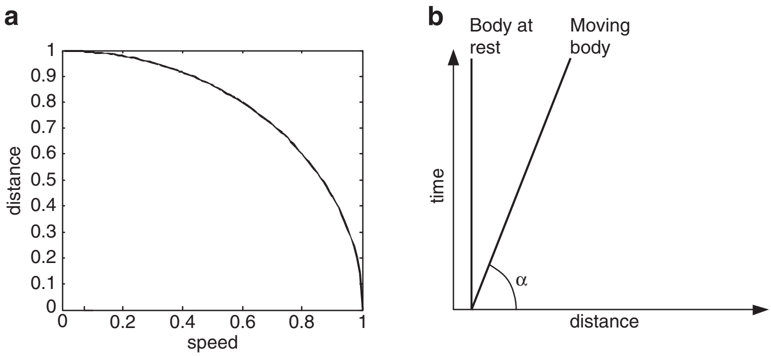

Fig. 3.7. Properties of Euclidean distance measure: (**a**) dependence of distance between points on speed; (**b**) determination of movement in Euclidean space
Source: own elaboration

Now, let's change the slope of a line. For a given segment of distance, one reads the time and then on the basis of Euclidean measure of distance, he/she reads the distance. It turns out that the distance decreases with increase in speed (Fig. 3.7b), i.e. space begins to shrink up to the moment when it shrinks to a point. Hence, there is a speed in the case of which it is insignificant if we are travelling from Warsaw to London or to the Moon as the distance is the same everywhere and equals zero. Physicists have established that this speed equals 299, 792, 458 ms^{-1} One unit of speed in Fig. 3.7b corresponds to this speed and one unit of distance is 299, 792, 458 m.[22]

Behaviour of space described results from the fact that only one axiom of metric space has not been satisfied, which prevents a part of space from shrinking to a point. Of course, the more axioms are not met, the more complex the behaviour of space is. Improper use of metric space (not dealing with its character) can bring about false results of comparison.

In vector space, directions are determined but without additional assumptions there is no definite location. If objects are represented by vectors, change in object's size leads to the elongation of vector and change in direction – to change in vector's coordinates ratios (Fig. 3.8). The less similar the objects, the more different their directions. Change in the absolute value of vector indicates only a difference in the scale of objects.

Such a simple interpretation is possible only in the case of standardization with zero unitarization. This standardisation reduces all coordinates of objects to the range from zero to one. This means that all vectors have certain allowable range of directions and absolute values. If the origins of all vectors are reduced to one point, forming the origin of the coordinate system, their ends will be within hypercube whose side's length equals one (Fig. 3.9a).

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[22]To find more, consult the following source: A. Einstein: *About Special and General Theory of Relativity*. [In Polish] Książnica Polska Towarzystwa Nauczycieli Szkół Wyższych, Lwów 1922.

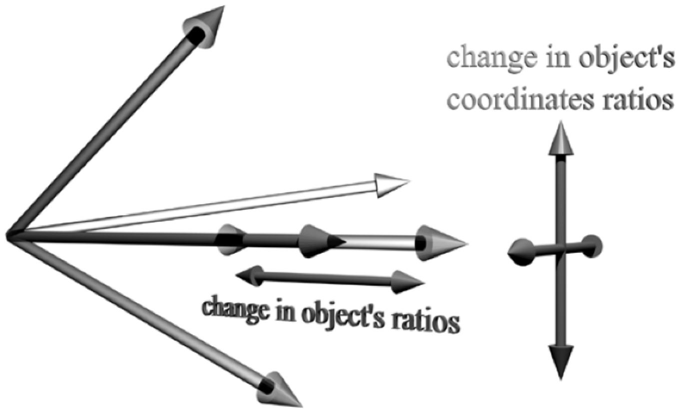

Fig. 3.8. Factors diversifying the vectors
Source: own elaboration

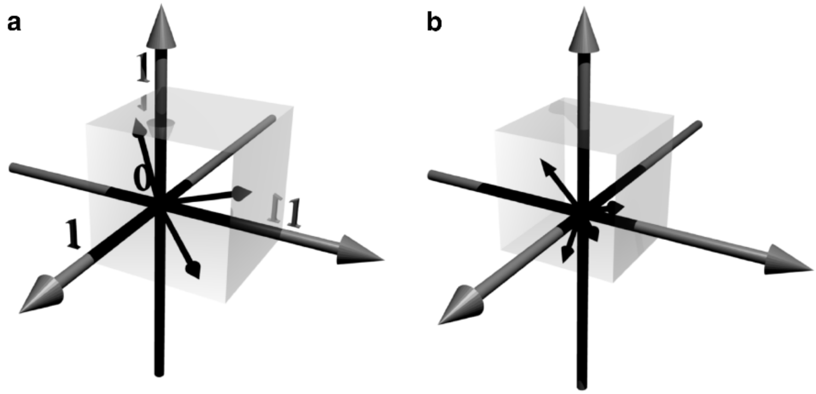

Fig. 3.9. Vectors after standardization: (**a**) zero unitarization; (**b**) unitarization
Source: own elaboration

Zero unitarization does not eliminate mean value. Mean value is not a factor diversifying the objects and is not vital for comparing them. For each coordinate of all objects, one can calculate the mean value and eliminate it by subtraction. Unlike zero unitarization, unitarization eliminates mean value. As a result of this operation, only the part diversifying the objects remains. As a consequence, the hypercube containing the ends of all vectors will be shifted in such a way so that the origin of coordinate system will be inside the hypercube (Fig. 3.9b) but not necessarily in its centre. Shift of hypercube depends on values of object's coordinates. Unitarization also brings about the fact that all ends of vectors will be inside the hypercube but directions of vectors can be arbitrary. Zero coordinate along a given axis of coordinate system implies that a given parameter describing the object equals the mean of all corresponding parameters of other objects. Any deviation from zero is tantamount to deviation from mean value, which changes the interpretation of the absolute value of vector. Absolute value of vector indicates deviation of object from "mean" object. Thus, the longer the vector, the more atypical it is. Just as previously, scale of objects changes with the elongation or shrinkage of vectors but in some cases it is very difficult to determine if the scale is increasing or decreasing with increase in absolute values.

Unitarization reduces the range of coordinates to the interval whose width equals one but standard deviation can be different. Unlike unitarization, classical standardization reduces coordinates of vector to the form in which their standard deviation always equals one but the variability range is different.

3.2.2. Vector Component Along Another Vector

Component c of vector $\vec{A}$ along the vector $\vec{B}$ can be calculated by means of the following formula[23]:

$$c = \frac{(\vec{A}, \vec{B})}{(\vec{B}, \vec{B})}. \tag{3.23}$$

Coefficient c is also called the coefficient of vector $\vec{A}$ projection onto vector $\vec{B}$. It is a measure of vector $\vec{A}$ along vector $\vec{B}$ and shows how many vectors $\vec{B}$ are contained in vector $\vec{A}$ along direction determined by vector $\vec{B}$ (Fig. 3.10a). Hence, it is the coordinate of vector $\vec{A}$ along vector $\vec{B}$. Value of coordinate depends on the absolute values of both vectors and angle between them.

As the coefficient of component of vector $\vec{A}$ along vector $\vec{B}$ does not have to equal the component of vector $\vec{B}$ along vector $\vec{A}$, i.e. this operation is not commutative, direct comparison between two vectors with the aid of projection is not very effective. However, this operation can be used indirectly for comparing two vectors (Fig. 3.10b). Both vectors are projected onto third vector and two components are obtained. The more similar the coefficients, the more similar the objects. One should remember that the selection of vector onto which projection is made has a profound influence on the result of comparison. If one draws a hyperplane perpendicular to arbitrary point lying on the line determined by the vector (onto which projection is made) all vectors with origin located in this point on the line, and ends on this hyperplane, will have the same coefficient of projection (Fig. 3.11). Consequently, coordinates that have the greatest influence on the direction of vector (onto which projection is made) will also have the greatest influence on comparison coefficients.

[23] M. Borawski: *op.cit.*, p. 47.

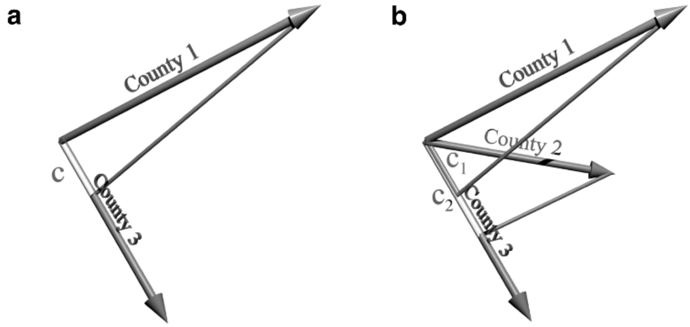

Fig. 3.10. Component of one vector along another vector: (**a**) component; (**b**) component of vector as a coefficient of comparison between two vectors
Source: own elaboration

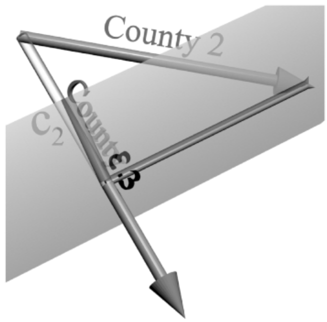

Fig. 3.11. Hyperplane containing the ends of vectors with the same coefficient of projection
Source: own elaboration

Vector onto which projection is made should be a vector representing the standard object, i.e. regarded as the best, and to which one would like to "improve" the objects compared, or the worst from which one should "move away". Selection of this object can be made on the basis of knowledge gained by experts or other method, e.g. taxonomic method discussed in Sect. 2.2.

If the standard object is chosen as the one that has maximal values among variables that are the stimulants and minimal among variables that are destimulants, the projection coefficient will never be greater than one for objects participating in the creation of the standard. Objects that have not participated in construing the standard can sometimes have values slightly higher than one, which means that they are "better" than the standard. Lower range of this coefficient value depends on the method of standardization selected. In the case of zero unitarization, its minimal value equals zero. Hence, the coefficient of the worst developed objects is close to zero. In the case of unitarization and classical standardization used for the creation of taxonomic synthetic development measure, negative values of coefficient may occur as well. Zero point is a point of average objects. Well-developed objects have values of coefficient close to one, partially developed objects – around -1, and at the same time the minimal value can be slightly higher or lower than -1.

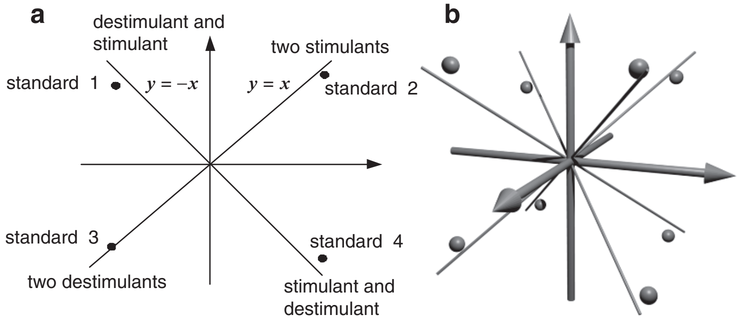

Fig. 3.12. Position of all possible standards: (**a**) in 2D space; (**b**) in 3D space
Source: own elaboration

Standard in vector synthetic measure[24] must have positive coordinates for stimulants and negative for destimulants. While determining the standard on the basis of maximal values among variables that are stimulants and minimal values for variables that are destimulants, this assumption is always satisfied if one uses classical standardization. In other methods for selecting the standard, this condition is not always met. In such a situation, it is enough to change the sign to the opposite for the coordinate of the standard that corresponds to variable not satisfying this condition.

The way in which the standard is created leads to the fact that if a great number of objects are analyzed, it is very probable that the position of the standard in space is close to one of lines with the points whose coordinates are equal as to absolute value (Fig. 3.12). Number of lines n_l depends on the dimension of space and, for n-dimensional space, it equals:

$$n_l = 2^{n-1}. \tag{3.24}$$

For any distance measure, one can determine the hypersurface with equal distance. Points lying on these surfaces have equal distance to a certain selected point in the space. In the case of distance measure used for the construction of synthetic taxonomic measure, this hypersurface has a shape of hypersphere (Fig. 3.13a) with a centre in this point. If coefficient of projection is used instead of Euclidean measure, one will create a hyperplane perpendicular to line connecting object-standard with the origin of the coordinate system (Fig. 3.13b).

Nominant cannot be used when synthetic taxonomic measure is calculated on the basis of Euclidean distance, which has been shown in Fig. 3.14a. From a theoretical point of view, the value of nominant should not participate in comparison, which means that distance measure should always be the same regardless of the value of

[24] K. Nermend: *Regions Grouping with Similarity Measure Based on Vector Calculus*. "Polish Journal of Environmental Studies" 2007, Vol. 16, No 5B, pp. 132–136.

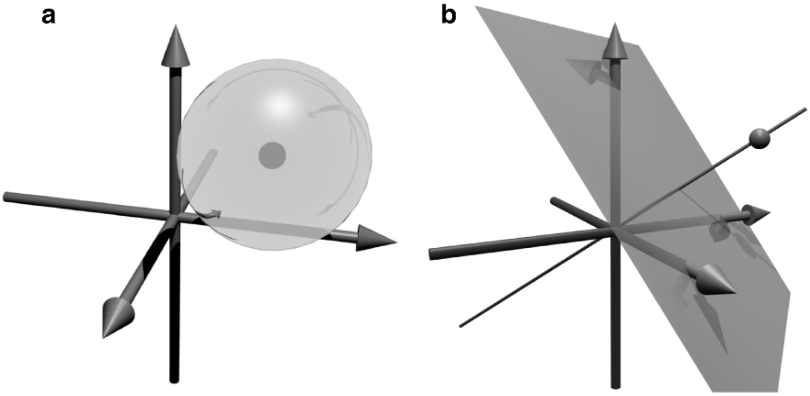

Fig. 3.13. Hyperplane with equal values of comparison coefficients for: (**a**) Euclidean distance measure; (**b**) measure using projection
Source: own elaboration

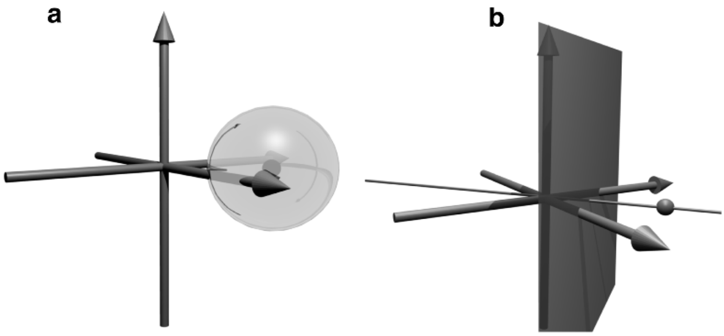

Fig. 3.14. Hyperplane with equal values of comparison coefficients with one axis being a nominant: (**a**) Euclidean measure; (**b**) measure using projection
Source: own elaboration

nominant. However, the Euclidean distance takes this value into account. Quite a different situation is observed in the case of projection- based measure. Hyperplane with equal values of comparison coefficients is always perpendicular to the line connecting the standard with the origin of coordinate system, which indicates that it is parallel to the axis of nominant. Thus, nominant has no influence on the value of comparison coefficient (Fig. 3.14b).

Hyperplane with equal values of comparison coefficient can be described with the use of the following formula:

$$a_1x_1 + a_2x_2 + \cdots + a_nx_n + b = 0 \tag{3.25}$$

A very important property of hyperplane follows from this formula. Change in the value of one coefficient must result in a linear change in values of other coefficients compensating for this change. Let's assume that there is an object lying on the line connecting the standard with the origin of coordinate system in 2D space. If the object is moved away from this line in such a way so that the value of comparison coefficient shall remain unchanged, i.e. along the line perpendicular to this line, two situations can be observed. In the first situation, one of coordinates increases and the other one must decrease correspondingly, and the other way round. Because the line connecting the standard with the origin of coordinate system as a rule runs at an angle of about 45°, changing one coordinate by one unit must bring about a one-unit change compensating for the second coordinate as well. Compensation principle is also valid for a greater number of dimensions but then changing one coordinate by one unit will cause change in other coordinates in such a way so that the sum of changes in other coordinates equals one unit.

Compensation principle matches the expectations. For objects with similar state of development, one expects that if there is a worse value of one parameter, it will be compensated for by better values of the remaining parameters. Euclidean measure does not satisfy this principle, which is shown in Fig. 3.15. Objects with similar level of development lying on the line connecting the standard with the origin of coordinate frame are marked with grey colour. It can be noticed that Euclidean distance gives worse results here. Departure from projection is the greater, the bigger the distance from the standard. Taking the fact that projection

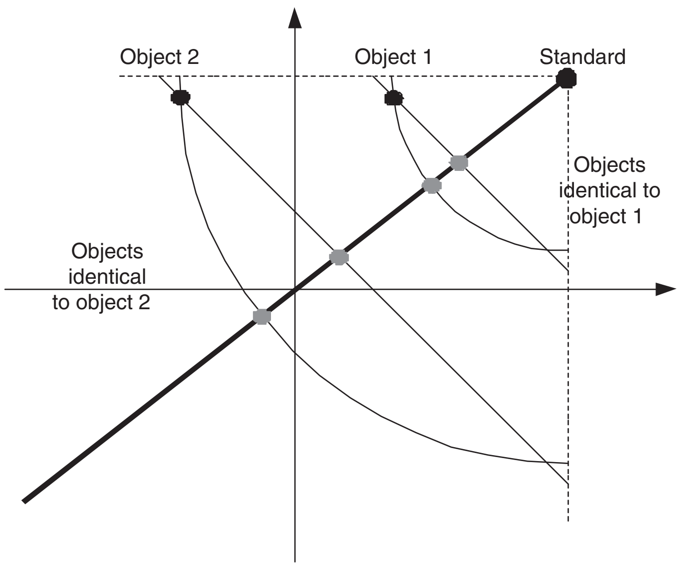

Fig. 3.15. Comparison between Euclidean measure and projection coefficient
Source: own elaboration

is in accordance with compensation principle into account, one can expect that it should provide values closer to reality.

Euclidean measure has one more disadvantage. Nevertheless, as only one octant of hypersphere is taken into consideration, this drawback has no influence on comparison results. However, if synthetic measure of development is calculated for object that has not participated in the creation of the standard, this property could produce false result. Let's assume that there is a situation in which there is an object with parameters much better than the standard. Then, synthetic taxonomic measure shall determine this object as less developed than the standard and its measure will be the worse, the better than the standard this object is (Fig. 3.16). Application of projection will eliminate this flaw, i.e. if there is an object better than the standard, synthetic measure for this object will have value higher than one. Such a situation can take place when investigation is carried out in base year and with reference to consecutive years. Using Euclidean distance, one should create a new standard for a new year but then the results for consecutive years could not be compared, or create one standard for both years under investigation. If investigation is conducted periodically, new standard would have to be created every time. In the case of projection, there is no need for creating a new standard, and standard from a previous year can be used in the current year. In the case of objects whose situation has improved substantially, it is possible to get results higher than one.

While calculating the development measure in a standard way, all stimulants and destimulants have identical influence on the measure. However, their influence on measure depends on angle between a hyperplane (with equal values of

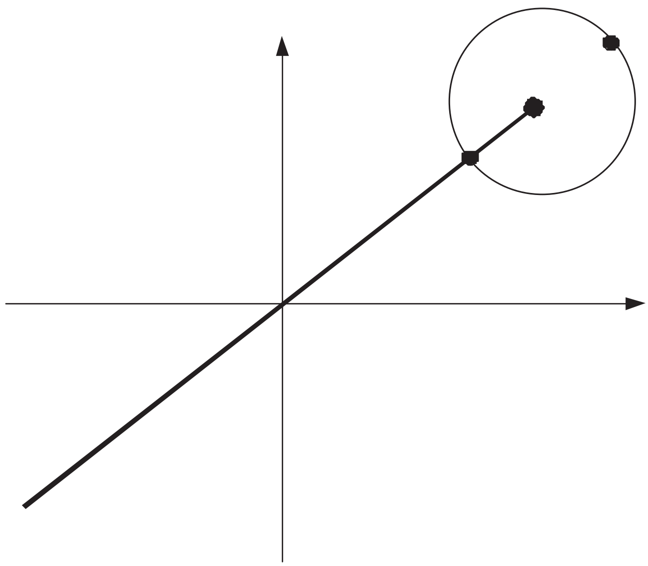

Fig. 3.16. Objects with parameters better than the standard and worse than the standard with the same comparison coefficient
Source: own elaboration

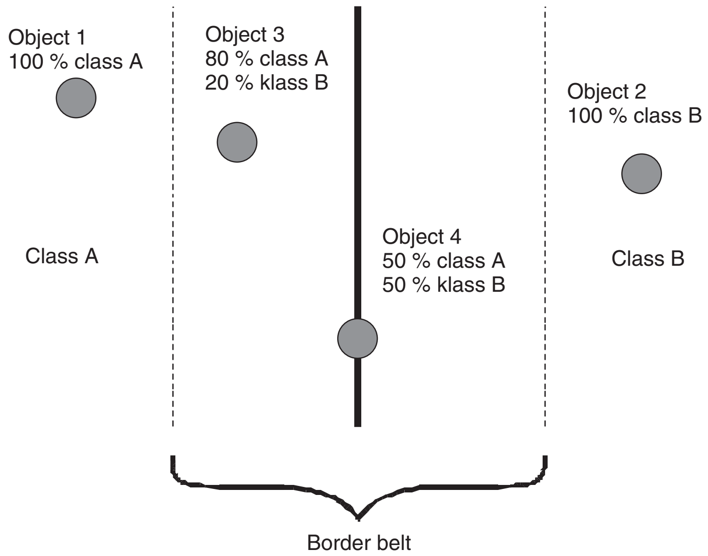

Fig. 3.17. Objects lying on the border of two classes
Source: own elaboration

comparison coefficients) and axis of stimulant (destimulant) This can be observed in Fig. 3.14 in which this angle is zero for nominant and hence it has no influence on development measure. Consequently, the smaller the angle, the slighter the influence of a given coordinate. Conventionally, if there are no dominants, the angle between all axes is about 45°. Nonetheless, it can be changed by multiplying the result obtained during standardization by weight coefficient with value from zero to one. In connection to the above, formula for classical standardization is as follows:

$$z_{ik} = wg_k \frac{x_{ik} - \overline{x}_k}{s_k}, \tag{3.26}$$

where wg_k ϵ(0; 1) – weight coefficient.

In practice, it is possible to assign weights higher than zero and lower or equal one to stimulants and destimulants. At the same time, the more important the stimulants and destimulants, the higher the values assigned to them. Hence, the angles between axes and the line connecting the standard with the origin of coordinate frame will change and consequently, participation of different coordinates in calculating the development measure will differ. This operation will have no influence on the range of development measure calculated.

Object lying on the border of two classes often poses major problems to the classification of objects based on taxonomic measures. Object no. 4 in Fig. 3.17 can be quoted as an example here. In principle, it is not known to which class it should be assigned. In practice, such obstacles can concern all the objects lying within a certain border belt. For such objects, one cannot precisely determine their membership of a given class, which results from inaccurate estimation of objects' coordinates. It is not always possible to determine the exact number of, e.g. the unemployed as many persons work illegally or are not registered. Inaccurate estimation leads to the fact that objects lying on the border can in fact have slightly different position and thus belong to a different class.

If a certain width of the border belt is adopted, it is plausible to determine the degree of certitude of objects' membership of particular classes. To do so, one should determine the border of classes. In the case of synthetic measures, mean value and standard deviation are used for reaching this aim. Borders can be determined by means of the following formulas:

$$\begin{aligned} gr_{12} &= \overline{m} + s_m, \\ gr_{23} &= \overline{m}, \\ gr_{34} &= \overline{m} - s_m, \end{aligned} \tag{3.27}$$

where:

s_m – standard deviation of synthetic measure,

$\overline{m}$ – mean value of synthetic measure,

$gr_{i12}, gr_{23}, gr_{34}$ – values representing the borders of the first and the second classes, the second and the third classes, as well as the third and the fourth classes.

For each object, one can calculate distance to borders:

$$\underset{i}{odl}_{jk} = |gr_{jk} - m_i|, \tag{3.28}$$

where:

m_i – synthetic measure of development for *i*-th object,

$\underset{i}{odl}_{jk}$ – distance to border of *j*-th adn *k*-th classes of *i*-th object.

On the basis of this distance, one can determine the relative percentage distance in relation to the width of a class:

$$\underset{i}{odl\_wzgl}_{jk} = \frac{100\, \underset{i}{odl}_{j,k}}{pas\ \overline{szer\_klas}}, \tag{3.29}$$

where:

pas – coefficient controlling the width of border belt,

$\overline{szer\_klas}$ – average width of classes for borders determined with the use of the formula (3.27) equals:

$$\overline{szer\_klas} = s_m . \tag{3.30}$$

Percentage certitude of the membership of a given object of the closest class can be determined by means of the formula:

$$pp_{ij} = \begin{cases} 50 + odl\_wzgl_{ijk} & \text{for } odl\_wzgl_{ijk} \leq 50 \\ 100 & \text{for } odl\_wzgl_{ijk} > 50, \end{cases} \quad (3.31)$$

where pp_{ij} – percentage certitude of the membership of i-th object of j-th class.

The closest border is selected from all borders of classes. Percentage certitude of the membership of a given object of the next class can be determined with the use of the following formula:

$$pp_{ij} = \begin{cases} 50 - odl\_wzgl_{ijk} & \text{for } odl\_wzgl_{ijk} \leq 50 \\ 0 & \text{for } odl\_wzgl_{ijk} > 50. \end{cases} \quad (3.32)$$

Percentage certitude of the membership of a given object of the remaining classes is zero. As a result, coefficient indicating the certitude of membership of a given class is obtained for each object. As a rule, it equals 100 for the closest class and zero in the case of the remaining classes. However, for objects lying within border belt, this coefficient is lower than hundred and determines the certitude of class membership. Sum of all certitudes of class membership always equals hundred. Coefficient *pas* determines a width of border belt expressed in units that are the average of width of classes. When $pas = 1$, width of border belt equals the average width of class. When $pas = 0{,}5$, width of border belt equals half of the average width of class.

3.2.3. Comparison of Vectors in Unitary Space

The simplest method of comparing two vectors $\vec{A}$ and $\vec{B}$ is to determine the absolute value of a vector that is their difference (Fig. 3.18a):

$$roz_{\vec{A}\vec{B}} = \sqrt{(\vec{A} - \vec{B}, \vec{A} - \vec{B})}. \quad (3.33)$$

If formula (3.17) can be adopted as a scalar product, this coefficient can be calculated by means of the following formula:

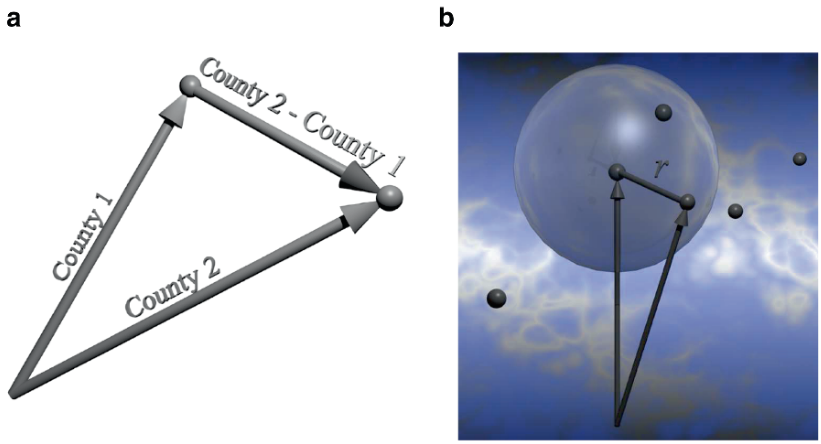

Fig. 3.18 Difference between the absolute values of vectors as a comparison coefficient: (**a**) difference between vectors; (**b**) hypersurface with equal values of comparison coefficients for coefficient *roz*
Source: own elaboration

$$roz_{\vec{A}\vec{B}} = \sqrt{\sum_{i=1}^{n}(a_i - b_i)^2}. \tag{3.34}$$

As it can be noticed, this coefficient is Euclidean distance. Consequently, hypersurface with equal values of coefficients has a shape of hipersphere (Fig. 3.18b).

Instead of a hypersphere, one can also use a projection of unit vector onto the unit vector (Fig. 3.18a):

$$c_{\frac{\vec{A}}{|\vec{A}|}\frac{\vec{B}}{|\vec{B}|}} = \left(\frac{\vec{A}}{|\vec{A}|}, \frac{\vec{B}}{|\vec{B}|}\right) = \frac{(\vec{A}, \vec{B})}{|\vec{A}||\vec{B}|} = \frac{\sum_{i=1}^{n} a_i b_i}{\sqrt{\sum_{i=1}^{n} a_i^2}\sqrt{\sum_{i=1}^{n} b_i^2}}. \tag{3.35}$$

If $\vec{A}$ and $\vec{B}$ are the vectors with subtracted mean value, the coefficient $c_{\frac{\vec{A}}{|\vec{A}|}\frac{\vec{B}}{|\vec{B}|}}$ is Pearson's correlation coefficient. This coefficient does not depend on the absolute values of vectors but on the angle between them. Hence, hypersurface with equal values of comparison coefficients has a shape of hypercone (Fig. 3.19b).

It is also possible to use coefficient combining the features of both coefficients:

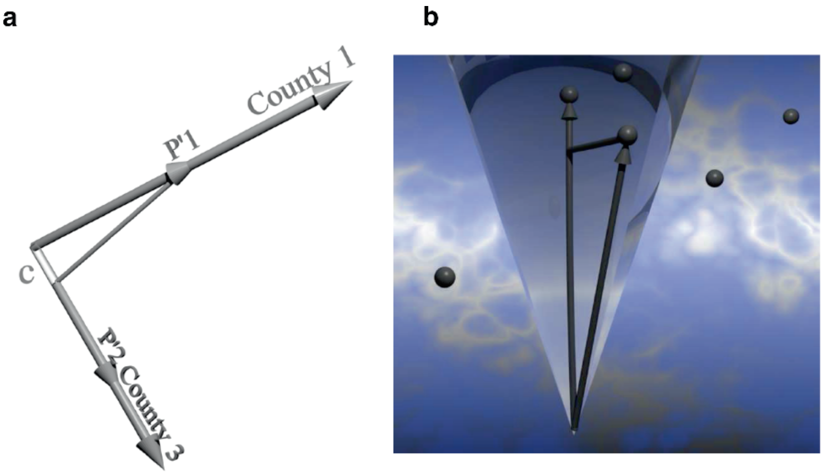

Fig. 3.19. Coefficient$c_{\frac{\vec{A}}{|\vec{A}|}\frac{\vec{B}}{|\vec{B}|}}$: (**a**) interpretation; (**b**) hypersurface with equal value of comparison coefficients
Source: own elaboration

$$cw_{\vec{A}\vec{B}} = \frac{\sum_{i=1}^{n} a_i b_i}{\max\left\{\sum_{i=1}^{n} a_i^2, \sum_{i=1}^{n} b_i^2\right\}}. \tag{3.36}$$

This coefficient behaves like $roz_{\vec{A}\vec{B}}$, to some extent when the difference between absolute values of vectors is small. However, when the difference between absolute values is too considerable, this coefficient has properties of projection (Fig. 3.20).

Let's investigate the similarity of objects to a certain object in 2D space. Let the object be represented by a point in space with coordinates $P(1, 1)$. In 2D space, one can determine curves with equal value of comparison coefficients, instead of hypersurface. Figure 3.21a shows curves with equal value of comparison coefficients$roz_{\vec{A}\vec{B}}$. These lines are circles with a centre in point $P(1, 1)$.

It is sometimes necessary to retrieve objects with similar ratios of co-ordinates (while their values are irrelevant). Comparison between different shops can be cited as an example here. If the comparison takes into account the scale of objects examined, the most suitable comparison coefficient would be$roz_{\vec{A}\vec{B}}$. Due to different scale of objects, small shops in housing estates and big shops, regardless of their profiles, will give very different comparison coefficients. If, however, the profile of a shop is more interesting than the scale (from the perspective of research purposes) coefficient $roz_{\vec{A}\vec{B}}$ is of little use. In this situation, it is much better to use coefficient $c_{\frac{\vec{A}}{|\vec{A}|}\frac{\vec{B}}{|\vec{B}|}}$. It is not sensitive to the scale of objects but to ratios of coordinates (Fig. 3.21b). Curves with equal value of comparison coefficients are straight lines, which indicates that the scale of object is completely unimportant here.

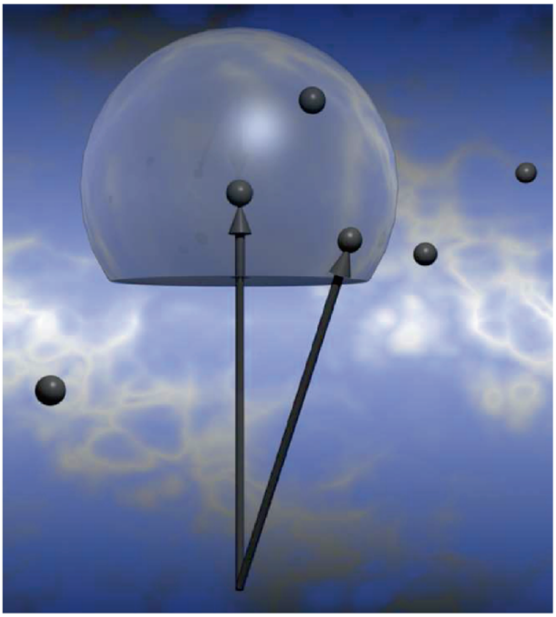

Fig. 3.20. Hypersurface with equal values of comparison coefficients for coefficient $cw_{\vec{A}\vec{B}}$
Source: own elaboration

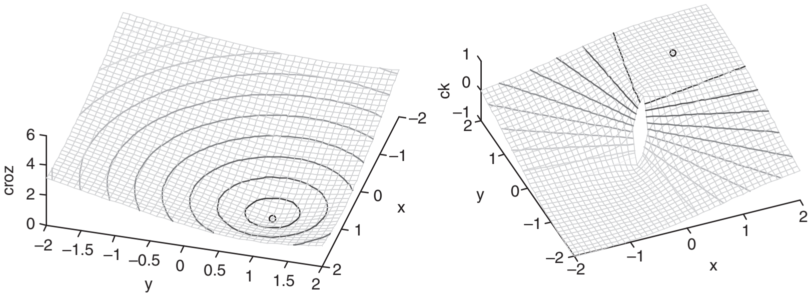

Fig. 3.21. Curves with equal values of comparison coefficients: (a) $roz_{\vec{A}\vec{B}}$; (b) $c_{\frac{\vec{A}}{|\vec{A}|}\frac{\vec{B}}{|\vec{B}|}}$
Source: own elaboration

In the case of certain comparisons, partial dealing with the scale of object is recommended, e.g. when investor investigates the cities with regard to the best location. Generally speaking, the size of city is of no importance but it should not be too small because it will not provide sufficient base or background. In such a situation, one can use coefficient$cw_{\vec{A}\vec{B}}$ (Fig. 3.22). For a small difference in objects' scale, its behaviour resembles coefficient $c_{\frac{\vec{A}}{|\vec{A}|}\frac{\vec{B}}{|\vec{B}|}}$, and for a considerable difference in scale, it will be similar to $roz_{\vec{A}\vec{B}}$.

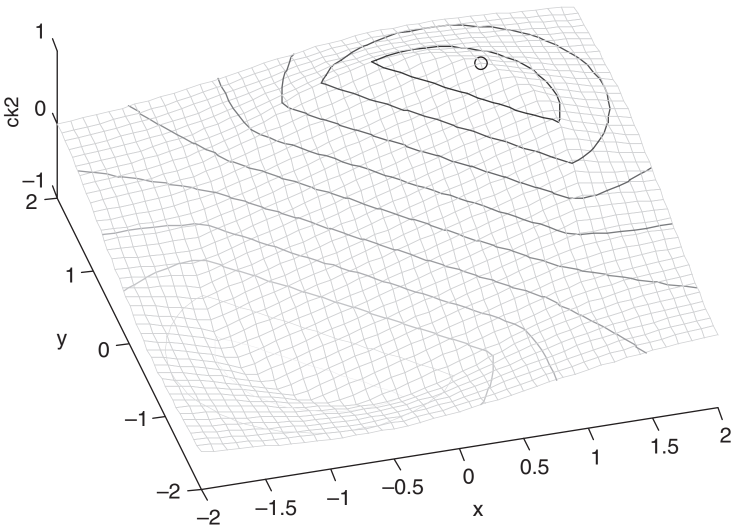

Fig. 3.22. Curves with equal values of comparison coefficient for $cw_{\vec{A}\vec{B}}$
Source: own elaboration

3.3. Visualization of Local Development Measures in 3D Space

In the systems of space information, there are two kinds of geometrical information, namely

- Data in the form of irregular grid,
- Data in the form of regular grid.

Data in the form of irregular grid is, as a rule, obtained from measurement equipment and most often forms a set of point's coordinates in 3D. The height above sea level or the number of households in a region can be quoted as examples of such data. In the case of height measurement, data is accurate for a specific measured point and does not include information about neighbouring points. One can only assume that heights in neighbouring points do not differ from the point measured very much. Data used in economic analyses has a different character. It regards not only the point in question but also certain space around it and thus it is not enough to know only three coordinates. One should know the size and character of this space, i.e. how information obtained is distributed over individual points of this pace.

It is difficult to carry out all operations on data in irregular grids because data has a very irregular character (Fig. 3.23). Hence, data is transformed into a so-called regular grid (Fig. 3.24). Data in regular grid is located in the nods of a grid, i.e. points of intersection of parallel vertical and horizontal lines spaced uniformly. Due to this fact, information about x and y co-ordinates is not needed but only

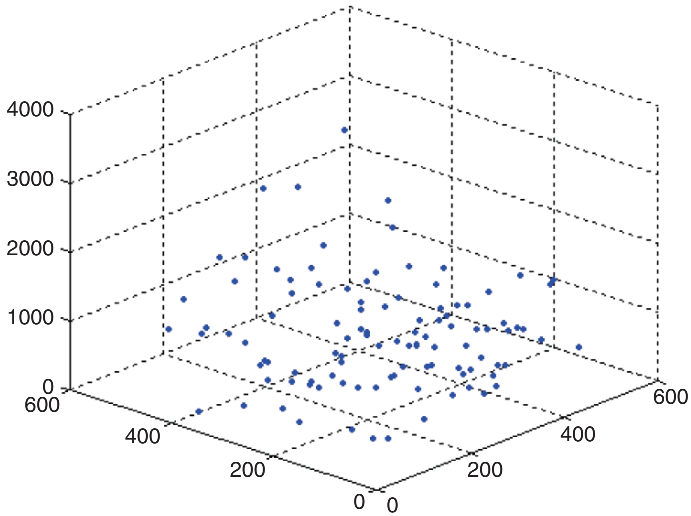

Fig. 3.23. Data in the form of irregular grid
Source: own elaboration

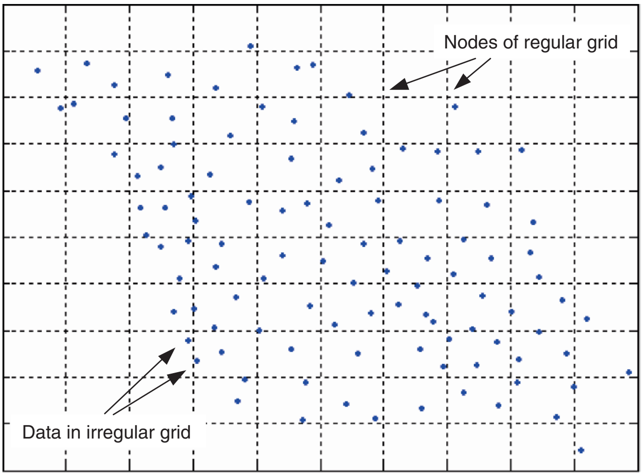

Fig. 3.24. Data in the form of irregular grid plotted on regular grid
Source: own elaboration

information concerning the coordinates of the grid's origin, its orientation, and spacing between consecutive horizontal and vertical lines and value of coordinate reg_k in the nodes. In a computer memory, it is simply the 2D table of data. This form considerably simplifies all kinds of numerical calculations.

As a rule, all kinds of spatial information is given in the form of irregular grid. Transformation into the form of regular grid requires interpolation process in order

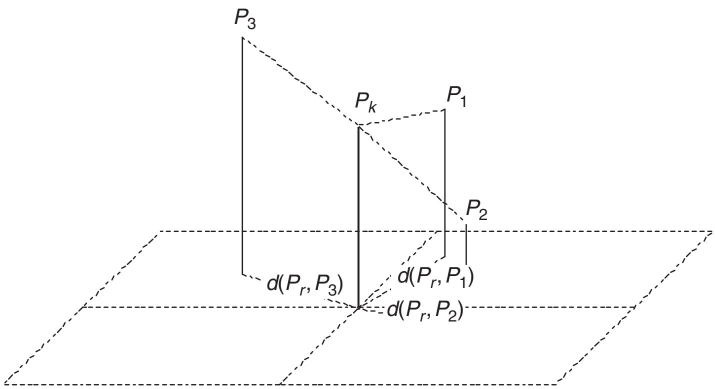

Fig. 3.25. Interpolation with the use of inverse distances method
Source: own elaboration

to determine the value of z coordinate in nodes of a grid. Examples of interpolation methods used in GIS systems are as follows: nearest neighbour method, triangle method, inverse distances and algorithms of global classes.

Building the regular grid for the purpose of economic analyses (due to spatial character of data), it is necessary to use methods based on distances from local centres. They make it easier to relate the distance from the centre to its influence. Method of inverse distances is an example here (Fig. 3.25).

In the method of inverse distances, the point in the node of regular grid is calculated by means of the following formula[25]:

$$reg_k = \frac{\sum_{i=1}^{o} \frac{nreg_i}{d(P_k,P_i)^p}}{\sum_{i=1}^{o} \frac{1}{d(P_k,P_i)^p}}, \tag{3.37}$$

where:

reg_k – value in point P_k of regular grid,
$nreg_i$ – value in point P_i of irregular grid,
p – coefficient of power,
$d(P_k, P_i)$ – distance between point P_k in regular grid and point P_i in irregular grid measured in a plane of the grid,
O – number of points in irreguler grid taken into account in point P_k.

For the purpose of interpolation, one usually selects a few points in irregular grid located closest to interpolated position. The power coefficient p determines the

[25]G. Koukharev: *Digital Image Processing and Analysis.* [In Polish] Wyd. Uczelniane Politechniki Szczecińskiej, Szczecin 1998, p. 150; K. Nermend: *Construction of Regular Grid...* [In Polish] pp. 506–513.

influence of distances on the result of interpolation. The higher this coefficient is, the slightest the influence of points located more distant.

Having been converted to regular grid, data can undergo further processing aimed at spatial analysis. In such a way, one can obtain information about spatial relations among groups of variables (e.g. demographic, infrastructural) under examination.

Summing up this chapter, it can be concluded that theoretical analysis of the properties of projection coefficient has shown that it has two properties which mark it out for the creation of synthetic measures. The fact that projection coefficient admits the existence of elements better than the standard is its main advantage, which may considerably extend the range of applications of synthetic measure. Furthermore, it provides a close relationship between ratios of object's coordinates and value of measure obtained. Data gathered on the basis of measure value can be further used for the creation of regular grid, which allows spatial analysis of data. In order to verify methods presented, the analysis and assessment of regional development (quoting the example of Polish counties) will be made in the next chapter.

Chapter 4
Taxonomic Synthetic Vector Measure in the Assessment of Regional Development: Results of Empirical Research

4.1 Selection of Diagnostic Variables

In order to verify the method based on vector calculus proposed in the present publication, an attempt was made to classify 314 counties with reference to their regional development in the period from 2002 to 2005.[1] Data has been derived from Regional Database of Central Statistical Office of Poland (GUS).[2] The time horizon adopted was determined by the availability of homogenous data for the period. Changes in administrative borders between counties and their status as well as the creation of particular counties and liquidation of other ones made it impossible to adopt a longer period. Investigating a longer period would make it necessary to reduce the number of variables and counties taken into account and still, some counties had not been analyzed because data available were not comprehensive and homogenous. Furthermore, urban counties have not been taken into consideration as data collected for them has a different profile (a certain part of diagnostic variables was not available). The character of these counties is very different from rural counties and hence it is not possible to compare them. As a result, 82 counties were eliminated.

Data used is burdened with a certain degree of unreliability stemming from measuring errors. In order to consider this unreliability, one may use values in a certain range instead of seemingly exact values, which makes it necessary to replace ordinary arithmetic operations with other arithmetic operations, e.g. interval calculus.[3]

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[1]Counties had been adopted as a subject matter of the research as there was no comprehensive and homogenous data available for communes for the time horizon under examination. On the other hand, the number of voivodships is too small to verify the method suggested thoroughly.

[2]To find more information about Regional Database see: chapter 1, section 1.2 of the present publication.

[3]To find more about intervallic calculus consult the following sources: R.E. Moore: *Interval Analysis*. Prentice-Hall, Englewood Cliffs, New Jersey 1966.

K. Nermend (ed.), *Vector Calculus in Regional Development Analysis*, Contributions to Economics,
DOI: 10.1007/978-3-7908-2179-6_4,

Nevertheless, it is not plausible with all the methods. Employing particular methods or groups of methods very often depends on meeting certain conditions. Having replaced traditional arithmetic with interval arithmetic, one must find out if all the conditions have been met. It is difficult to use interval arithmetic as a set of ranges with addition and multiplication operations is not a field. It is not possible to construe a vector space above a set of ranges. Because a component of vector is used for creating vector synthetic measure, it is not plausible to store unreliable information as ranges. Therefore, it is necessary to seek for other numerical sets describing unreliable information that (together with addition and multiplication) represent a field. Average-variance representation is an example of such a numerical set.[4] Data provided in the present publication has been derived from a widely available statistical yearbooks. It was assumed that data was reliable and represented expected values. In other cases, when data has been derived from unreliable sources or collected randomly, one ought to use average-variance representation on the account of using vector calculus for the creation of synthetic measure.

Initially, 42 variables (divided into four groups) were selected for the analysis of regional development of counties. The variables, arranged by weights calculated on the basis of variability coefficient, have been presented below.

Infrastructural and technical variables form the first group. The following variables were selected for the analysis:

- Length of working sewage system for every 100 km,
- Length of working water supply system for every 100 km,
- improved county hard surface roads for every 100 km^2,
- county hard surface roads for every 100 km^2,
- average floor surface of a flat per one occupant,
- number of flats per capita.

Demographic variables represent another group, namely

- Birth rate for every 1,000 of population,
- Population density,
- Difference between the number of women and men determined with the use of the following formula: $\frac{\inf antmortalityrate}{birthrate}[100]$,
- Infant mortality,
- Population growth for every 1,000 of total population,
- Population decline for every 1,000 of total population,
- Population of pre-working age for every 100 of population of working age,

[4]Research conducted with the use of this representation has been discussed in: K. Nermend: *Using Average-Variance Representation for Supporting the Classification of Communes*. [In Polish] In: *New...*; K. Nermend, M. Borawski: *Using Average-Variance...*; K. Nermend: *Using Average-Variance Representation in Economic Analyses*. “Polish Journal of Environmental Studies” 2006, Vol. 15, No 4c, pp. 123–126.

- Married couples for every 100 of total population,
- Population of working age for every 100 of population.

Another group of variables (environmental in nature) encompasses:

- Sewage channeled for every 100 firms,
- Emission of gaseous pollutants for every 100 firms,
- Emission of particulate pollutants for every 100 firms,
- Sewage channeled for every 100 inhabitants,
- Population served by sewage treatment plants in per cent,
- Sewage purified in municipal sewage treatment plants to sewage channeled in per cent.

The last group of factors taken into account in the research included the following socio-economic variables:

- Total expenditure on health service for every 1,000 inhabitants,
- Total average monthly gross remuneration,
- County investment income for every 1,000 of population,
- Personal income tax for every 1,000 of population,
- Industrial production sold per capita,
- Total expenditure on public safety and fire safety for every 1,000 of population,
- Per capita personal income,
- Surface area of forests and wooded land to surface area of a county (%),
- Other county income for every 1,000 of population,
- Number of firms in public sector to total of firms (%),
- Total expenditure on education and upbringing for every 1,000 of population,
- Unemployed registered for every 100 of population of working age,
- Special subsidies and grants for every 1,000 of population (in Zlotys),
- Total of working population for every 100 of population of working age,
- Number of firms for every 1,000 of population,
- Total per capita expenditure,
- Total per capita income,
- Surface area of arable land to surface area of a county in per cent,
- Number of working women to total of working population in per cent,
- Number of firms in private sector to total of firms in per cent.

It was assumed that each group had a 25% share. Variability, i.e. a parameter specifying the weight and hence the influence of a feature on taxonomic measure was determined for each variable.

Some variables depend on increase in other variables, which may make them extremely changeable after the standardization. This problem is particularly evident in the case of birth rate. This variable is the most changeable among all variables, thanks to which 18.93% weight has been attached to it (taken variables from other groups into account) and as high as 75.72% weight in the group of demographic variables. As a result, birth rate has a profound influence on the assessment of counties from demographic perspective. This variable is indeed one of components

Table 4.1 Population numbers in counties for which data in the period 2002–2005 was available

Year	Population numbers	Absolute growth compared to the previous year	Percentage growth compared to the previous year
2002	38 088 807	–	–
2003	38 190 608	101,801	0.27
2004	38,173,835	–16,773	–0.04
2005	38,157,055	–16,780	–0.04

Source: own elaboration

Table 4.2 Variability and weights of technical variables

Variable	$\frac{s_k}{\bar{x}_k}$ 100 in the year				Weight of a variable in the group (%)	Weight of a variable (%)
	2002	2003	2004	2005		
Length of working sewage system for every 100km	91.03	89.35	90.79	90.11	38.76	9.69
Length of working water supply system for every 100 km	56.91	55.88	54.76	54.20	23.45	5.86
Improved county hard surface roads for every 100 km^2	30.37	30.00	29.61	29.40	12.61	3.15
County hard surface roads for every 100 km^2	28.87	28.66	28.35	28.27	12.06	3.01
Total average monthly gross remuneration	12.98	13.07	13.35	13.60	5.85	1.46
Average floor surface of a flat per one occupant	7.56	8.68	8.81	8.91	3.90	0.98
Number of flats per capital	6.98	7.29	7.36	7.47	3.36	0.84

Source: own elaboration

of the first derivative after the population numbers. Table 4.1 shows total of population living in counties for which data in the period 2002–2005 was available. It can be noticed that the population numbers have changed slightly yet growth fluctuations are considerable. In the case of real data, for which the ratio of growth to value is very low, fluctuations of growth are very often considerable compared to its mean value. However, in comparison with integral value, its fluctuations are minor. Hence, it is necessary to replace this kind of variables with variables that take the level of basic value into account. Birth rate has been eliminated as a variable, and demographic dynamics will take over its function. The weight of demographic dynamics amounts only to 1.88% (compared to 18.93% in the case of birth rate), which stems from its variability. The same rule was applied while eliminating other variables of this type. Furthermore, some variables were replaced with standardized variables.

Table 4.2 shows the results of the analysis carried out with reference to the variability of infrastructural-technical variables. Weights of variables in the group were determined in accordance with variability criterion and then used in calculations. It is evident that weight of some variables is not considerable at all, which indicates they have a limited influence on the result. Thus, variables left carry the

Table 4.3 Variability and weights of variables from technical group after eliminating slightly changeable variables

Variable	Weight of variable in a group (%)	Weight of variable (%)
Length of working sewage system for every 100 km	44.61	11.15
Length of working water supply system for every 100 km	26.99	6.75
Improved county hard surface roads for every 100 km^2	14.52	3.63
County hard surface roads for every 100 km^2	13.88	3.47

Source: own elaboration

most considerable weight on the assumption that their total weight should amount to c.a. 80–90%. Moreover, it has been assumed that a minimum number of variables in a group amounts to three.

In the end, 22 variables in four groups were left. Taken infrastructural-technical variables into consideration, the following variables were excluded: length of working sewage system for every 100 km, length of working water supply system for every 100 km, improved county hard surface roads for every 100 km^2 and county hard surface roads for every 100 km^2. Population density, infant mortality, regional attractiveness coefficient and demographic dynamics were eliminated from the group of demographic variables. The group of environmental variables was also reduced and the following ones were excluded: sewage channeled to 100 firms, emission of gaseous pollutants for every 100 firms and emission of particulate pollutants for every 100 firms. Finally, several variables were also eliminated from socio-economic group, namely total expenditure on health service for every 1,000 inhabitants, county investment income for every 1,000 of population, personal income tax for every 1,000 of population, industry production sold per capita, total expenditure on public safety and fire safety for every 1,000 of population, per capita personal income, surface area of forests and wooded land to surface area of a county (%), number of firms in public sector to total of firms (%), total expenditure on education and upbringing for every 1,000 of population, and unemployed registered for every 100 of population of working age.

For instance, having excluded slightly changeable variables from infrastructural-technical group, there were four variables left whose total weight amounted to 86.88%, i.e. their influence on the final result amounted to 86.99%. Table 4.3 shows new weights calculated after the elimination of slightly changeable variables.

4.2 Construction of the Standard Object

The research under discussion was conducted with the use of synthetic measure and vector synthetic measure. The following variables have been adopted as destimulants:

- Sewage channeled for every 100 firms,
- Emission of particulate pollutants for every 100 firms,
- Emission of gaseous pollutants for every 100 firms,
- Unemployed registered for every 100 of population of working age,
- Infant mortality.

Figure 4.1 shows the results of the classification of counties based on synthetic measure. Class 1 represents counties with the lowest value of measure whereas class 4 – counties with the highest value. It can be noticed that southern part of Poland as well as areas surrounding Poznań and Warszawa are the best developed territories.

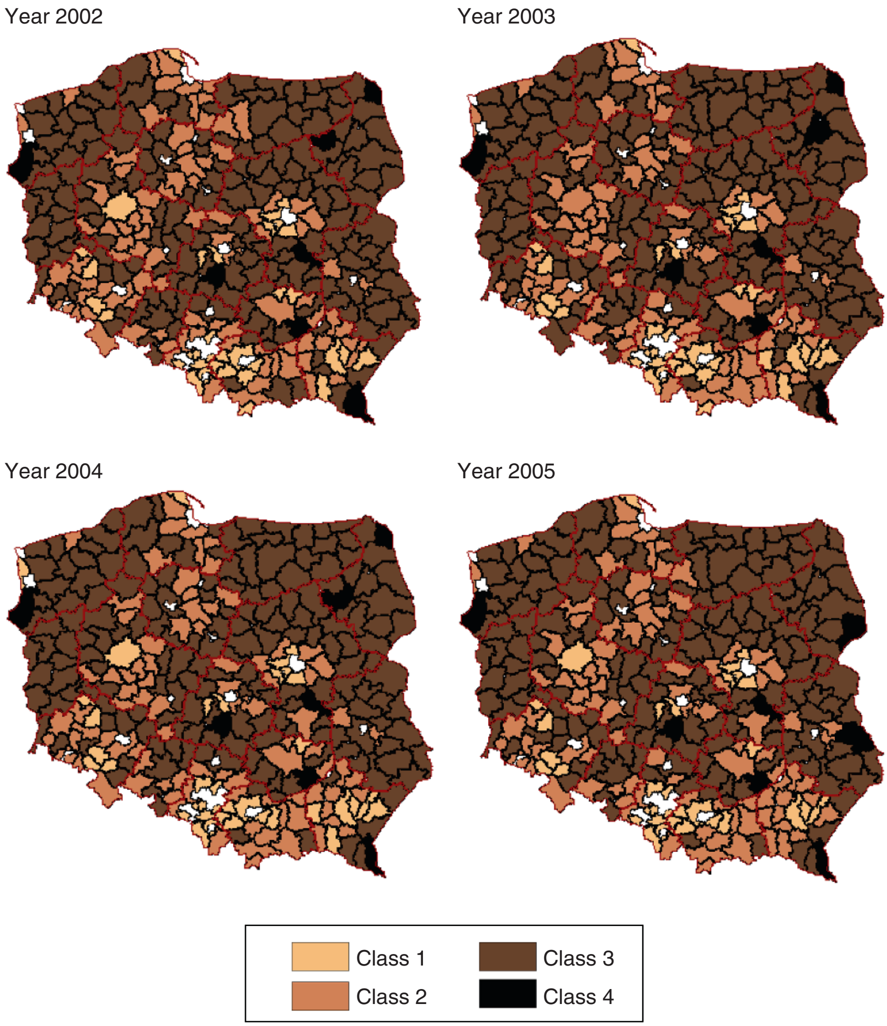

Fig. 4.1 Classification based on synthetic measure
Source: own elaboration

Figure 4.2 shows the results of classification based on vector synthetic measure. The results are similar to the aforementioned case yet a greater number of weak counties in eastern Poland can be observed here.

On the basis of Figs. 4.1 and 4.2, it may be stated that county of Bełchatów was classified in quite a different manner. According to synthetic measure, it was classified into the weakest class (i.e. class 1) while in the case of vector synthetic measure, it was classified into class 3. Table 4.4 shows the position of county of Bełchatów taken particular years into account.

County of Bełchatów is special as two large industry plants are located there, namely Bełchatów Brown Coal Mine employing 8,210 workers and Bełchatów

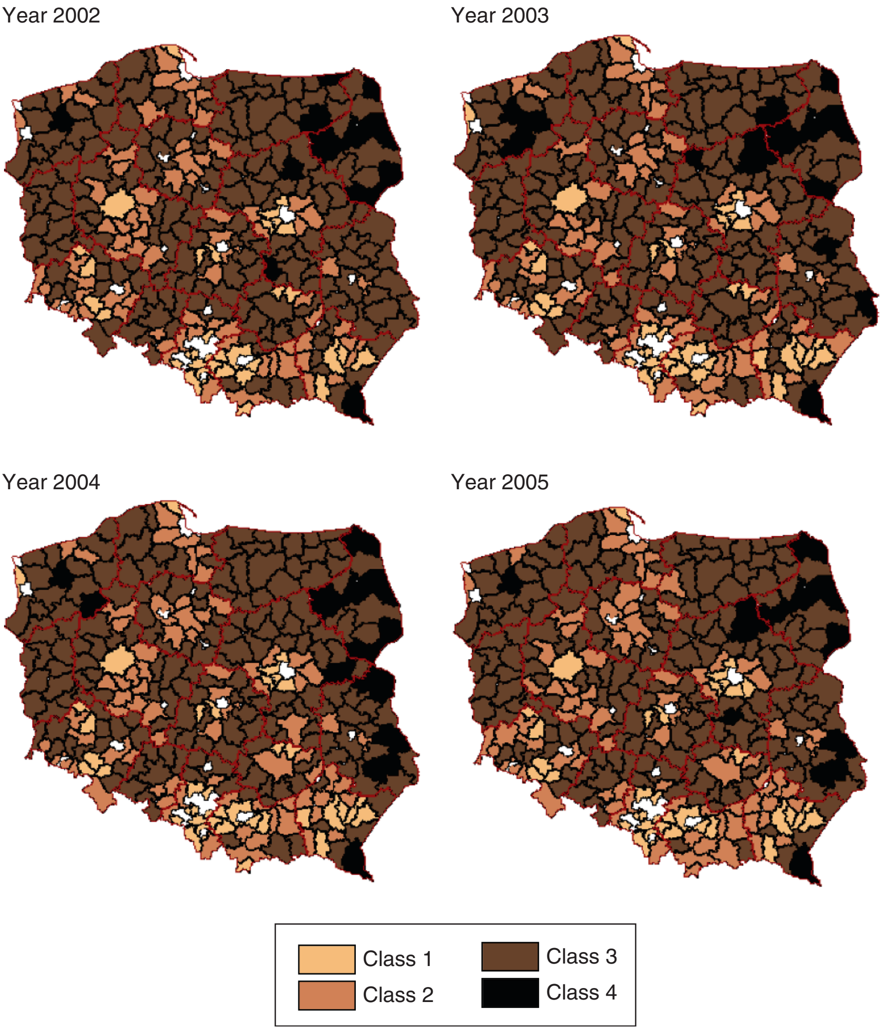

Fig. 4.2 Classification based on vector synthetic measure
Source: own elaboration

Table 4.4 Position of county of Bełchatów in the ranking

Measure	Position in the raking in consecutive years (taken 314 counties analyzed into account)			
	2002	2003	2004	2005
Synthetic	312	312	312	313
Vector	77	85	85	92

Source: own elaboration

Power Station employing 4,369 workers which, taken the population of the county into consideration (i.e. 112,548 out of which 75,168 people of working age), constitutes 11.2% (16.7%). Bełchatów Power Station has a 20% share in the national production of electric energy. Many variables in the county of Bełchatów differ from analogous variables from other counties due to these plants. Environmental variables may be used as example in this case. Emission of gaseous pollutants for every 100 firms is 57 times higher in county of Bełchatów than mean value in other counties whereas sewage channeled constitute only 68% of the average. Standardization of a variable, in the case of which one of objects achieves a very high value compared to others, makes it less changeable for other objects, which lessens their influence on synthetic measure calculated. If the number of variables is small, one may expect that objects in the case of which value of one variable is very different from the mean value will be automatically classified into the best or the worst class. County of Bełchatów may be quoted as an example. As a result of high levels of gaseous pollutants emission, it was classified as the last but one in the ranking.

While determining the standard, variables of this kind bring about atypical standard – Fig. 4.3. It does not matter in the case of synthetic measure. However, vector measure is sensitive to the location of the standard. If the difference between values of variables is small, the standard is near a hyperline in which there are points with equal coordinates. Such values makes the standard stand off the line. Line connecting the standard to the origin of the coordinate system changes in such a way so that the sensitivity of measure to variables with single values differing a lot from the others changes to a degree depending on standard translation. This can be noticed in Fig. 4.3 with county of Bełchatów marked in the coordinate system in which the y-axis is emission of gaseous pollutants and x-axis – production sold. Taken production sold into consideration, Bełchatów is placed very close to the standard, and in the case of emission of gaseous pollutants it is placed farthest from the standard, which leads to the fact that synthetic measure is very small. Nevertheless, it is an anomaly resulting from the functioning of power station there that produces 20% of national electric energy and is a source of high level of pollution. This leads to the translation in location of the standard and reduces the influence of the variable discussed on vector measure, due to which county of Bełchatów is eventually placed on 80th position in the ranking and classified into class 3. Vector measure partly neutralizes the influence that values differing from other values have on classification result. It also takes other variables into account.

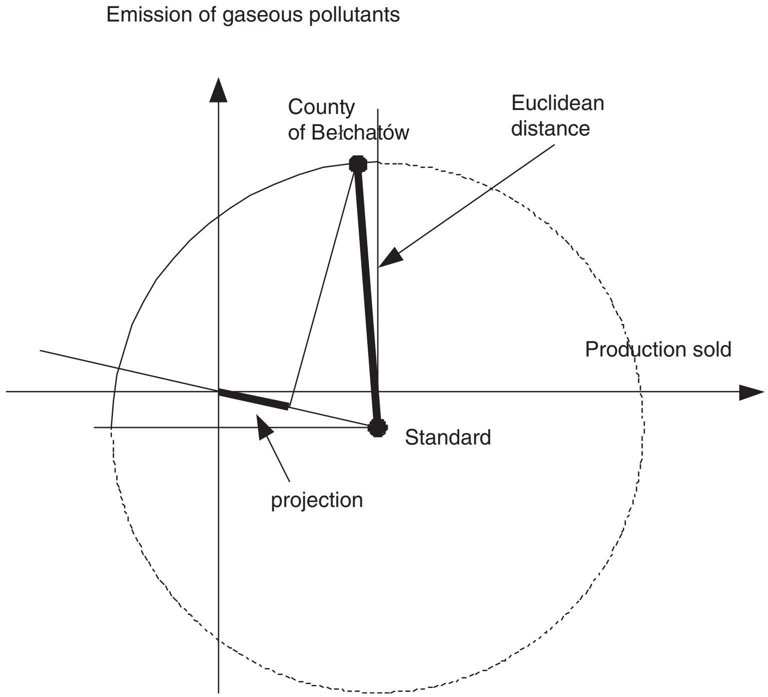

Fig. 4.3 Difference in determining the distance from the standard taken Euclidean distance and projection for county of Bełchatów into account
Source: own elaboration

However, these values affect the way in which the standard is crated and hence classify most objects into one class.

The results of the research shown in Figs. 4.1 and 4.2 do not allow to compare the development of counties in consecutive years, which results from different standardization, different standards and different range limits. In such a case, making the standardization and determining the standard, it is possible to combine variables from all the years. Synthetic measure may be determined for each particular year whereas range limits may be determined for one particular year and then used for all the years under examination. Figures 4.4 and 4.5 show the results of classification made in such a way for the group of socio-economic variables. In Fig. 4.4, showing the results of classification based on synthetic measure, it can be noticed that Poland is divided into two parts, namely well developed economically West and less developed East. Nonetheless, changes occurring with time are hardly noticeable.

Figure 4.5 shows the results of classification based on vector synthetic measure. Division into east and west is less evident here. This measure was the most sensitive to changes occurring in particular years. What could be noticed easily was a decline in values of variables observed the end of 2002 and the beginning of 2003, and jump in these values the end of 2003 and the beginning of 2004.

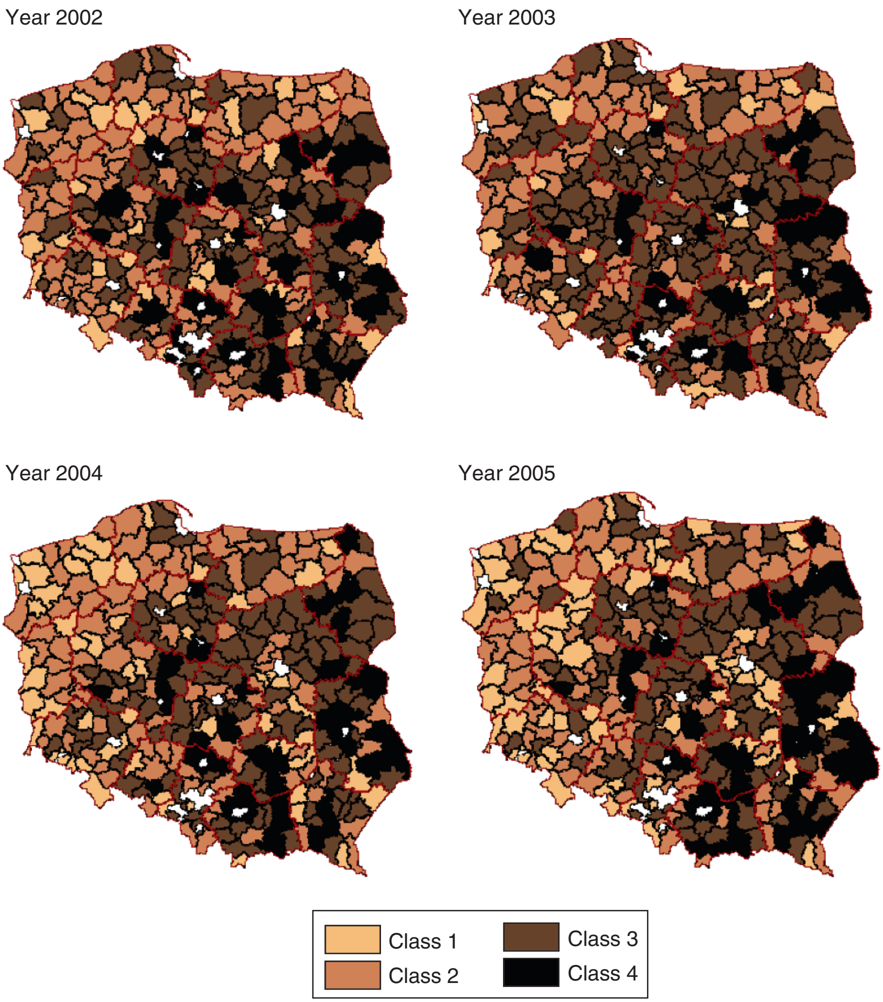

Fig. 4.4 Classification based on synthetic measure taking common standardization of results, common standard and identical range limits into account (determined for the year 2002) – the group of socio-economic variables
Source: own elaboration

Jump in values at the end of 2003 and the beginning of 2004 resulted from Poland's accession to the European Union and the fact that EU grants have been taken into account by the district (commune) budgets. Before the accession, support funds had not been included in statistics. Once grants had been included in communes' income, they were taken into consideration in public statistics, which resulted in a considerable increase in all the indicators. The use of vector synthetic measure has resulted in translating all the counties one class higher (Fig. 4.6). This was not reflected in classical synthetic measure to such a large extent.

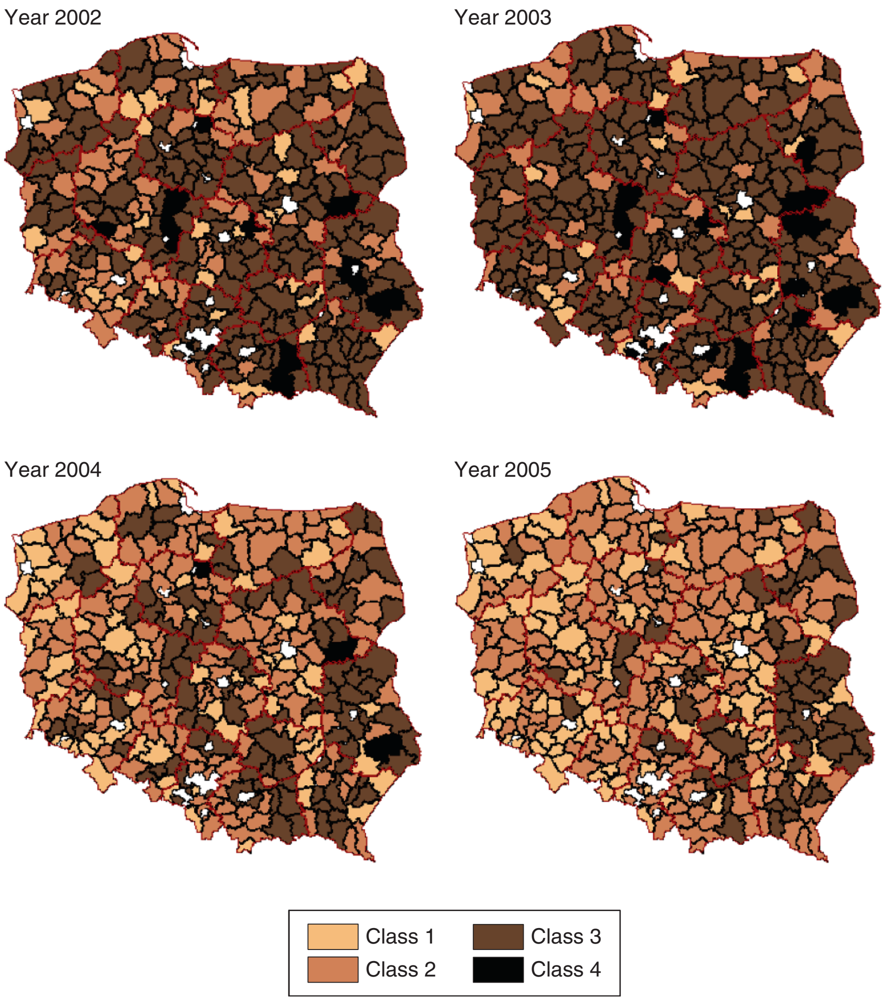

Fig. 4.5 Classification based on vector synthetic measure taking common standardization of results, common standard and identical range limits (determined for the year 2002) – the group of socio-economic variables
Source: own elaboration

Poor differentiation into weak and good regions in a particular year, resulting from a small number of classes, is a side effect of a high sensitivity of vector synthetic measure. As all the regions went up by at least one position in the period 2002–2003, there were only two or three classes left in the outermost years 2002 and 2005, which made it difficult to differentiate between weak and strong regions. Therefore, it is necessary to increase the number of classes. Figure 4.7 shows the results of classification based on the division into ten classes. Division into western and eastern parts of Poland is evident here.

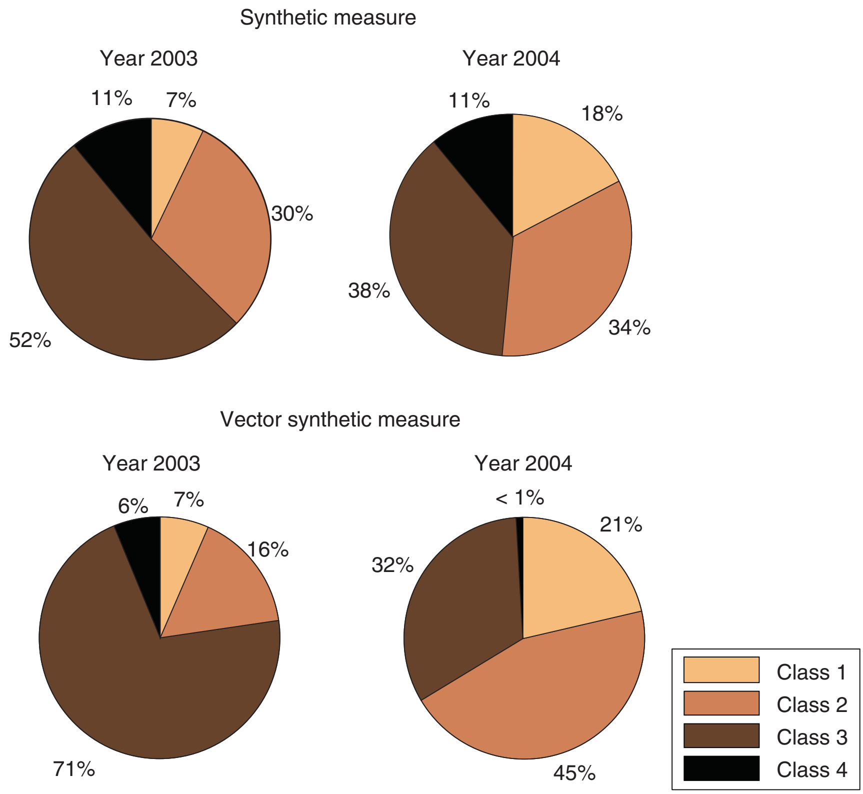

Fig. 4.6 Comparison made with respect to the number of counties classified into particular classes based on synthetic measure and vector synthetic measure for socio-economic variables
Source: own elaboration

Unlike simple synthetic measure, vector measure "allows" objects better than the standard and for which value of measure is higher than unity. This property may be used for comparing objects in particular years keeping the standard from a chosen year. In such a situation, one should assume that there are objects better than the standard. For instance, a year compared is the year in which economic situation was the best and hence one could analyze how much the situation had worsened, or the other way round – the year in which economic situation was the worst to see how much it had improved. Figure 4.8 shows the results of this kind of research. The year 2002 was adopted as the standard year. Standardization was carried out for the year 2002 and then mean value and standard deviation from the year 2002 were used for the standardization in the period 2002–2005. The standard remained, and borders between classes were created on the basis of the year 2002. The main advantage of such an approach is that one does not have to construe the standard every time. It is possible to choose any year and refer it to the standard construed. If comparative research was conducted with the use of classical measure

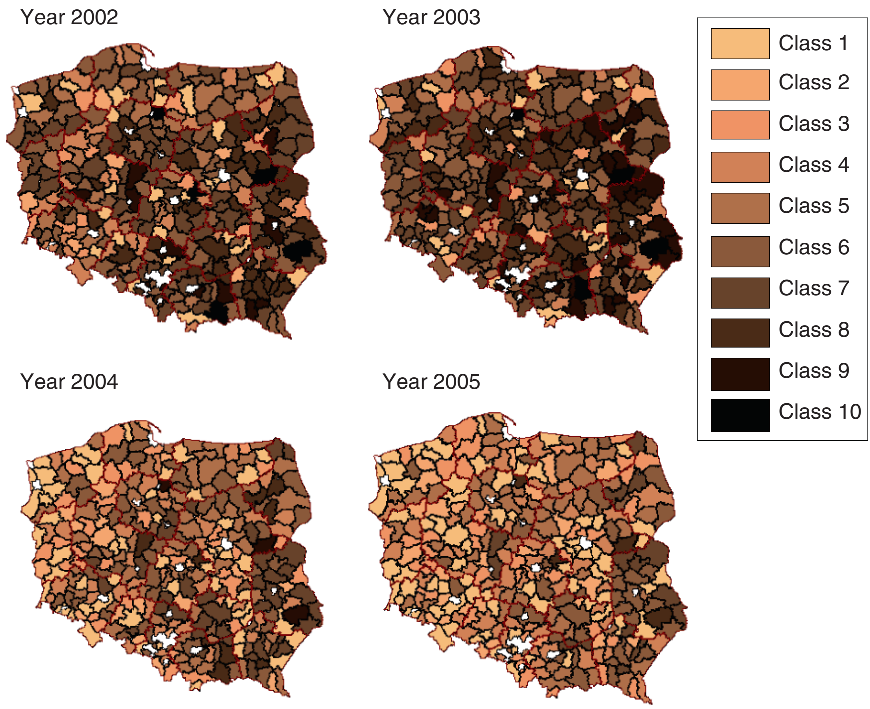

Fig. 4.7 Classification based on vector synthetic measure taking common standardization of results, common standard and identical range limits as well as division into 10 classes into account – the group of socio-economic variables
Source: own elaboration

every year, one would have to create a new standard and take another year into account. As a result, membership of the classes of objects would change every time. Using vector measure, it is not necessary to construe the standard every time the research is conducted and hence classification in the standard year will not be subject to change.

Similar investigation may be carried out for the group of environmental variables (Fig. 4.9). There are only three classes. Class 1 is the smallest whereas class 4 is the largest.

Analyzing the values of variables in counties belonging to the first group (Table 4.5), it may be noticed that they differ grossly from other values. Hence, this indicates that large industrial plants emitting high pollution level are located in these counties.

The fact that large industrial plants function in particular counties brings about the division (environmental in nature) into counties in which there are large industrial plants (class 1 and class 2) as well as the remaining ones (class 3). Due to considerable difference in values of indicators observed between classes 1 and 2 as well as class 3, increasing the number of classes does not change the situation (Fig. 4.10) but only leads to the division into additional classes 1 and 2.

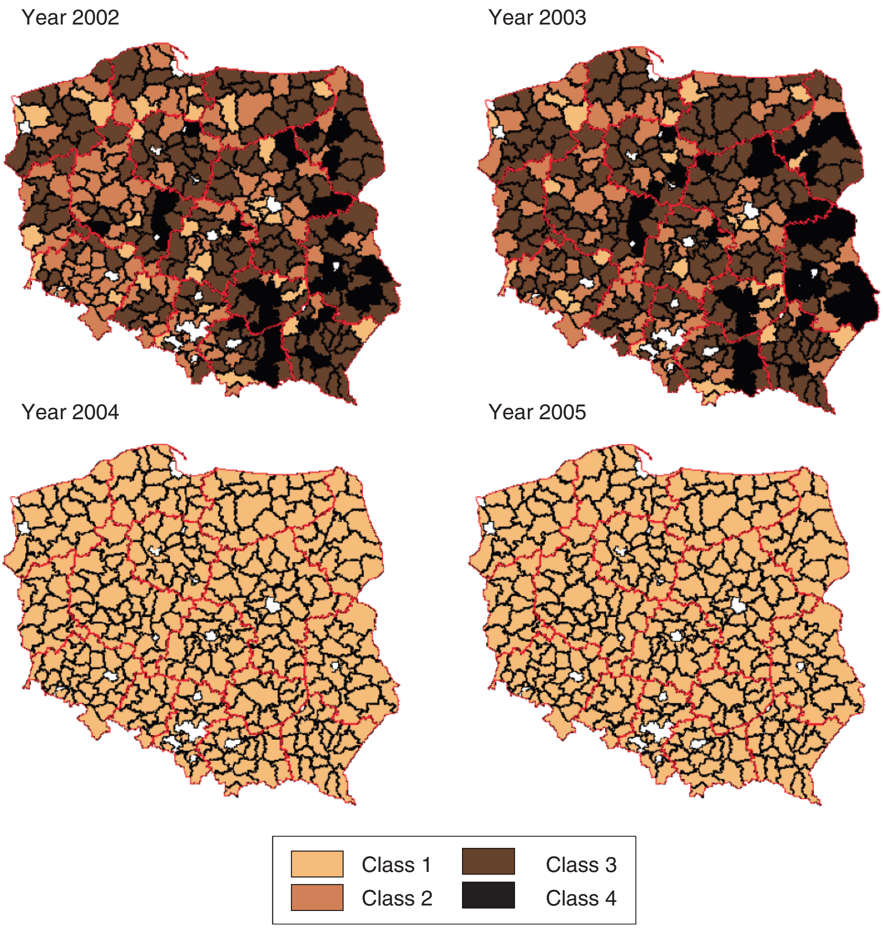

Fig. 4.8 Classification based on vector synthetic measure taking common standardization of results, common standard from the year 2002 and identical range limits into account – the group of socio-economic variables. *Source:* own elaboration

The problem with division into classes consists in a nonlinear relationship between values of synthetic measure and position in the ranking (Fig. 4.11). Making the division into classes on the basis of mean value and standard deviation, it is assumed that ranges have the same width, which leads to the situation in which no county has been classified into class 4, and 14% of counties have been classified into class 1 and class 2. Class 3 includes the remaining counties, i.e. 86%. Increasing the number of classes up to 10 does not change situation. Still, 86% of counties belong to the largest class and hence it is not possible to analyze them.

Determining the borders of classes with the use of nonlinear function is a solution to the problem. As it follows from Fig. 4.11, there is a roughly logarithmic

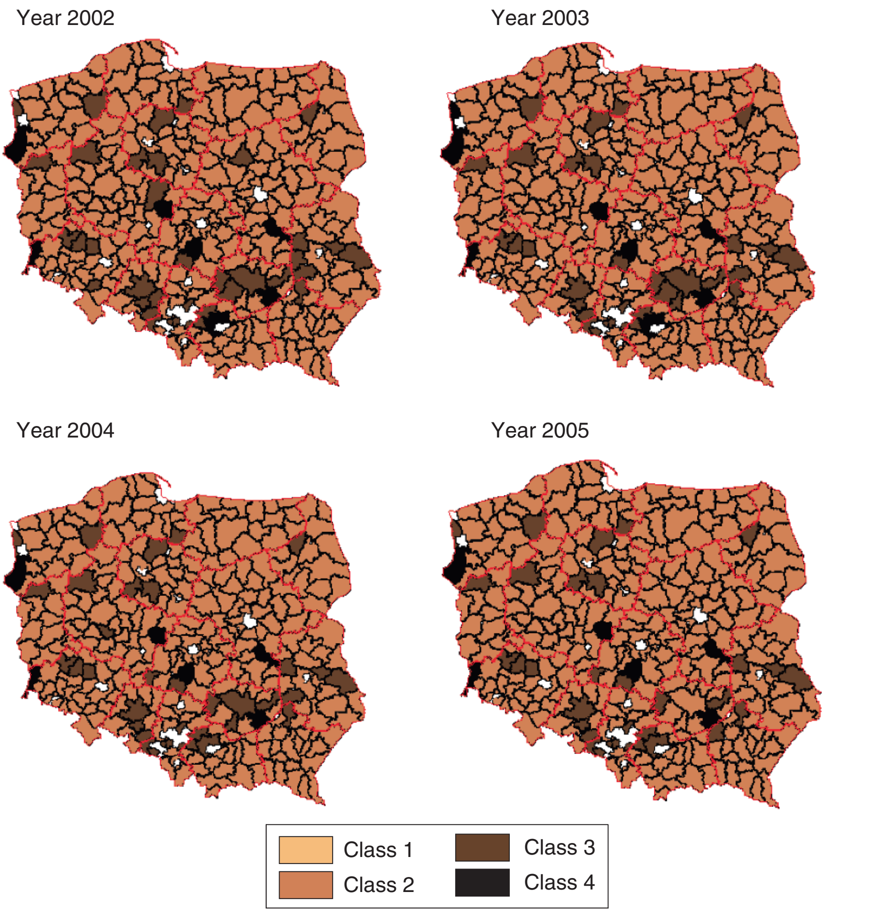

Fig. 4.9 Classification based on vector synthetic measure taking common standardization of results, common standard from the year 2002 and identical range limits into account – the group of environmental variables. *Source:* own elaboration

relationship between the position in the class and value measure. Thus, the following function may be used for determining limits of ranges:

$$y_j = x_j^a, \tag{4.1}$$

where:

$$x_j = 0,\ 1, \ldots, l\_klas - 2,$$

l_klas – number of classes,
a – power coefficient selected experimentally.

Table 4.5 Values of variables for counties from class 1

County	Value of measure	Sewage channeled for every 100 firms (weight 56%)	Emission of particulate pollutants for every 100 firms (weight 13%)	Emission of gaseous pollutants for every 100 firms (weight 31%)	Industry plants emitting high level of pollution
of Kozienice	–55.3818	35,631.18	56.64	207,658.88	Kozienice Power Station
of Staszów	–32.2607	20,336.52	38.60	128,437.08	Połaniec Power Station
of Bełchatów	–23.3343	222.55	27.11	476,621.31	Bełchatów Power Station
of Gryfino	–20.5169	15,488.11	6.68	64,120.47	Dolna Odra Power Station
of Zgorzelec	–11.7461	376.31	68.75	119,184.56	Turów Power Station and Mine
of Turek	–6.5225	1,025.18	26.64	81,122.90	Adamów Power Station
of Kraków	–4.4444	2,855.80	14.50	14,735.30	Nowa Huta
Average for all counties	0	310.37	4.44	6,485.26	

Source: own elaboration

New borders may be calculated through replacing y_j with the number calculated in (4.1) formula, namely

$$ggr_j = gr_{12} + (gr_{N-1,N} - gr_{12}) \frac{y_j - \min\limits_k (y_k)}{\max\limits_k (y_k) - \min\limits_k (y_k)}, \tag{4.2}$$

where ggr_j – upper limit of j th class.

Values gr_{12} and $gr_{N-1,N}$ must be given as parameters. It is possible to calculate them on the basis of standard deviation:

$$gr_{12} = \bar{m} - wsp_1 s_m + wsp_2, \tag{4.3}$$

where:

$\bar{m}$ – mean value of synthetic measure,

s_m – standard deviation of synthetic measure,

$wsp1$, $wsp2$ – parameters selected experimentally.

$$gr_{N-1,N} = gr_{12} + wsp_1 s_m. \tag{4.4}$$

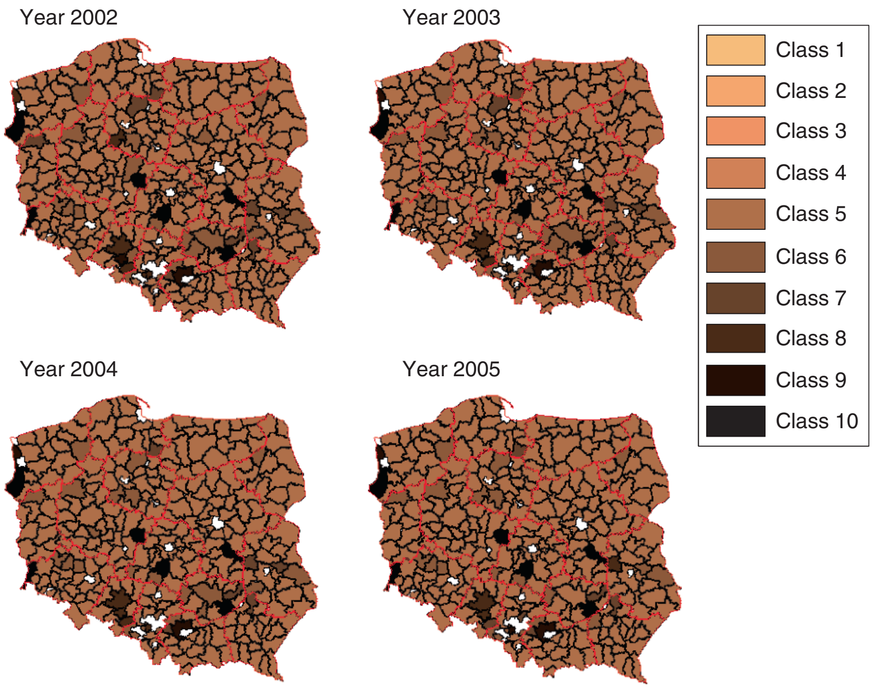

Fig. 4.10 Classification based on vector synthetic measure taking common standardization of results, common standard from the year 2002, identical range limits and ten classes – the group of environmental variables. *Source:* own elaboration

Figure 4.12 shows the result of classification taking uneven distance between classes' borders into account. In the course of classification, ten counties with highest values of synthetic measure were eliminated, which allowed the even distribution of counties in classes. The number of counties did not exceed 27% in any class, thanks to which it was possible to distinguish which areas emitted lower and which higher level of pollution. Region with the largest number of counties emitting high level of pollution covers the following voivodships: Śląskie voivodship, Świętokrzyskie voivodship and areas near Kraków. Nevertheless, this region does not differ from the remaining ones considerably. Situation improved slightly in the period 2002–2005. In the year 2002, 58% of counties belonged to the best class, and in the year 2005, this percentage rose to 63%.

Measure construed on the basis of projection is used when the standard is from outside of the sample examined. This is unacceptable in taxonomy. Consequences produced by using the standard from outside the sample to construe synthetic measure have been presented below.

Figure 4.13 shows comparative research for the purpose of which the standard has been created on the basis of data derived from the following voivodships: Zachodniopomorskie voivodship, Wielkopolskie voivodship and Podlaskie voivodship.

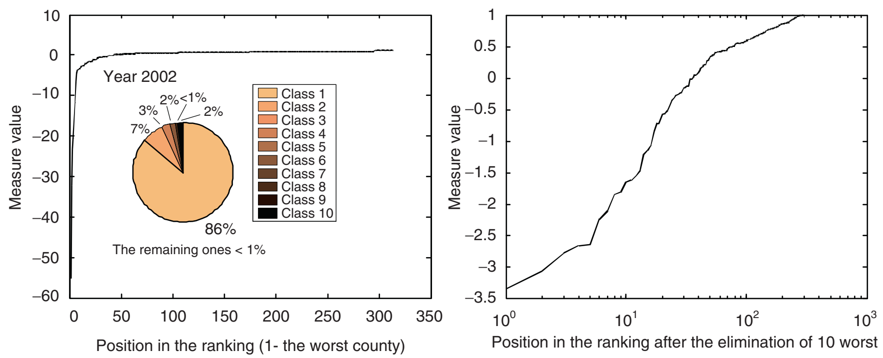

Fig. 4.11 Relationship between position in the ranking and measure value
Source: own elaboration

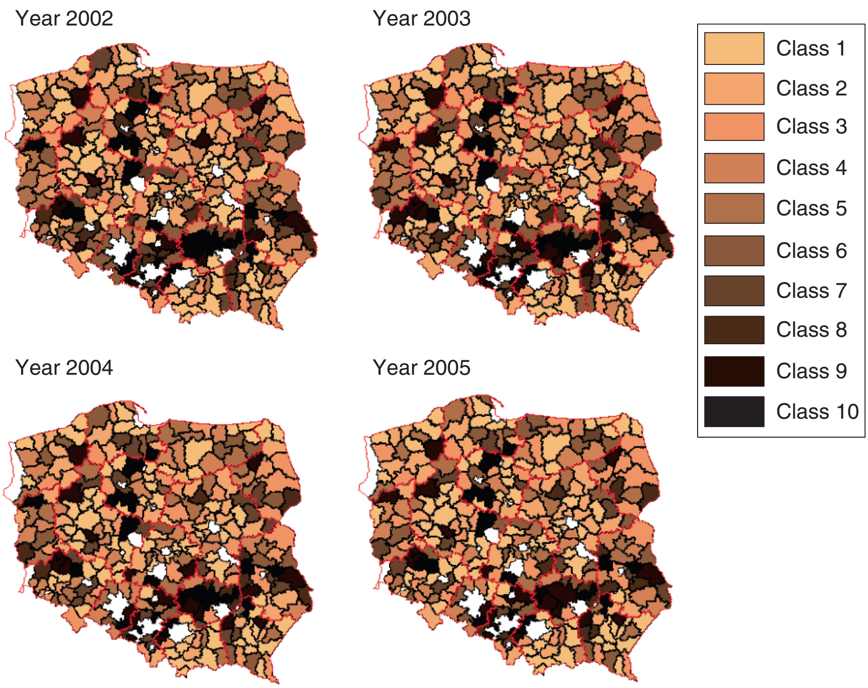

Fig. 4.12 Classification based on vector synthetic measure taking common standardization of results, common standard from the year 2002, identical range limits determined in a nonlinear manner and ten classes without 10 counties with highest values of synthetic measure – the group of environmental variables
Source: own elaboration

In the case of classical synthetic measure, it has been made a rule that objects better than the standard cannot exist. Such objects make the classification incorrect, which can be easily noticed in the case of county of Poznań. This county was rated

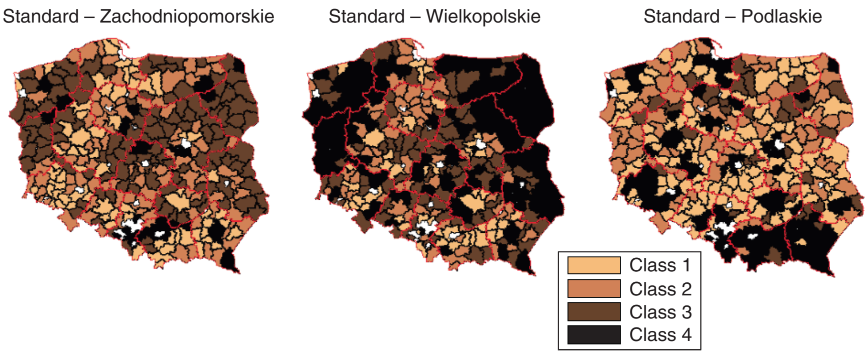

Fig. 4.13 Classification based on synthetic measure for the year 2005 taking different standards for the group of technical variables into account
Source: own elaboration

among the best ones as a result of choosing the standard from counties situated in Zachodniopomorskie and Wielkopolskie voivodships. On the contrary, if the standard is selected from counties located in Podlaskie voivodship, county of Poznań is rated among the worst ones, which stems from the fact that in Podlaskie voivodship there are no counties comparable to county of Poznań. Values of variables of all the counties in Podlaskie voivodship are much lower than variables of county of Poznań. It is evident when the standard is chosen from counties in Wielkopolskie voivodship. In this classification, all the counties situated in Podlaskie voivodship were classified into the worst class.

Classical synthetic measure is used for measuring the distance from the standard regardless of the location of the object compared. Standard procedure for determining the standard creates a situation in which there cannot be objects better than the standard. However, using the standard in the manner suggested brings about the fact that such objects may appear. In such a situation, the better the objects with parameters better than the standard, the worse class they are classified into. That is why county of Poznań that is far better than the best county in Podlaskie voivodship have been classified into the worst class. Hence, classical synthetic measures should not be used for this kind of investigation.

Vector measure is based on distance measures, thanks to which it allows the existence of objects better than the standard. Figure 4.14 shows the results of investigation analogical to the aforementioned ones with the use of vector measure. County of Poznań does not pose any problem as it is always classified into the best class.

What follows from Fig. 4.14 is that Zachodniopomorskie voivodship is rated among the weakest as far as infrastructure is concerned. Construing the standard on the basis of this voivodship, it can be noticed that it is comparable to the weakest voivodship situated in north–eastern Poland and Lubuskie voivodship. Taken Polish counties into account, 54% of counties are better or comparable to the best counties in Zachodniopomorskie voivodship, and only 1% is weaker or comparable

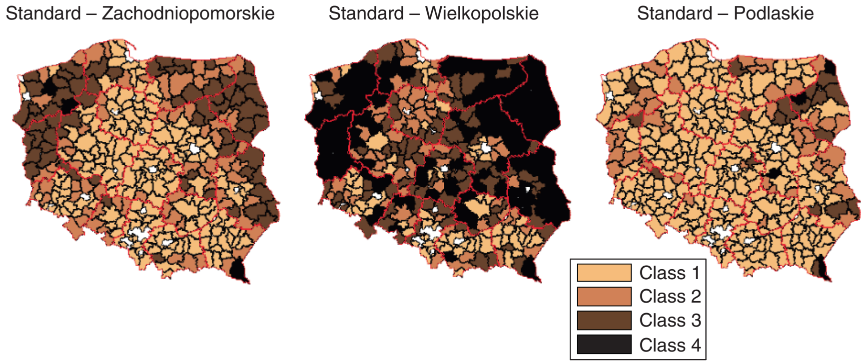

Fig. 4.14 Classification based on vector synthetic measure for the year 2005 taking various standards for the group of technical variables into account
Source: own elaboration

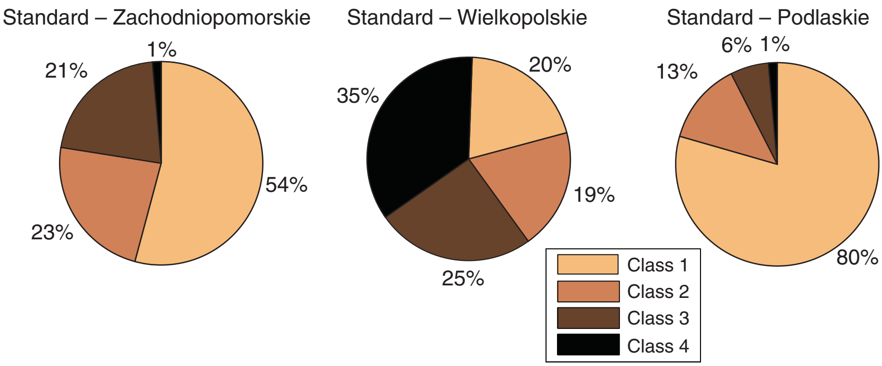

Fig. 4.15 Statistics of membership of different classes taking various standards into account
Source: own elaboration

to the weakest counties in the voivodship under discussion (Fig. 4.15). Figure 4.14 shows precisely that voivodships situated in central and eastern Poland have well developed infrastructure whereas voivodships in north–eastern and north–western Poland have poorly developed infrastructure.

What follows from Fig. 4.14 is the fact that when the standard is construed for counties in Zachodniopomorskie voivodship, Podlaskie voivodship is comparable to Zachodniopomorskie voivodship, while when the standard is created for Podlaskie voivodship, Zachodniopomorskie voivodship comes out a bit better. Such a situation results from a small number of classes.

Until now, investigation was carried out on the assumption that the standard was calculated on the basis of maximum and minimum values. Nevertheless, this is not always favourable due to outermost elements that very often have abnormal

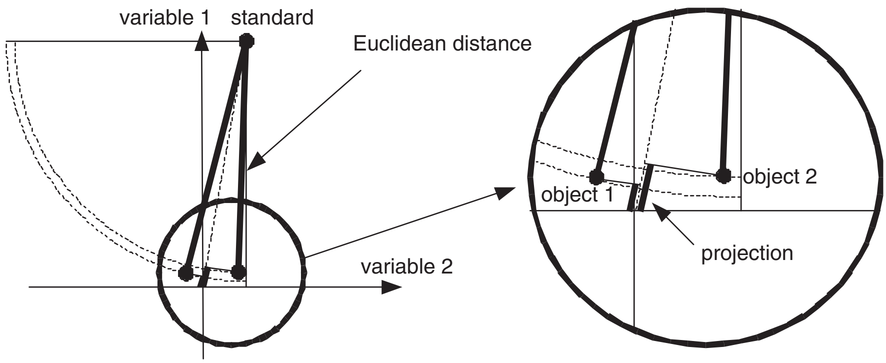

Fig. 4.16 Comparing the objects with standards calculated as a maximum value on the assumption that there are objects with abnormally high values of variables
Source: own elaboration

structure (e.g. counties with large industrial plants). All the variables calculated for every 100 firms have extremely high values, i.e. several dozen or several hundred times higher than the others. Standard determined in such a way poorly diversifies counties in which there are no large industrial plants.

All the variables undergo standardization, which brings about the fact that maximum values of variables are apparently similar. However, if there are objects with values of variables differing considerably from the remaining objects, the standard for these variables has a coordinate several dozen higher than the remaining variables. The objects are diversified mainly along this coordinate, and other coordinates have minor influence on the value of synthetic measure. Figure 4.16 shows two objects compared. They are very much diverse in relation to variable 2. The distance of object 2 along variable 2 from the standard is very small so it is supposed to be classified into the highest class. The distance of object 1 along variable 2 is very large, larger than the average value of all the objects so it is supposed to be classified two classes lower due to the distance along variable 2. The distance along variable 1 between objects and the standard is so large that difference between distances along variable 2 has a minor influence on synthetic measure calculated. Hence, both objects will be classified into the same class.

The problem discussed refers to both classical synthetic measure and vector measure. Vector measure only reduces the difference in values of measures of objects near the standard (i.e. characterized by abnormally high values of variables) and objects lying in the area near “average objects”. However, vector measure diversifies ordinary objects very poorly (just as classical measure) if the standard is created on the basis of abnormally high values of variables.

The problem with abnormally high values of variables can be solved by changing the rules about choosing the standard. If the choice of the standard is not based on maximum or minimum values of variables, the problem will not occur. Nonetheless, such a solution is plausible only in the case of vector measure.

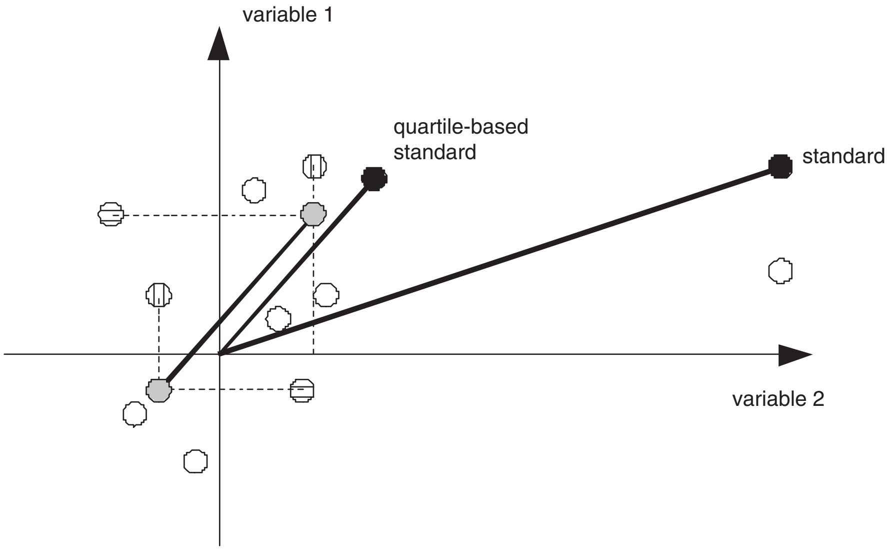

Fig. 4.17 Comparing the objects with standards calculated as a maximum value on the assumption that there are objects with abnormally high values of variables
Source: own elaboration

The first and third quartiles may be used for the calculation of the standard.[5] These quartiles establish two standards, i.e. of the first and third quartile. The difference between coordinates of these standards provides coordinates of the quartile-based standard, and at the same time the standard of the first quartile is deducted from the standard of the third quartile for a stimulant, whereas for a destimulant, it is the other way round.

Figure 4.17 shows the standards of the first and third quartiles (marked with grey colour). The standard was created on the basis of quartiles thanks to difference between coordinates. Looking at the location of the quartile-based standard and standard calculated on the basis of maximum and minimum values, it can be noticed that quartile-based standard reduces the weight of variable 2, due to which variable 1 and variable 2 will have a similar influence on the value of measure.

In the case of synthetic measure calculated in a standard way, atypical objects (if any) are always the standard, which is shown in Fig. 4.18. Almost all the objects, except for one, are located within the rectangle marked. This standard is supposed

[5]Definitions of a quartile have been presented in: A.D. Aczel: *Statistics in Management*. [In Polish] Wyd. Naukowe PWN, Warszawa 2000, p. 18. Quartiles are also called quarter values. Cf. K. Zając: *Outline of Statistical Methods*. [In Polish] PWE, Warszawa 1971, p. 188. The first and third quartiles are also called lower and upper quartiles. Cf. N.W. Smirnow, I.W. Dunin-Barkowski: *Crash Course of Mathematical Statistics for Technical Purposes*. [In Polish] PWN, Warszawa 1966, p. 121.

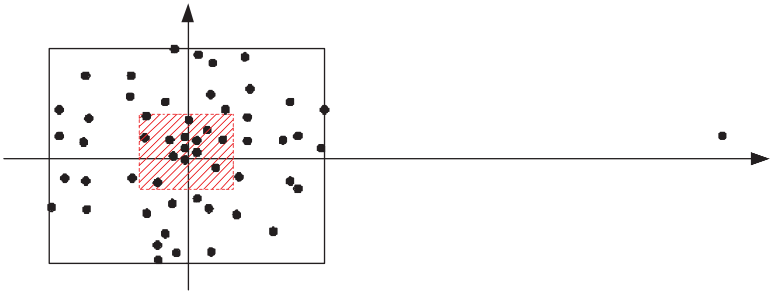

Fig. 4.18 Comparing objects with the standard calculated as a maximum value on the assumption that there are objects with abnormally high values of variables
Source: own elaboration

to be located in one of corners of this rectangle. However, the location of the standard will be determined by the right-most object (if the standard is calculated on the basis of maximum values), thanks to which variable connected with the horizontal axis will be taken into account in the creation of synthetic measure more often than variable connected with vertical axis. Objects differing from other objects a lot are extremely rare. Sometimes, they may have an atypical value for only one variable. Thus, the fact they had been included in the set investigated was a pure coincidence.

Let's assume that the group of environmental variables for chosen counties of Lódzkie voivodship is being examined. The share of particular variables in the examination will be determined by considering (or not) county of Bełchatów. Hence, the result will differ depending on the fact if county of Bełchatów has been taken into consideration, which implies that a random factor will determine the result (i.e. considering or not considering the atypical county). The quartile-based standard will be the standard for typical objects and will be located in the corners of red rectangle shown in Fig. 4.18. Adding or eliminating the right-most objects will have a minor influence on standard's location and hence investigation carried out with the use of quartile-based standard will have practically the same result regardless of the fact if atypical object has or has not been taken into account.

It is not enough to change the way of establishing the standard to eliminate the influence that objects with abnormal values have on the classification of objects. It is also necessary to change the manner in which borders are determined. A standard way of determining the borders takes objects with abnormal values of variables into consideration. In order to eliminate their influence, borders may be determined only on the basis of objects located between the first and the third quartiles. As standard deviation will be calculated only in this scope, it can be multiplied by correction coefficient (that should be a bit higher from unity) to establish the borders.

Figure 4.19 shows the result of classification based on the quartile-based standard. Comparing the result with the previous analysis based on standard calculated

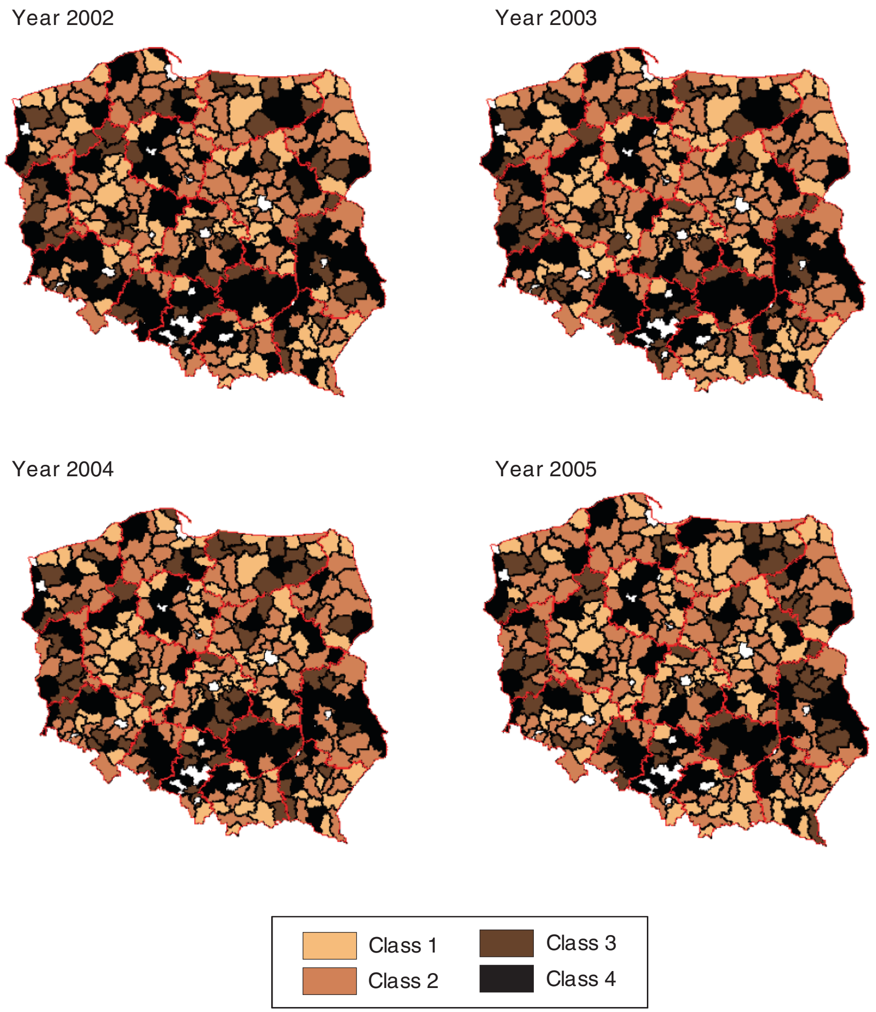

Fig. 4.19 Classification based on vector synthetic measure taking common standardization of results, common standard from the year 2002, identical range limits and quartile-based standard into account – the group of environmental variables
Source: own elaboration

with the use of maximum and minimum (Figs. 4.10 and 4.12), it can be noticed that the diversity of classes is greater. Hence, it turns out that the classification is oriented at counties with values similar to mean value, which has been achieved thanks to not considering the counties differing a lot from the average while establishing the borders between classes. Looking at the map, it can be noticed that industry plants are located in southern counties and hence pollution levels are the highest there.

4.3 Investigation of Spatial Relationships Between Groups of Variables

It is possible to calculate values of measures individually for particular groups of variables. In the case under discussion, there are four groups. Counties classified into particular classes are characterized by a certain location in space and form areas in certain shapes. Different groups of variables form different shapes yet very similar to one another. It is also crucial to determine the extent to which spatial arrangement of counties for particular groups of variables are similar.

Spatial analysis of data (represented by coordinates of counties' borders and values of measures for these counties) requires using extremely complex algorithms and making time-consuming calculations. Hence, it is necessary to convert data into the form facilitating and speeding up the calculations. One should transfer data to a regular grid that is a two-dimensional table of values of coefficients. Such a transfer may be carried out via the method of opposite distances.

Figure 4.20 shows values of synthetic measure for counties after transferring it to regular grid. In a two-dimensional presentation, the degree of brightness depends on synthetic measure. Black color implies maximum values of measure, while white color – minimum values.

As it can be noticed, borders between counties are at the same time limits between different values of synthetic measure, which results from the manner in which measure value is determined (measure calculated for indicators known for county's area). However, these values are averaged. As a matter of fact, they oscillate depending on their location within a county, and the transition of values from county to county is smooth. In order to map this situation, values of synthetic measure on regular grid may undergo low-pass filtration,[6] which leads to the averaging of measure values on the borders of a county (shown in Fig. 4.21). This is of profound importance to the analysis of spatial distribution of synthetic measure values. Some methods may react too strongly to changes in irregular values of synthetic measure on the borders of counties.

On the basis of a regular grid, Poland may be divided into sub areas with values of synthetic measure in certain ranges, which has been shown in Fig. 4.22. Such a presentation allows to find local maximums and minimums of measure values (these are the areas that may have a positive or negative effect on neighboring areas). As far as demographic variables are concerned, big cities with high population density, good medical care and large population influx are such local maximums.

Regular grid considerably facilitates the examination of spatial relations. In this grid, each county is described with the number of points depending on its surface area. Hence, the result depends on its size. It can be assumed that regular grids for particular years are vectors. Therefore, the location of a particular value of synthetic measure in

[6] M. Borawski: *op.cit.*, p. 139; K. Nermend: *Object recognition …*

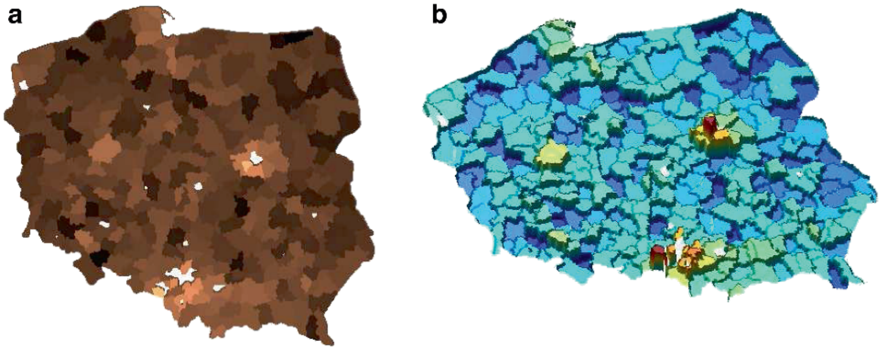

Fig. 4.20 Values of vector measures for the year 2002 while determining the quartile-based standard for the group of demographic variables: (**a**) two-dimensional presentation; (**b**) three-dimensional presentation. *Source:* own elaboration

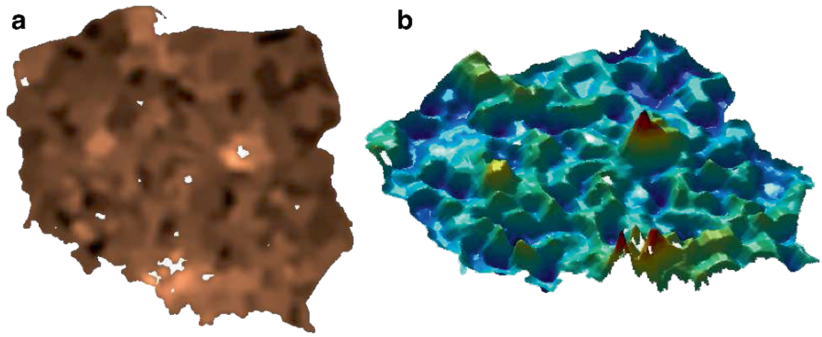

Fig. 4.21 Values of vector synthetic measure for the year 2002 while determining the quartile-based standard for the group of demographic variables when borders between counties are blurred: (**a**) two-dimensional presentation; (**b**) three-dimensional presentation. *Source:* own elaboration

the grid is determined by the direction of vector. If values of synthetic measures in each county increase evenly every year, the direction of vector will not change. However, if some counties accelerate or slow the development, the direction of vector will be subject to change. Changes in directions of vectors in particular years can be determined with the use of two-dimensional correlation coefficient[7]:

[7]Two-dimensional correlation coefficient is also know as spatial correlation. See: G.S. Maddala: *Econometrics*. [In Polish] Wyd. Naukowe PWN, Warszawa 2006, p. 271.

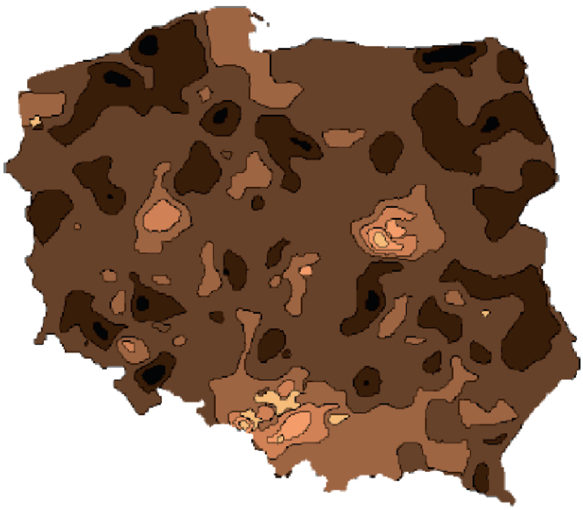

Fig. 4.22 Borders between areas with different values of synthetic measure for the group of demographic variables. *Source:* own elaboration

$$c_{\frac{\vec{A}}{|\vec{A}|}\frac{\vec{B}}{|\vec{B}|}} = \left(\frac{\vec{A}}{|\vec{A}|}, \frac{\vec{B}}{|\vec{B}|}\right) = \frac{\left(\vec{A}, \vec{B}\right)}{|\vec{A}||\vec{B}|} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{o} a_{ij}b_{ij}}{\sqrt{\sum_{i=1}^{n}\sum_{j=1}^{o} a_{ij}^2}\sqrt{\sum_{i=1}^{n}\sum_{j=1}^{o} b_{ij}^2}} \tag{4.5}$$

where n, o – number of elements in vertical and horizontal of regular grid.

Table 4.6 shows the results of examination involving correlation for different groups of variables. It can be noticed that changes in directions are slight in the case of environmental and technical variables. By contrast, considerable changes had been observed in the group of socio-technical variables, particularly in the direction of vector at the turn of 2003 and 2004, which resulted from Poland's accession to the European Union.

Correlation coefficient does not offer the answer to the question about the extent to which values of measures have changed. It only enables one to determine the degree to which the distribution of measures has altered. In order to calculate change in measures, one can use the ratio between absolute values of vectors. In the second part of Table 4.6, values of these ratios have been presented, and at the same time standards to which years (placed in verses) are referred have been presented in columns. It can be noticed that a situation is rather stable in the case of demographic and technical variables, and values of ratios oscillate around 1. Values of ratios for environmental variables show that the situation is slightly worsening. Socio-economic variables tended to increase in the period 203–2004, which resulted from the fact that EU support funds were taken into account in statistics. Nevertheless, once the change in correlation coefficient has been

Table 4.6 Correlation and ratio between distances of vectors in regular grids of synthetic measures for particular years

Year	Correlation				Ratio between distances			
	2002	2003	2004	2005	2002	2003	2004	2005
Demographic variables								
2002	1.00	0.70	0.73	0.69	1.00	1.07	1.12	1.09
2003	0.70	1.00	0.68	0.73	0.93	1.00	1.04	1.02
2004	0.73	0.68	1.00	0.73	0.90	0.96	1.00	0.98
2005	0.69	0.73	0.73	1.00	0.91	0.98	1.02	1.00
Socio-economic variables								
2002	1.00	0.81	0.52	0.48	1.00	1.08	0.12	0.08
2003	0.81	1.00	0.48	0.43	0.93	1.00	0.11	0.07
2004	0.52	0.48	1.00	0.98	8.64	9.34	1.00	0.69
2005	0.48	0.43	0.98	1.00	12.5	13.5	1.45	1.00
Technical variables								
2002	1.00	0.99	0.98	0.97	1.00	1.10	1.04	0.98
2003	0.99	1.00	0.99	0.99	0.91	1.00	0.94	0.89
2004	0.98	0.99	1.00	1.00	0.96	1.06	1.00	0.94
2005	0.97	0.99	1.00	1.00	1.02	1.13	1.06	1.00
Environmental variables								
2002	1.00	0.95	0.93	0.93	1.00	0.93	1.07	1.13
2003	0.95	1.00	0.98	0.98	1.07	1.00	1.15	1.21
2004	0.93	0.98	1.00	0.99	0.93	0.87	1.00	1.06
2005	0.93	0.98	0.99	1.00	0.88	0.82	0.95	1.00

Source: own elaboration

Table 4.7 Correlation of variables from different groups

Variables	Demographic	Economic	Technical	Environmental
Demographic	1.00	0.23	0.61	−0.04
Economic	0.23	1.00	0.11	−0.11
Technical	0.61	0.11	1.00	−0.07
Environmental	−0.04	−0.11	−0.07	1.00

Source: own elaboration

considerable, it can be concluded that there is a huge disproportion as far as the use of these funds in particular counties is concerned.

Spatial distribution of values of synthetic measures for different groups of variables may be correlated. This fact can be verified with the use of two-dimensional form of Pearson's correlation. Table 4.7 shows the results of such a comparison. As it can be noticed, two groups of variables, namely technical and demographic, are correlated spatially to the largest extent, which stems from the fact that a good technical infrastructure leads to population migrations from areas with worse infrastructure. This is also related to population density and higher quality of medical services that has a major influence on a decline in infant mortality.

Empirical research has proven conclusions drawn as a result of theoretical analysis and also allowed to formulate proper means of conducting the research depending on the type of objects examined. Transformation of measures obtained into regular grid enabled to carry out spatial analysis. The results received allow to formulate the concept of computer system that uses methods analyzed for regional research.

Chapter 5
Computer-Aided Regional Development Analysis

5.1 Computer System for Regional Development Analysis as a Decision Support System

The complexity of regional development analyses determines the selection of supporting methods and tools directed toward IT solutions. They allow a more effective collecting, storing and processing of large databases, making various computations, simulations and stunning visualizations of results received. On the basis of properly collected and prepared data, one may get information useful in management and decision support.[1]

The fact that computer systems develop into decision support systems may be justified by the following factors[2]:

1. Technological (hardware and software improvement, easier way of communicating with a computer);
2. Theoretical (development of mathematical and simulation methods, development of operational research and its application in decision support);
3. Psychological (enabling the managers who are not educated in the scope of IT to use computer systems directly).

The importance of decision support systems is the more profound, the more complex a decision in management process is, i.e. the poorer the ability of a human being to describe the reality investigated precisely and make right decisions. Computer systems directed toward supporting a decision-maker in decision-making

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[1]J. Czermiński: *op.cit.*, p. 59.

[2]J. Zabawa, E. Radosiński: *Concept of a Hybrid of Intelligent Decision Support System and Industrial Enterprise Simulator*. [In Polish] In: *Economic Systems Simulation*. [In Polish] Wyd. Wyższa Szkoła Przedsiębiorczości i Zarządzania im. L. Koźmińskiego, Warszawa 2000, pp. 298–299.

K. Nermend (ed.), *Vector Calculus in Regional Development Analysis*,
Contributions to Economics,
DOI: 10.1007/978-3-7908-2179-6_5, © Springer Physica-Verlag Berlin Heidelberg 2009

are called decision support systems. In the world literature, one may come across many different definitions of systems of this class that determine their applications and elements of architecture. For instance, Leigh and Doherty (1986) characterize decision support system (DSS) as an interactive computer system directed to users who are not IT specialists but specialists in other fields and who can fully make use of its planning and decision-making functions.[3]

Sprague (1980) provides a more precise notion. He defines DSS as a system the range of which encompasses areas that are not well structuralized and offers access to decision-making models (apart from typical functions of computer systems) as well as provides one with analytical tools. He also mentions a certain feature that every DSS must have, namely flexibility so that it could adjust to changing conditions in which decisions are made.[4]

Sol (1983) defines DSS as the application of computer system technologies for improving the effectiveness of actions taken by decision-makers in situations when the system may support a human being in carrying out very difficult tasks by determining certain existing elements in advance.[5]

A few years later, Klein and Methlie (1992) characterized DSS as a computer system that provided information from a particular field on the basis of analytical decision-making models and databases. Thanks to such information, the system may support decision-makers in decision-making in complex and poorly structuralized environments.[6]

What follows from the aforementioned definitions is that decision support system is a computer system whose receivers are specialists in particular fields. It is equipped with base of models, database and friendly interface with the use of which user communicates with the system. The system supports a decision-maker in solving specific decision-making situations. DSS allows the simulation of various real situations, selection of models and interactive work with the system in the scope of defining the models and assessing decision-making variants obtained. Procedures for decision-making process have been defined by means of certain parameters and are a fixed element of user software.[7]

The notion of DSS is very often used excessively for defining computer systems facilitating solving certain tasks which, however, do not meet all the requirements connected with the application and architecture of this class of systems.

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[3] W.E. Leigh, M.E. Doherty: *Decisions upport and expert systems*. South-West Publ. Co., Dallas 1986.

[4] R.H. Spargue: A Framework for the Development of Decision Support Systems.“[66]MIS Quarterly” 1980, Vol. 4, p. 2.

[5] H.G. Sol: Processes and Tools for Decision Support: Inferences for Future Developments. In: Processes and Tools for Decision Support. North Holland, Amsterdam 1983, pp. 2–3.

[6] M. Klein, L.B. Methlie: Expert Systems. A Decision Support Approach with Applications in Management and Finance. Addison-Wesley Publishing Company, London 1992.

[7] Z.J. Klonowski:.: *Computer Systems for Corporate Management. Models of Development and Functional Properties*. [In Polish] Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2004, pp. 53–54.

DSS systems are aimed at supporting strategic(long-term) decisions and tactical (medium-term) decisions. They have practical applications in many domains of life, namely[8]

- Economic activity planning,
- Supporting investment decisions,
- Financial transactions, banking,[9]
- Electronic market (agent systems),[10]
- Sale of goods and services,
- Supply.

In the context of issues relating to regional development, the application of DSS in supporting regional development analyses is of profound importance as it enables to generate different decision-making variants on the basis of statistical data gathered, lists of indicators, model and decision-maker's preferences. Solutions reached in such a way will allow to indicate regions that are the best with respect to a particular decision-making situation or will form a basis for comparing them.

Decision support systems differ from other computer system mainly in computer methods and techniques used, access to data, modelling functions and sphere in which they are used. Depending on management level, decision-making requires various information items that are processed in different ways and hence one must use DSS variants that differ in, e.g. modelling functionality or the way in which data is accessed. At the peak of the pyramid showing the relation between management level and DSS functionality (Fig. 5.1), there are decision support systems based on decision-making models to a large extent that enable one to reach decision-making variants. Control level corresponds to system based mainly on databases in which large number of data items used for analytical processing are collected.

Relations between management levels and DSS functionality shown in Fig. 5.1 are in keeping with the classification of these systems made and described by Power,[11] Alter,[12] Wierzbicki et al,[13] Bonczka et al[14] with reference to data-based DSS and model-based DSS.

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[8] J. Czermiński: *op.cit.*, pp. 64–65.

[9] K. Michalik: Aitech DSS – Example of model Solving Complex Decision-making Problems with the use of Hybrid Methods of Artificial Intelligence. [In Polish] In: SWO '2001 – Organization Support Systems. [In Polish] Red. J. Goluchowski, H. Sroka. Katowice 2001.

[10] R. Budziński, J. Becker, A. Becker: *Concept of DSS Generator for Agent Systems on Electronics Market*. [In Polish] Studia i Materiały Polskiego Stowarzyszenia Zarządzania Wiedzą nr 8. Wyd. BEL Studio Sp. z o.o., Warszawa 2007, pp. 13–21.

[11] D.J. Power: *Decision Support Systems: Concepts and Resources for Managers*. Westport, CT: Greenwood/Quorum Books 2002, pp. 123–176; *idem*: *What is a DSS?* "DSstar, The On-Line Executive Journal for Data-Intensive Decision Support" 1997, October 21, Vol. 1, No 3.

[12] S.L. Alter: Decision Support Systems. Current Practice and Continuing Challenges. Addison-Wesley, London 1980; idem: Why is Man-Computer Interaction Important for Decision Support Systems? "Interfaces" 1977, 7, 2, February, pp. 109–115.

[13] *Model-Based Decision Support Methodology with Environmental Applications*. Red. A. Wierzbicki, M. Makowski, J. Wessels. Kluwer Academic Publishers 2000, pp. 9–27.

[14] R.H. Bonczek, C.W. Holsapple, A.B. Whinston: *Foundations of Decision Support Systems*. Academic Press, New York 1981.

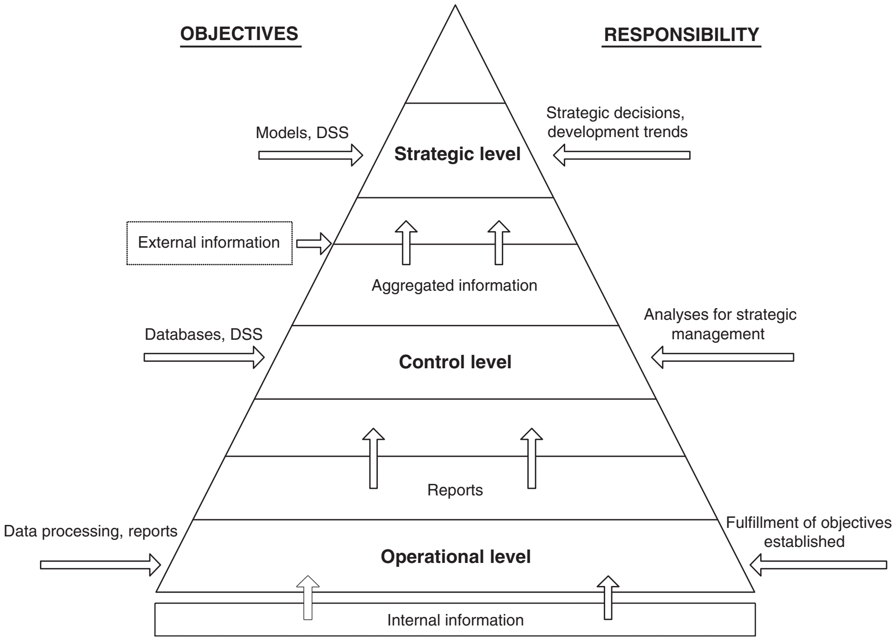

Fig. 5.1 Relations between management levels and decision support systems
Source: elaboration based on E. Tomeski, H. Lazarus: Decision Support Systems – can they improve management effectiveness. [In Polish] "Nauki o Zarządzaniu" 1987, no 3–4, p. 130

The first group of DSS provides access to data and allows to obtain cross-sectional information fast in a cyclical mode or *ad hoc*. In order to do so, analytical databases, independent from operational databases, are construed and are very often a basis for data warehouse. Thanks to various analytical models, one can carry out data drain operations and look for relations among analytical solutions generation data.

The second category of model-based DSS encompasses systems directed toward creating decision-making models. These models form a basis for making final decisions (generating decision-making variants). Models such as algebraic, statistical (e.g. forecast about the number of unemployed in voivodships), financial (for instance, calculation of income in regions), operational (e.g. maximization of economic effects of ventures), simulation (e.g. simulation of investors' behavior), etc. may be used in this case.[15]

[15] M. Łatuszyńska: *Modelling of Effects Produced by International Transport Corridors Development*. [In Polish] Wyd. Naukowe Uniwersytetu Szczecińskiego 2004, p. 177; K. Nermend: *Human Behaviour Simulation*. [In Polish] Szczecin 2005; *idem*: *Simulation Computer Games as a Source of Information about a Consumer*. In: *Problems Faced by Global Information Society*. Szczecin 2005; K. Nermend, M. Borawski: *Concept of Consumer Behaviour Model in Multidimensional Vector Space*. [In Polish] Edukacja Informacyjna, Szczecin 2005; K. Nermend: *Concept of Building Sites Purchase Simulation*. In: *Computer-integrated Management*. [In Polish] Opole 2006.

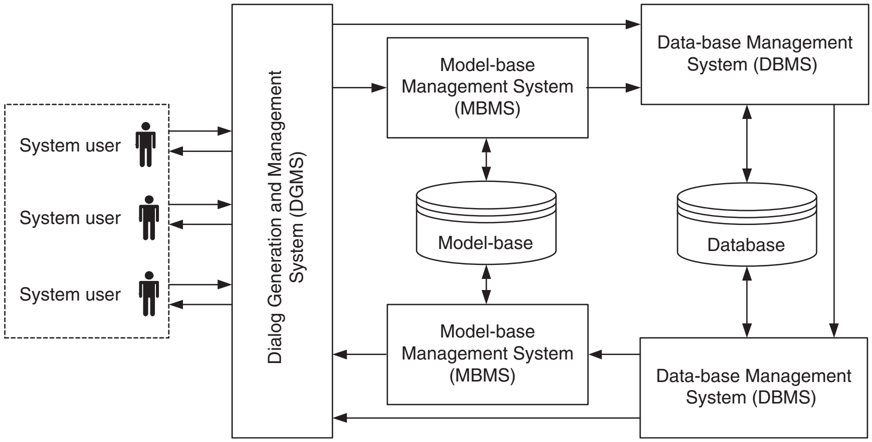

Fig. 5.2 General structure of decision support system (DSS)
Source: elaboration based on: A.P. Sage: Decision Support Systems Engineering. John Wiley & Sons, Inc., USA 1991, p. 40

In practice, one may come across the integration of both approaches to the creation of decision support systems (data-based and model-based ones) and enriching them with additional modules of graphical presentation of results. Therefore, data collected in analytical databases may form a basis for the creation of decision-making models, and libraries of graphical, simulation or statistical packages may support the visualization of results received.[16]

Figure 5.2 shows a generalized architecture of decision support system that encompasses the following functional modules[17]:

1. Data-base management system (DBMS) sometimes called data-base module;
2. Model-base management system (MBMS);
3. Dialog generation and management systems (DGMS) also known as user cooperation module.

[16] S. Morton: *Management Decision Systems. Computer – Based Support for Decision Making*. Harvard University, Harvard 1971, pp. 34–36; J. Bennett: *Integrating Users and Decision Support Systems*. Proceedings of the Sixth and Seventh Annual Conferences of the Society for Management Information Systems. Red. J.D. White. Ann Arbor, University of Michigan 1976, pp. 76–86; I. Benbasat, B.R. Nault: *An Evaluation of Empirical Research in Managerial Support Systems*. Decision Support Systems 1990, Vol. 6, pp. 203–226.

[17] A.P. Sage: *Decision Support Systems . . .*, pp. 39–41; P.G.W. Ken, M.S. Scott Morton: *Decision Support Systems. An Organizational Perspective*. Addison-Wesley, Reading, MA 1978; P.N. Finlay: *Introducing Decision Support Systems*. Oxford, UK Cambridge, Mass., NCC Blackwell, Blackwell Publishers 1994; J.F. George: *The Conceptualization and Development of Organizational Decision Support Systems.*"Journal of Management Information Systems" 1992, Vol. 8, No 3, pp. 109–126.

Database gathers data derived from a system user, operational processing systems and other specialist bases. Furthermore, it stores decision-making models implemented into the system (depending on a purpose) and all the models that will be construed by DSS users. System for generating and managing a dialog with user is supposed to provide easy operation and communication with system users.

From a technological point of view, systems of DSS class may be examined at three levels.[18] The first one is a level of so-called specialist dedicated DSS that are solutions for particular decision-makers or groups of decision-makers as well as allow to solve specific decision-making problems. The second level is connected with DSS generators. DSS generator is an integrated software package for fast, easy and inexpensive construction of DSS. It is very functional and used for modelling and making different analyses, visualization of results and reports generation. A perfect DSS may be, for instance a specialist language used for easy construction of DSS application or integration of software based on spreadsheet.[19]

The third level, also known as a basic level of DSS technology, is a set of DSS utility routines and includes elements such as computer hardware, program elements as well as scientific methods and research work necessary to design certain specialized decision support systems. These elements allow to design both DSS generators as well as dedicated specialist DSS. The example of such tools are editors, spreadsheets and systems enabling one to send in queries to databases. Specialist DSS may be created directly with the use of these tools whereas DSS generators make the platform, from the level of which DSS may be constantly developed without major effort or time, available.[20] Figure 5.3 shows DSS technological levels.

Different development trends can be observed as far as decision support systems are concerned. One of these trends, crucial from the perspective of spatial data processing, for instance in the context of regional data analysis, is a direction of spatial information systems of GIS type (Geographical Information Systems).

DSS enriched with components of GIS are refereed to as Spatial Decision Support Systems (SDSS).[21] SDSS are equipped with analytical abilities of DSS and effectiveness of spatial data processing typical of GIS. DSS have been inves-

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[18] R.H. Sprague, E.D. Carlson: *Building Effective Decision Support Systems*. Prentice-Hall, New Jersey 1982, p. 47; A. Maryam: *The Evolution of Information Systems Development Approach. Some Field Observations*.“ACM SIGMIS Database” 1984, Vol. 15, No 3, pp. 19–24.

[19] E. Turban: *Decision Support and Expert Systems. Management Support Systems*. 4th edit., Macmillan Publishing Company, New York 1995, p. 135; M. Beynon, S. Rasmequan, S. Russ: *A New Paradigm for Computer-Based Decision Support*.“Decision Support Systems” 2002, Vol. 33, No 2, pp. 127–142; D. Power: *What is the Difference Between a DSS and a DSS Generator?* “DSS News” 2004, Vol. 5, No 20; C. Fierbinteanu: *A Decision Support Systems Generator for Transportation Demand Forecasting Implemented by Constraint Logic Programming*.“Decision Support Systems” 1999, Vol. 26, No 3, pp. 179–194.

[20] R.H. Sprague, E.D. Carlson: *op.cit*., p. 48.

[21] Densham used the term“spatial decision support system” to define a system that is usually implemented in a specified domain. Database of the system integrates various spatial and non-spatial data and hence facilitates the application of analytical and statistical modelling techniques.

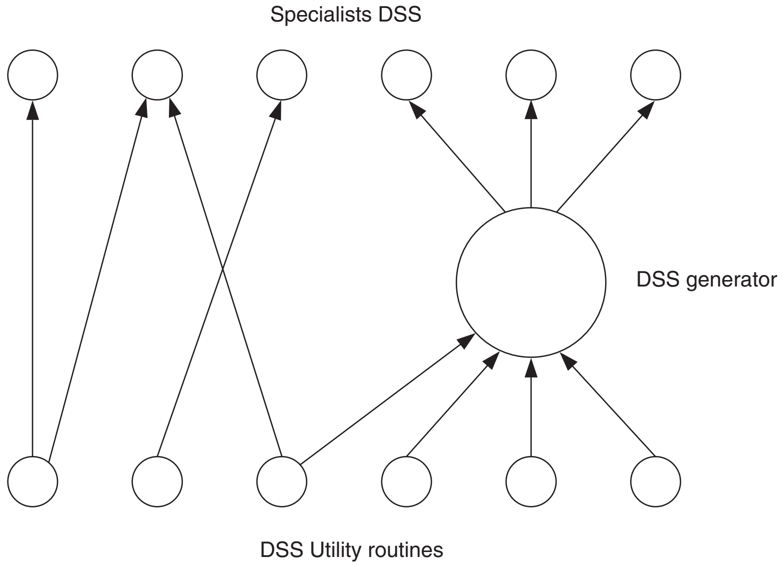

Fig. 5.3 DSS technological levels
Source: elaboration based on R.H. Sprague, H.J. Watson: *Decision Support Systems. Putting Theory into Practice*. Prentice-Hall, Englewood Cliffs, New Jersey 1996, p. 178; R.H. Sprague, E.D. Carlson: op.cit., p.48

tigated in terms of computer systems for many years, however they are imperfect as they lack spatial data support. GIS offer effective solutions in the scope of spatial data collection and processing yet they lack tools supporting decision-making at managerial level.

Need for integrating both systems has already been discussed in the world literature.[22] In some situations, Geographical Information Systems should be an effective tool in decision-making processes and hence it seems appropriate to consolidate them with software that is capable of model management. Thanks to such integration, it is possible to use the functionality of GIS and procedures for modelling and generating decision-making variants within one system.[23]

Graphical user interface provides decision-makers with information, including the results of analyses, presented in various forms. Furthermore, the system adjusts to the style of decision solving imposed by a decision-maker and submits itself to modifications widening its possibilities. To find more information consult the following sources: P.J. Densham: *Spatial Decision Support System*. In: *Geographic Information Systems. Principles and Applications*. Red. M.F. Goodchild (i in.). Longman Scientific and Technical, London 1991, pp. 403–412.

[22] T.C. Ryan: *Spatial Decision Support Systems*."Urban and Regional Information Systems Association Proceedings" 1992, Vol. 3, pp. 49–59; R. White, G. Engelen: *High-resolution integrated modeling of spatial dynamics of urban and regional systems*. Computers, Environment, and Urban Systems 2000, Vol. 24, pp. 383–400.

[23] S. Segrera, R. Ponce-Hernández, J. Arcia: Evolution of Decision Support System Architectures. Applications for Land Planning and Management in Cuba."JCS & T" 2003, Vol. 3, No 1, pp. 42–44; P. Jankowski: Integrating Geographical Information Systems and Multiple Criteria Decision Making

As far as the architecture of decision support systems are concerned, several main components may be distinguished. Malczewski[24] mentions four elements of architecture, Klosterman[25] speaks of four whereas Armstrong and Densham[26] suggest the following five modules:

1. Data-base management system (DBMS) that includes functions for operating on the base of spatial data;
2. Analytical procedures in model-base management system (MBMS) with functions for user and model management (e.g. simulation models);
3. Software generating screen forms;
4. Report generator;
5. User interface, i.e. DGMS allowing a communication between user and other components of the system.

Figure 5.4 shows the description of SDSS development.

Evolution of DSS is defined by four main stages, namely DSS based on traditional models, systems using knowledge base, systems using Web technology, and service-based DSS. The development of GIS (directed toward decision support) is presented in a similar way and consists of the following stages: traditional GIS, DSS with GIS components, SDSS based on Web technologies, intelligent SDSS, mobile SDSS, and service-based SDSS.

With the development of the Internet, traditional decision support systems and SDSS were subject to evolution toward Web technologies. Compared to DSS based on personal computers, decision support systems directed toward Web technologies are more functional, available and easier to operate. Easier updating of information and modification of technological solutions within systems themselves are main benefits accruing from such solutions.[27] This fact is particularly important from the perspective of applications for DSS users that may be complemented with real time-available information, e.g. the weather forecast for a particular region or level and changes in pollution in a certain area.[28]

Methods."Int. J. Geo. Inform. Sys." 1995, 9 (3), pp. 251–273; J.R. Eastman, P.A.K. Kyem, J. Toledano, W. Jin: GIS and Decision Making. United Nations Institute for Training and Research (UNITAR), Geneva 1993, p. 127.

[24] J. Malczewski: *Spatial Decision Support Systems*. NCGIA Core Curriculum in GIScience 1998, p. 127; *idem*: *GIS and Multicriteria Decision Analysis*. John Wiley and Sons Inc. 1999.

[25] R.E. Klosterman: Planning Support Systems. A New Perspective on Computer-Aided Planning. In: Planning Support Systems: Integrating Geographic Information Systems, Models, and Visualization Tools. Red. R.K. Brail, R.E. Klosterman. ESRI Press, Redlands, California 2001, pp. 1–23.

[26] M.P. Armstrong, P.J. Densham: Database Organization Alternatives for Spatial Decision Support Systems."International Journal of Geographical Information Systems" 1990, Vol. 3 (1): Describes the Advantages of the Extended Network Model for Network-Based Problems 1990, pp. 11–14.

[27] A.P. Abhijit, K.A. Ravindra: Developing Web-Enabled Decision Support Systems Using VB. NET and ASP.NET. Dynamic Ideas. Belmont, Massachusetts 2007; K.R. Molenaar, A.D. Songer: Web-Based Decision Support Systems. Case Study in Project Delivery."J. Comp. in Civ. Energ." 2001, Vol. 15, Issue 4, pp. 259–267.

[28] D. Yanxin: A Spatial Decision Support System for Economic Analysis of Sediment Control on Rangeland Watersheds. The University of Arizona, Arizona 2005, pp. 51–52.

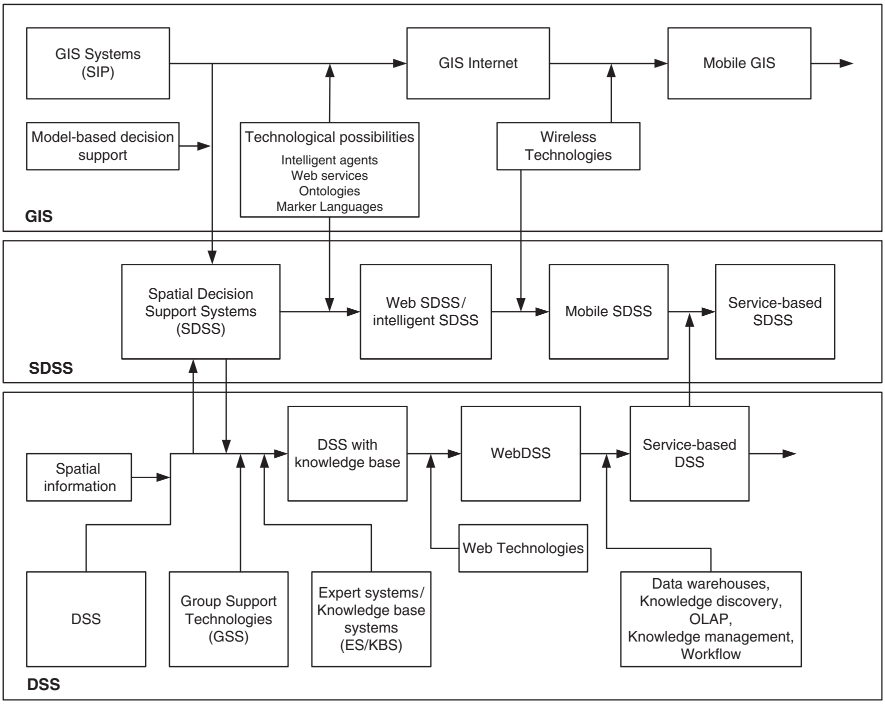

Fig. 5.4 Development of Spatial Decision Support Systems
Source: elaboration based on V. Sugumaran: Web-Based Spatial Decision Support Systems *(WebSDSS). Evolution, Architecture and Challenges*. Third Annual SIGDSS Pre-ICIS Workshop Designing Complex Decision Support. Discovery and Presentation of Information and Knowledge 2005, pp. 3–5

In the world literature, one may come across many practical realizations of DSS in Web technology, which may reflect the need for such solutions. For instance:

DSS supporting global analyses of changes in small basins[29];

DSS using Web techniques for distributing models of spatial data and hydrological models[30];

DSS supporting the management of grazing land in the case of which forms are used for feeding the system with data. On the other hand, output data is presented in the form of tables and charts in such a way so that the results received could be understood by non-professional users (non-specialists)[31];

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[29] R. Ludwig et al: Web-Based Modelling of Energy, Water And Matter Fluxes to Support Decision Making in Mesoscale Catchments – the Integrative Perspective of GLOWA-Danube "Physics and Chemistry of the Earth." 2003, Vol. 28 (14–15), pp. 621–634.

[30] S.L. Markstrom, G. McCabe, O. David: *Web-Based Distribution of Geoscientific Models*. "Computers & Geosciences" 2002, Vol. 28 (4), pp. 577–581.

[31] R.H. Mohtar, T. Zhai, X. Chen: *A World Wide Web-Based Grazing Simulation Model (GRASIM)*."Computers and Electronics in Agriculture" 2000, Vol. 29 (3), pp 243–250.

DSS providing the tools for the analysis of decision-making problem connected with environmental management based on AHP methodology.[32]

The expected functionality of decision support system in the scope of regional data analysis determines solutions directed toward Web technologies and SDSS. It is spatial data and analytical functions, required for regional development analysis, that stress the necessity to combine GIS components with DSS. Making system interface available to a larger group of users dispersed territorially (communes, counties, etc.) as well as easiness of administrating and operating the system confirm that it is justified to select Web technology as a basis for implementing the system.

5.2 Concept of Decision Support System in Regional Development Analysis

The main objective of decision support system in regional data analysis is to provide information on the development of particular units of local administration, make it possible to asses and compare selected regions and obtain decision-making variants in accordance with certain preferences of decision-makers. Multi-faceted criteria for regional development assessment, dealing with a wide range of factors determining decision-making, necessity to model different real situations and need for decision-making by various groups of decision-makers have determined the choice of DSS as a supporting tool. In this selection, it is of major importance to define the models for particular decision-making situations, e.g. econometric models or simulation models as they allow to obtain conditions (similar to real ones) in which decisions on regional data analysis are taken. The system should enable one to solve problems in the scope of regional data processing and modelling, making various economic and investment analyses, and provide user with attractive visualization.

The concept of decision support system proposed (Fig. 5.5) is not a finite solution as it is possible to modify its particular modules in a flexible way. For instance, one may add models into model-base, operate various types of databases and add analytical tools. This solution integrates different technological elements such as Web components of user interface, Internet applications, calculation modules as well as base of text data and bases including information described spatially (digital maps).

In the case of system architecture suggested, users may communicate with the server on which data is processed by using Web browser. The results of query to system bases are sent back to browser which user may use for holding dialog with DSS. Feedback (including graphic objects of different types) sent to browser is interpreted and visualized properly there. As consumer computers have the basic

[32] X. Zhu, A.P. Dale: JavaAHP. A Web-Based Decision Analysis Tool for Natural Resources and Environmental Management."Environmental Modeling & Software" 2001, Vol. 16, pp. 251–262.

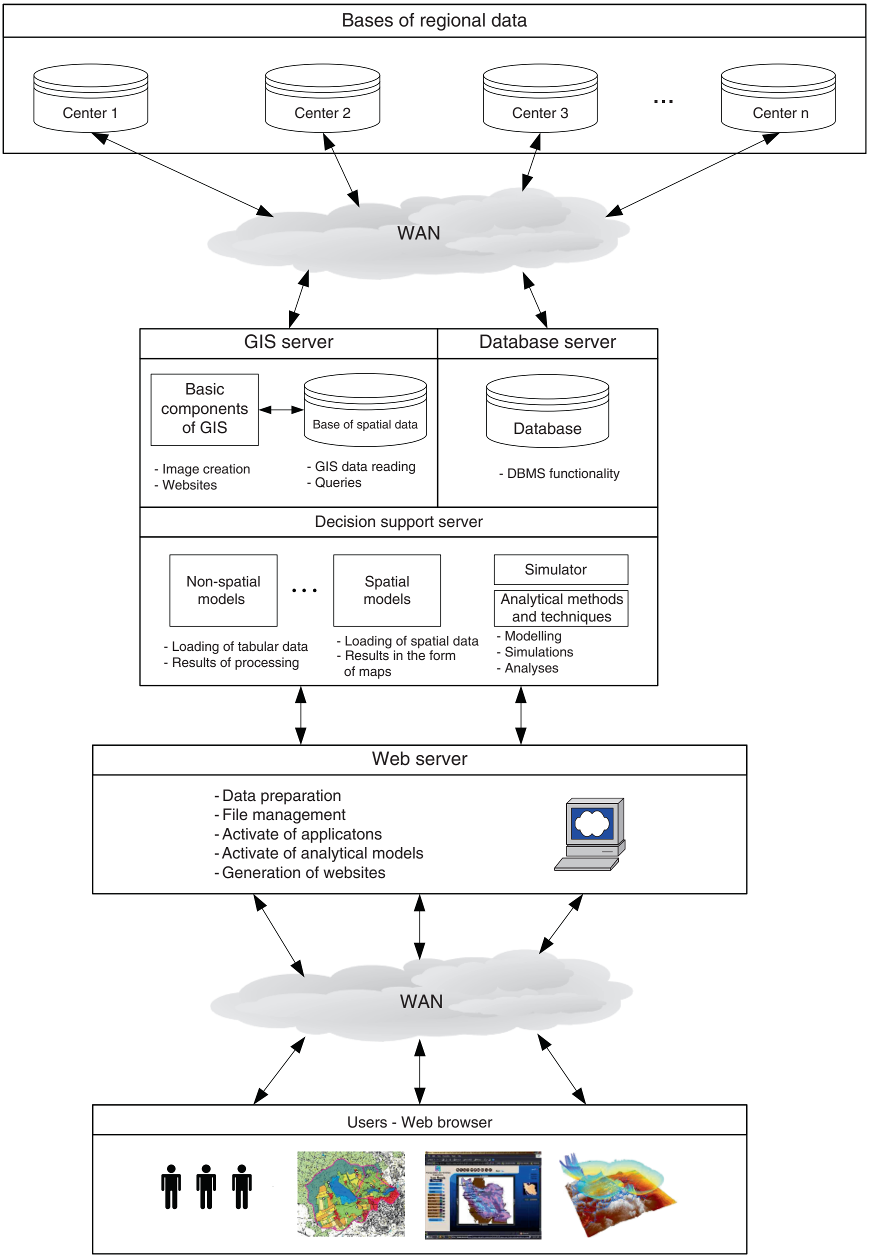

Fig. 5.5 Generalized structure of DSS for the purpose of regional development analysis
Source: own elaboration

functionality of GIS, part of processing is done in users machines to which data prepared properly is sent.

Decision support system used in regional data analysis should allow to use many regional databases. Central DBMS of DSS must integrate and permit data processing in accordance with methodology adopted. Database module in regional analyses support system (database server in Fig. 5.5.) is a central place of data collection derived from both external regional centers as well as entered directly by DSS users. Data imported into the system from external systems should undergo a stage of so-called transformation and integration before being saved. The concept of the system proposed involves also the possibility of deriving data from simulator with the use of which one may generate a set of data corresponding to real situations connected with formal aspect of regional development.

Thanks to the content of databases, the system may select indicators in an appropriate way. These indicators will form a basis for taking analytical actions, due to which it is possible to determine the level of regional development. They can also be used for comparing the regions and their appropriate selection determines certain results of computations depending on the context of comparison.

In the system, statistical models and models based on artificial intelligence that allow to identify unknown relations among indicators are supposed to be implemented. Applying the methods suggested requires not only the knowledge of methods themselves and issues relating to the analysis and assessment of regional development but mainly the knowledge of a particular region itself. Both linear and nonlinear models are going to be used for analyses. If relations among variables are nonlinear and in the unknown form, neural networks will have to be used.

The concept of decision support system in regional data analysis presented is in keeping with the general architecture of DSS (see: Fig. 5.2) and consists of the following three main subsystems: database management, model-base management, as well as dialog generation and management.

5.3 Data-Base Management System (DBMS)

5.3.1 System Functions

The system is aimed at providing the proper operation of DSS with data derived from various sources, namely internal, external (e.g. Regional Database of Central Statistical Office, Eurostat), commercial bases or sets of unprocessed data.[33] According to Radosinski,[34] database module that includes data-base management system should be characterized by the following functional aspects:

[33] E. Turban, E. McLean, J. Wetherbe: *Information Technology for Strategic Advantage*. 2th edit. John Wiley & Sons Inc., New York 2001, p. 65.

[34] E. Radosiński: *op.cit.*, pp. 38–44; S. Chaudhuri, U. Dayal, V. Ganti: *Database Technology for Decision Support Systems*.“Computer” 2001, Vol. 34, Issue 12, pp. 48–55.

- Data collection, up-dating and deletion;
- Paying attention to internal coherence of database through eliminating data with improper structure;
- Defining data determining the structure of database;
- Making data available on the basis of methods for searching and operating it in order to find data meeting certain criteria for search;
- Authorization of access to data.

Data collection may take place via properly prepared interface by means of which user enters data. For instance, it is possible to enter data reflecting new economic indicators, important in certain regional analyses, that has not been taken into account yet. Data collection may also be based on results generated by simulators (e.g. simulator of different variants of regional development suggested), computing applications (spreadsheet) and different types of databases and data repositories both internal and external, for instance commercial ones. Properly prepared procedures for data extraction and transformation are aimed at verifying data validity paying special attention to its semantics and formal aspects. These procedures may be used for data retrieval from regional databases in communes, counties, etc. Access to particular database resources is gained by means of SQL (Structured Query Language) – DML (Data Manipulation Language) which provides a set of operations for data processing (adding new data, modification of data stored in database, data search and its elimination from database). The concept of DSS proposed involves carrying out the scenario methods and hence database should also include a proper module storing the software and hitherto generated decision-making cases, thanks to which it is possible to use them again for creating new decision-making variants or comparing the results of simulations or modelling. A typical case is a set of decision-making variants, examined by particular investors in a certain region, generated for various preferences of decision-makers.

Database management system, which is a part of decision support system for regional data analyses, may be implemented in accordance with architecture shown in Fig. 5.6. It includes typical elements of DBMS such as mechanisms for sending in queries to databases, data catalog (dictionary) and many tools supporting database management. Furthermore, there are also mechanisms providing effective data retrieval for the purpose of DSS, e.g. tools known from data warehouse as ETL (Extract, Transform, and Load).

DBMS described should support the independence of database's real structure from programs, which is most often achieved through the application of perspective or sub-schema mechanisms. This independence may have a form of logical independence and physical independence. Logical independence entails the resistance of external schemas to changes in conceptual schema such as adding and destruction of attributes, relations or entity. On the other hand, physical dependence of data defines the resistance of conceptual schema to changes made in internal schema, e.g. interchange of memory devices, reorganization of structures or files in memory, modification of indicators.

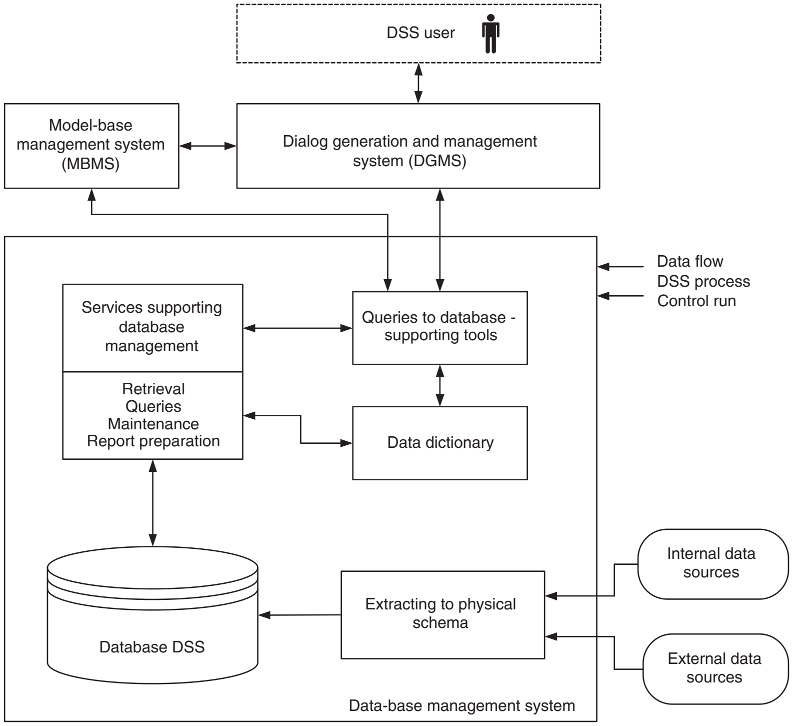

Fig. 5.6 Main elements of data-base management system in decision support system
Source: own elaboration based on A.P. Sage: Decision Support ..., pp. 41–42; C.J. Date: An Introduction to Data Base Systems. Addison-Wesley, Reading, MA, 1985, pp. 124–128

Database integrity is another feature that DBMS should have. It refers to validity and lack of contradiction among data items stored in this base, i.e. to their quality. Integrity is expressed in the form of so-called bonds that database interprets as inviolable conditions of data coherence. The example of integrity condition is the necessity to describe the indicator showing the number of registered unemployed for every 100 of population of working age as a non-negative value. Moreover, data-base management system must provide mechanisms for reducing data redundancy, data transmission service, right conducting of transaction, concurrency control and authorization service.[35]

Data-base management system must also be equipped with a set of tools supporting database administration. Some of these tools are dedicated to database administrator while the others will be used by DSS users. The example of utility routines can be programs importing and exporting data from files to database and

[35] T. Connolly, C. Begg: *Database Systems.* [In Polish] T. 1. Rada Ministrów, Warszawa 2004, pp. 48–52; D.M. Kroenke: *Database Processing. Fundamentals, Design, and Implementation.* Prentice–Hall, Inc. 1997, pp. 130–144.

the other way round, applications for physical release of memory after records deleted, memory merging and making it available when necessary, etc.

The selection of technological solution with reference to database module should be dictated by possibilities for its further development and integration with other systems, e.g. functioning in local administration units among which data will be exchanged. It can be in a sense facilitated as data-base management systems are designed on a larger scale than just for the purpose of decision support systems. This is a fundamental difference compared to model-base management systems (MBMS) and dialog generation and management systems (DGMS) that are dedicated solutions.[36] The following database management systems can be mentioned as examples of solutions: MS SQL, MySQL, DB2, Sybase, Oracle.

5.3.2 Model-Base Management System (MBMS)

Making decision-making propositions available in DSS is closely connected with the module of model-base management. It is the application of MBMS that allows to make very many sophisticated analyses and provides possibilities of interpreting the phenomena investigated (e.g. influence of increase in per capita income on the development of housing construction). Model-base management systems enable decision-makers to simulate decision-making situation on the basis of existing DSS databases as well as model-bases of algorithmic procedure in certain decision-making situations. This may take place, for instance through using instructions and commands for the creation of decision-making models recorded in procedural or non-procedural languages, through abstract models of data, and can be based on mathematical and econometrical software packages.[37] Decision support systems should enable user to use many models (simulation, optimization models, etc.) in such a way so that he/she could analyze decision-making situation in a flexible manner.[38]

Figure 5.7 shows the architecture of model-base management system in computer system of regional development analyses. MBMS structure includes model-base, model management system, model dictionary and links with other DSS modules such as DBMS and DGMS.

MBMS structure presented in Fig. 5.7 may be subject to certain modifications depending on a particular decision-making situation. For instance, in the case of

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[36] C.J. Date: *Database*. Addison-Wesley, Reading, MA 1983.

[37] A.P. Sage, C.C. White: *ARIADNE. A Knowledge Based Interactive System for Decision Support*. “IEEE Transactions on Systems, Man and Cybernetics” 1984, Vol. 14, No 1, pp. 35–47.

[38] A.P. Sage: *Decision Support …*, pp. 14–15; J.D.C. Little: *Models and Managers. The Concept of a Decision Calculus*. “Management Science” 1970, Vol. 16, No 8; G.M. Marakas: *Decision Support Systems in the Twenty-First Century*. Upper Saddle River, Prentice-Hall., New Jersey 1999.

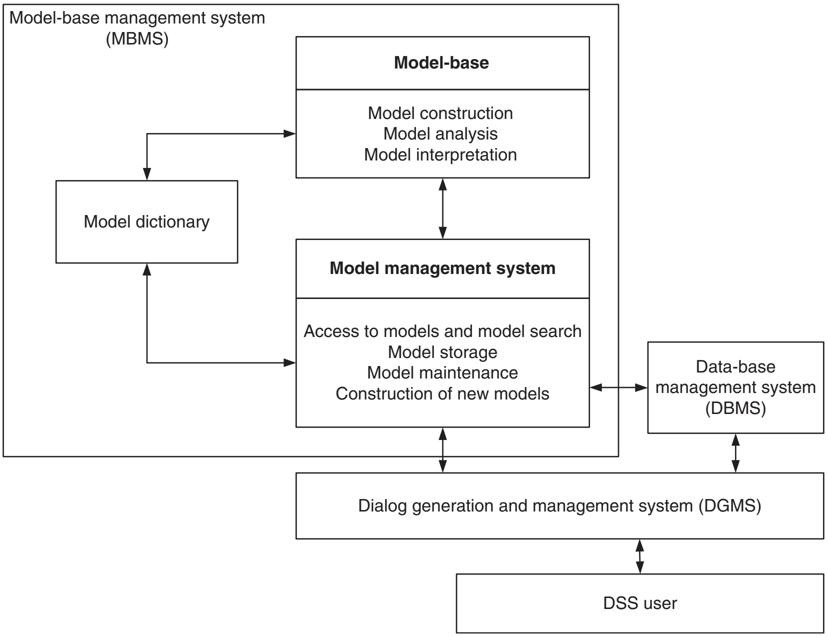

Fig. 5.7 Model-base management system structure
Source: own elaboration based on A.P. Sage: Decision Support . . ., pp. 120–123; D.J. Power, R. Sharda: Model-Driven Decision Support Systems. Concepts and Research Directions. "Decision Support System " 2007, Vol. 43, pp. 1046–1048

regional data analyses, a component connected with simulation model creation and management can be elaborated, and in the case of crop planning in a farm, the aspect of optimization models construction and verification is highlighted. Base of ready models devised by DSS user is subject to constant modification. For example, while investigating decision-making variants for chosen aspects of regional development, innovative models for solving other classes of problems may be created. Once saved in model-base, these models enrich the existing base. Hence, generation of a new model may consist in reconstruction of model that has already been construed or its modification and adjusting to current requirements.

Several areas of functionality should be distinguished here. Integrated and shared MBMS module ought to provide these areas.[39] They encompass model construction, model management, model storage and operation as well as access

[39] T.P. Liang: Integrating Model Management with Data Management. In: Decision Support Systems."Decision Support Systems" 1985, Vol. 1, No 3, pp. 221–232; B. Konsynski: Model Management in Decision Support Systems. In: Data Base Management: Theory and Applications. Red. C.W. Holsapple, A.B. Whinston, D. Reidel. Boston 1983.

to models. Furthermore, a group of attributes ascribed to MBMS should be taken into account, namely[40]

- Control allowing a complete automation and manual control over the selection of models for decision-making task or e.g. enabling user to deicide about access to the process of solution search at each stage;
- Flexibility connected with possibilities of modifying the models at any time and then making them available to other users;
- Feedback supposed to enable DSS user to return to any place in the process of obtaining the solutions at any time;
- User interface offering a convenient and friendly access to models without necessity to know model development principles;
- Removal of model redundancy in model-base by eliminating recurrent models;
- Model coherence characterized by possibility of using the same models by different users and avoiding situations in which there may be various data and versions of the same models.

Therefore, functionality of MBMS module must provide users with:

- Access to models and model search,
- Possibility of using the models and manipulating them,
- Model storage,
- Management of existing models,
- Construction of new models.

Taken certain applications into account, MDBS module may include specific models for a certain area, e.g. econometric, mathematical, statistical models. One may also use ready models oriented toward solving certain decision-making problems, for instance packages such as IBM Optimization Library, SLAM, GPSS.

5.3.3 Dialog Generation and Management System (DGMS)

Dialog Generation and Management System is aimed mainly at providing DSS user with possibility of communicating, making commands and influencing tasks accomplished at different stages in decision-making process. Thus, DGMS is responsible for proper transfer of output information from DBMS and MDBS to DSS users. It is also responsible for right data entry and communication to DBMS and MDBS. Hence, it must provide mechanisms in the form of interface for effective

[40] C.C. White, A.P. Sage, W.T. Scherer: Decision Support with Partially Identified Parameters. "Large Scale Systems" 1982, Vol. 3, pp. 177–190; H.K. Soung, H.Ch. Sang, K.K. Jae: An Interactive Procedure for Multiple Attribute Group Decision Making with Incomplete Information. Range-Based Approach. "European Journal of Operational Research" 1999, Vol. 118, Issue 1, pp. 139–152.

communication between system and user as well as data-base management system and model-base management system. DGMS module is very often a factor determining the success of the entire undertaking as it is a direct interface between DSS and user who usually is not an IT specialist and needs friendly mechanisms offering access to applications.[41] DSS may be operated, e.g. by managers working in regional development departments in communes and counties who can manage the entire decision-making system with the use of DGMS module. User interface is most often used for carrying out the following actions[42]:

– User data entry (decision-making variables, indicators, other information);
– Making final results available (collations, visualizations);
– Configuration of DSS functional modules: data, model, computing techniques, visualization);
– Launching of processing;
– Activating and deactivating system.

Taken interface between a human being and computer into consideration, it can be found in the following three forms (interface itself in integrated form): programming interface, application interface and control interface. The first mentioned provides graphical and window layers of system visible to user. The second one provides a direct contact with user and makes basic feedbacks available. Finally, the last one refers to the visualization of results and is a consequence of the influence that user has on system elements.[43] Communication between user and DSS must be interactive, which results among other things from stages of decision-making process (creation of decision-making variants, construing or using decision-making models, analysis of solutions reached and making a final decision).[44] Figure 5.8 shows a generalized architecture of dialog generation and management system in decision support system for the analysis of regional development and their mutual influence.

Application level encompasses both DBMS module and MBMS module and consists of certain utility routines used in DSS. These programs are very often specialist applications devised for certain purposes and groups of users. Model generation modules based on hitherto existing models, and applications converting the formats of data derived from outside are examples of such programs. Presentation level includes interaction mechanisms of various types appropriate for each

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[41] A.P. Sage: *Decision Support ...*, p. 15.

[42] E. Radosiński: *op.cit.*, pp. 47–49; C.W. Holsapple, S. Park, R.D. Stansifer, A.B. Whinston: *Flexible user interface for decision support systems.*"*System* Sciences" 1988, Vol. III, pp. 217–222; T.P. Liang: *User Interface Design for Decision Support Systems. A Self-Adaptive Approach.* "Information and Management" 1987, Vol. 12, Issue 4, pp. 181–193.

[43] B.A. Myers: *User Interface Tools. Introduction and Survey.*"IEEE Software" 1989, Vol. 6, No 1, p. 18.

[44] I. Benbasat, B.R. Nault: *op.cit.*, pp. 211–213; S.Y. Hung, Y.Ch. Ku, T.P. Liang, Ch.J. Lee: *Regret Avoidance as a Measure of DSS Success. An Exploratory Study.*"Decision Support Systems" 2007, Vol. 42, No 4, pp. 2093–2106.

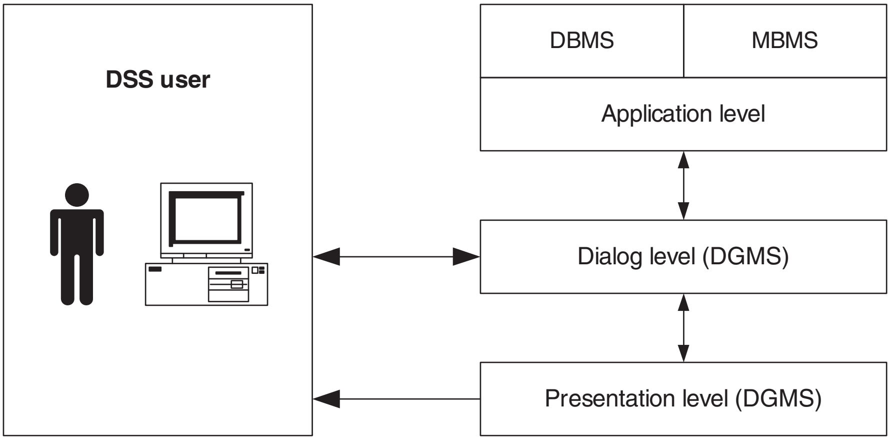

Fig. 5.8 Generalized architecture of dialog generation and management system
Source: own elaboration based on A.P. Sage: *Decision Support* . . ., pp. 152–153

user interface designed. Programs allow to hold a dialog between decision-making model and system user. In such a situation, user can decide about the end of modelling process or its continuation if results received are unsatisfactory. On the other hand, the level of DGMS module dialog permits adding, eliminating or modifying interaction mechanisms regardless of a certain application. Hence, it is a superordinate layer which, thanks to modular construction of dialog generation and management system, offers a possibility of adopting new solutions.

Therefore, dialog generation and management system provides mechanisms for communication with user through different kinds of forms, charts or tables. These objects may be defined and stored in libraries or generated whenever the need arises. The example is a module generating charts or maps on the basis of regional development simulations made for various combinations of economic indicators. Apart from creators of charts and a set of graphical forms, DGMS may also include procedures for conversion of tables into graphical objects, and make mechanisms for their modification as well as many functions explaining DSS operation (help) available.[45] User interface is supposed to provide visual mechanisms that would enable DSS user, who usually is not an IT specialist, to carry out certain tasks, for the purpose of which the system has been created, effectively. Therefore, special emphasis should be put on emission of active graphical screens in the case of which developed forms of visualization replace alphanumeric characters. It is assumed that a good and effective module for dialog generation and management ought to be a combination of various communication techniques. Hence, it is suggested that interface modules are, wherever possible and necessary, implemented in the form as similar to so-called Multimedia User Interface (MMUI) as possible. Interfaces of

[45]A. Dix, J. Finlay, G. Abowd, R. Beale: *Human Computer Interaction*. Prentice-Hall, Upper Saddle River 1993, p. 257.

this type enable user to among other things use Natural Language Processors (NLP) and Virtual Reality (VR) generation systems. Such solutions provide extra functionality in the context of data visualization, i.e. using computer animations.[46] The example of VR system implemented for the system of regional development analyses is a simulator aimed at data collection. In this simulator, user becomes an element of virtual world and any action taken by him/her is interpreted properly and saved in a database.

5.4 Functioning of Computer System for Regional Development Analysis

On the basis of assumptions that have already been presented, a prototype of decision support system in the scope of regional data analysis has been created. This prototype encompasses selected functional modules. The main aim was to create system fragments that would verify the functionality of DSS connected with data collection for the system, generation of decision scenarios, and visualization of results in the form of numerical maps. On the contrary, totally functional solution that could be implemented commercially was not the aim here.

Methodical solution proposed, implemented in the form of decision support system for regional development analyses, is addressed to the following groups of users:

- Persons employed in local government administration at different levels (national, voivodship, county, commune) who are responsible for regional development planning;
- Scientific workers and persons employed in research and development institutions dealing with devising regional development strategy;
- Potential investors looking for the most optimum areas for making investments.

On the basis of system environment prepared, tests have been performed to determine if application solution proposed meets assumptions of decision support system. Having conducted many experiments, it was possible to confirm a thesis that the system enabled a decision-maker to obtain decision-making variants in accordance with preferences he/she had determined, and these solutions were effective and difficult to obtain without computer aid. Functionality, known from spatial information systems, allows to receive the results of computations in the from that is clear and comprehensible to user, i.e. in the form of a digital map. One of the main features of DSS, i.e. system flexibility, enables one to devise its particular modules gradually and partly.

Data for the database of decision support system is collected with the use of proper dialog boxes generated dynamically depending on the character of data

[46] E. Radosiński: *op.cit.*, p. 51.

downloaded. In the course of data entry, the system automatically checks data validity via the verification of completeness and conformity with the standards adopted. This solution turns out to be satisfactory at the stage of prototype creation and initial testing. Yet, it can be unsatisfactory in the case of reading in a larger number of data items from the perspective of interface ergonomics. The solution suggested, particularly when a particular data set will be fixed and it will be possible to forecast its size in advance, involves using a proper sheet for data entry. Similar situation occurs in the case of collecting data from simulator or external databases.

The architecture of DSS proposed has a major advantage, namely it has been construed with the use of Web technologies. Access to decision support system occurs via Web browser, which makes this solution independent from the place where it is used. Thus, operations such as data entry, modelling or decision scenarios generation, can be carried out practically anywhere in the world. This fact is of profound importance especially to potential investors who can seek for variants closest to their expectations at any time and in any place.

In the context of gaining user preferences, it is crucial to create friendly forms with the use of which decision-makers will be able to specify their expectations about a certain decision-making situation. For instance, a form in which he/she could specify his/her expectations (with the use of certain indicators) should be made available to a future investor interested in receiving a map presenting the results of comparison among regions in accordance with certain criteria. Figure 5.9 shows dialog box of DSS in which indicators are selected.

The way of collecting information from system users proposed provides only a basis for determining the current or historical situation. Forecasting of future states may be based on the analysis of change in indicators from the past. Computer simulation "imitating the reality" is an alternative for this solution. It allows to obtain several variants of regional development depending on various external factors forecasted. The result of simulation forms a basis for determining the potential of regions and comparing them (comparison made between the future and time during which the investigation is being conducted).[47]

The concept of decision support system for regional development analysis provides for the implementation of simulator in model-base management system. It consists of two main layers, namely simulation and visualization layers. Such a construction allows a true reflection of a certain fragment of reality, generating many decision-making variants and transferring simulated situations into two- or three-dimensional space, due to which it is possible not only to get to know user preferences but also response to certain ensuing situations.

The way in which simulator operates allows its easy implementation into object technology in which every standard becomes a class on the basis of which objects are created. Inheritance mechanism can be used here for construing a hierarchical structure of standards, i.e. a tree of standards. At the top of this hierarchy, there is a

[47] M. Lipiec-Zajchowska: *Computer Simulation Methods in Macroeconomic Forecasting*. [In Polish]. PWE, Warszawa 1990, pp. 56–58.

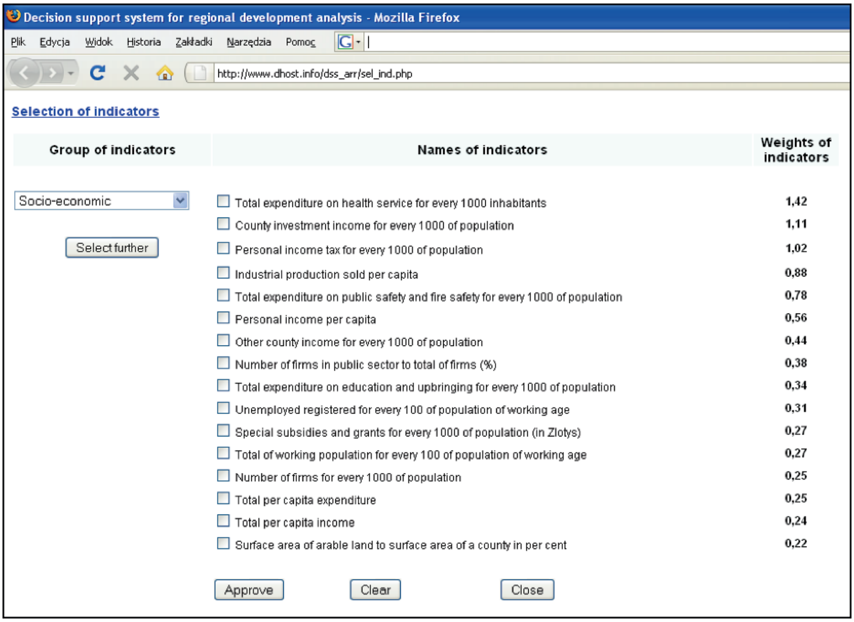

Fig. 5.9 Form for selecting the indicators
Source: own elaboration

standard of standards that has general features (inherited by standards at lower levels) on the basis of which another standards are created. These standards describe objects in a more detailed way. The lower the standards are placed in the hierarchy, the more accurate they are. Such a structure of the structure eliminates the necessity to repeat elements in each model as it is enough to include recurrent feature of object in the standard placed higher. Moreover, standards may include not only rules of object behavior but also procedures, thanks to which objects using various methodologies (depending on needs) may coexist next to one another.

The decision support system suggested enables users to create standards and then compare them with other objects. Figure 5.10 shows the box in which standards and objects are compared.

If the standard is situated outside the area examined, there is no point in using synthetic models and measures based on distance measures, which stems from the fact that objects better than the standard may be described as worse ones, and the better the object is, the more probable it is that it will be described as worse one. At the end, objects similar to the standard will be classified as the best (and not the ones that are the best in reality). The selection of proper measures based on the assessment of actions taken by a decision-maker may be a solution to this problem. As far as decision support system is concerned, model-base management system (MBMS) is responsible for this selection. Models (measures) collected within this system are called as a result of dialog between system user and decision support system. In the case under examination (non-effective classical synthetic measures), other way of

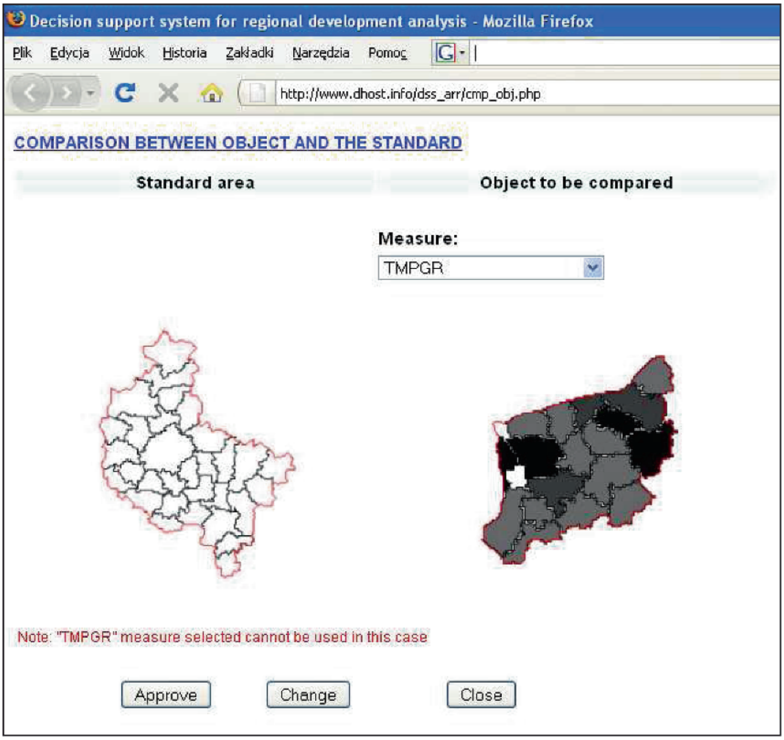

Fig. 5.10 Dialog box with comparison between objects and standard area
Source: own elaboration

making computations should be chosen because of mutual interaction, e.g. with the use of projection-based synthetic measure.

Figure 5.11 shows the example of the visualization of results of modelling process in DSS with the use of traditional TMPGR indicator. Figure 5.12 presents the classification of counties for the above decision-making situation but with the use of projection-based indicator.

As it can be noticed, both measures increased considerably in the years 2003–2004 yet it was TWMRR that was characterized by larger increase than TMPGR. Practically all communes were classified into the highest class. However, due to a small number of communes, there is no diversity among counties. Once the number of classes has been increased (TWMRR values are real numbers) and computing process has been launched again, one will be able to observe differences on the map generated.

Increase in values of TMPGR and TWMRR was caused by the way in which EU grants had been shown in statistics. These grants were not taken into account until 2003, i.e. before Poland's accession to the European Union. They have been shown since 2004, which has led to increase in values of many indicators (in some cases extremely considerable increase).

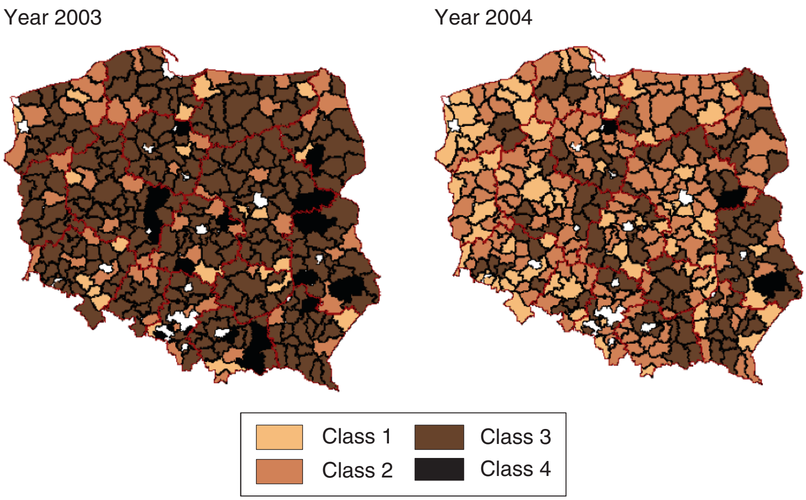

Fig. 5.11 Visualization of the classification of counties with the use of traditional TMPGR indicator. *Source:* own elaboration

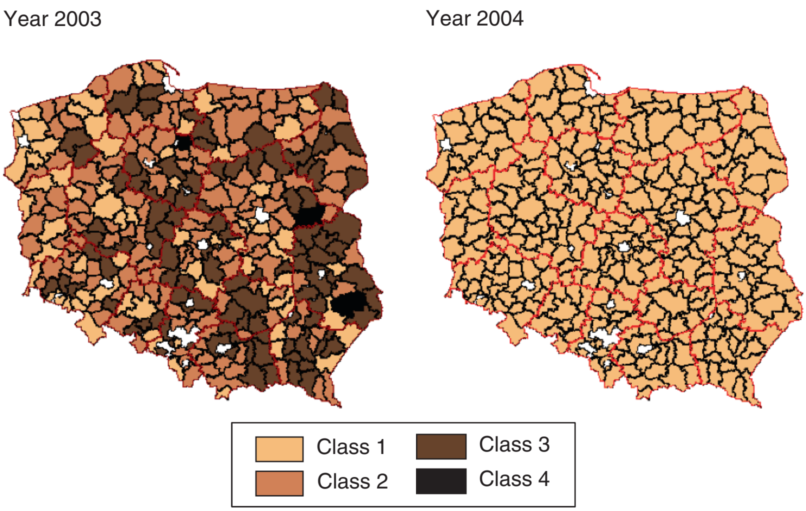

Fig. 5.12 Visualization of the classification of counties with the use of TWMRR (Taxonomic Vector Measure for Regional Development). *Source:* own elaboration

The aforementioned examples confirm that it is effective to select proper models and measures by DSS depending on a particular decision-making situation. As a result of dialog between user and system, it is also possible to interfere into decision-making process.

Verification of DSS solutions oriented to supporting regional analyses must be based on certain real situations. Thanks to user interface (DGMS), decision-maker can adjust technical-economic parameters of decision-making task by taking certain data categories into account and carry out processes of obtaining different decision-making variants.

Two decision scenarios connected with the selection of regions in a country for certain investments will be examined.

5.4.1 Scenario I

The analysis of possibilities for taking investment actions connected with the construction of large shopping center. Four decision-making variants, in which a decision-maker defines indicators he/she is interested in from the perspective of investment planned (Tables 5.1–5.4), are taken into account. For each decision-making variant (variants 1–4), DSS user may add (eliminate, modify) criteria (indicators) determining his/her investment preferences. These indicators have been categorized and names of groups have been presented in Tables 5.1–5.4. Furthermore, weights of particular indicators determining the importance of a particular criterion, weights of indicators in a particular group and their real weights have been specified.

Figure 5.13 shows a form for the selection of indicators. Certain indicators have been marked for each group of indicators. Figure 5.14 shows the visualization of results received.

For the purpose of particular decision-making variants, regions were grouped into four classes characterized by varying degree to which they meet preferences (class 1 – the most desired areas, class 4 – regions characterized by the smallest investment interest). Analyzing the results (maps) received that reflect investment attractiveness of regions (taken changing preferences expressed by a decision-maker into account – variants 1–4), one may observe the degree to which particular indicators influence the results.

5.4.2 Scenario II

The analysis of possibilities for investing in fruit-vegetable-processing plant. Four decision-making variants (variant 1–4) have been examined. In each variant, a decision-maker manipulates indicators from his/her point of view (Tables 5.5–5.8). The selection of indicators in DSS is analogical to the one that has been shown in Fig. 5.13.

Figure 5.15 shows the distribution of investment attractiveness for variants under examination (1–4). It can be noticed that in this decision-making scenario not all new indicators (that have been added) have a profound influence on the map of investment attractiveness. Summing up the discussion on the concept of decision support system used for supporting regional analyses, it should be stated that the

Table 5.1 Selection of indicators and their weights for variant 1 in the first decision-making scenario

Number	Indicator	Group	Weight of indicator	Weight of indicator in a group (%)	Real weight of indicator (%)
5	Population of working age for every 100 of population	socio-demographic	0.04	100.00	50.00
42	Unemployed registered for every 100 of population of working age	socio-economic	0.31	100.00	50.00

Source: own elaboration

Table 5.2 Selection of indicators and their weights for variant 2 in the first decision-making scenario

Number	Indicator	Group	Weight of indicator	Weight of indicator in a group (%)	Real weight of indicator (%)
5	Population of working age for every 100 of population	socio-demographic	0.04	100.00	33.33
42	Unemployed registered for every 100 of population of working age	socio-economic	0.31	100.00	33.33
45	County hard surface roads for every 100 km^2	infrastructural-technical	0.29	100.00	33.33

Source: own elaboration

functionality of such solutions meet expectations aroused by complex issues relating to regional development planning. Methodical solutions proposed, implemented into DSS, work in real situations connected, e.g. with the selection of a region by future investors. The possibility of implementing different types of decision-making models (simulation, optimization models, etc.) into the system as well as the functionality of solutions in the scope of geographical information systems, provides one with an interesting tool both for making multi-faceted analyses, simulations, modelling and for effective data collection as well as visualization of results received (for instance in the form of numerical maps). On the other hand, Web technologies offer access to such systems and provide easy and comprehensible to everyone navigation at the level of Web browsers.

Table 5.3 Selection of indicators and their weights for variant 3 in the first decision-making scenario

Number	Indicator	Group	Weight of indicator	Weight of indicator in a group (%)	Real weight of indicator (%)
45	County hard surface roads for every 100 km^2	infrastructural-technical	0.29	100.00	33.33
5	Population of working age for every 100 of population	socio- demographic	0.04	100.00	33.33
42	Unemployed registered for every 100 of population of working age	socio-economic	0.31	58.82	19.61
38	Surface area of arable land to surface area of a county in per cent	socio-economic	0.22	41.18	13.73

Source: own elaboration

Table 5.4 Selection of indicators and their weights for variant 4 in the first decision-making scenario

Number	Indicator	Group	Weight of indicator	Weight of indicator in a group (%)	Real weight of indicator (%)
32	Length of working sewage system for every 100 km	infrastructural-technical	0.92	76.27	25.42
45	County hard surface roads for every 100 km^2	infrastructural-technical	0.29	23.73	7.91
5	Population of working age for every 100 of population	socio-demographic	0.04	100.00	33.33
42	Unemployed registered for every 100 of population of working age	socio-economic	0.31	58.82	19.61
38	Surface area of arable land to surface area of a county in per cent	socio-economic	0.22	41.18	13.73

Source: own elaboration

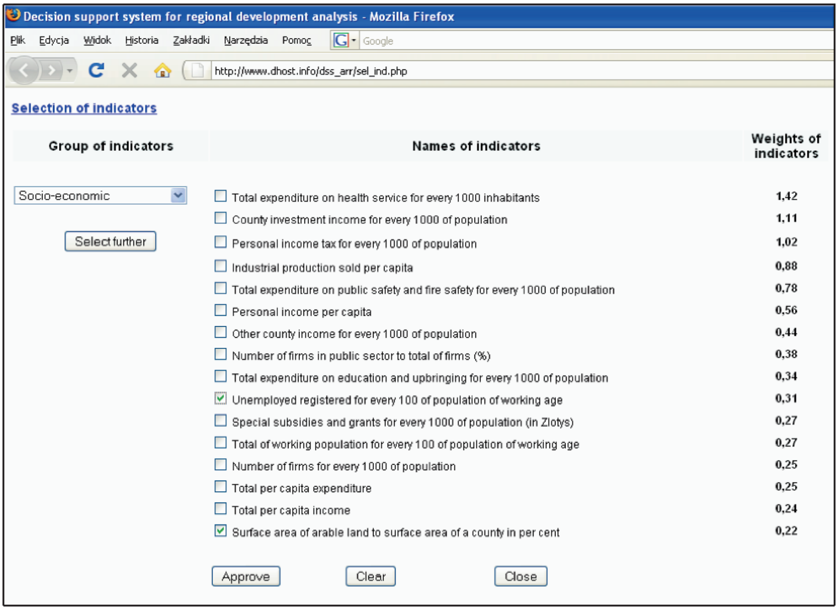

Fig. 5.13 The example of a form for indicator selection (variant 4). *Source:* on elaboration

Fig. 5.14 Schematic distribution of regions' attractiveness for the first scenario: (**a**) variant 1; (**b**) variant 2; (**c**) variant 3; (**d**) variant 4. *Source:* own elaboration

Table 5.5 Selection of indicators and their weights for variant 1 in the second decision-making scenario

Number	Indicator	Group	Weight of indicator	Weight of indicator in a group (%)	Real weight of indicator (%)
33	Number of flats per one occupant	infrastructural-technical	0.08	100.00	50.00
2	Population density	socio-demographic	0.74	100.00	50.00

Source: own elaboration

Table 5.6 Selection of indicators and their weights for variant 2 in the second decision-making scenario

Number	Indicator	Group	Weight of indicator	Weight of indicator in a group (%)	Real weight of indicator (%)
33	Number of flats per one occupant	infrastructural-technical	0.08	100.00	50.00
2	Population density	socio-demographic	0.74	76.58	38.29
48	Dynamics of demography	socio-demographic	0.23	23.42	11.71

Source: own elaboration

Table 5.7 Selection of indicators and their weights for variant 3 in the second decision-making scenario

Number	Indicator	Group	Weight of indicator	Weight of indicator in a group (%)	Real weight of indicator (%)
33	Number of flats per one occupant	infrastructural-technical	0.08	100.00	33.33
2	Population density	socio-demographic	0.74	76.58	25.53
48	Dynamics of demography	socio-demographic	0.23	23.42	7.81
11	Personal income tax for every 1,000 of population	socio-economic	1.02	100.00	33.33

Source: own elaboration

Table 5.8 Selection of indicators and their weights for variant 4 in the second decision-making scenario

Number	Indicator	Group	Weight of indicator	Weight of indicator in a group (%)	Real weight of indicator (%)
11	Personal income tax for every 1,000 of population	socio-economic	1.02	100.00	33.33
33	Number of flats per one occupant	infrastructural-technical	0.08	100.00	33.33
48	Dynamics of demography	socio-demographic	0.23	40.23	13.41
50	Regional attractiveness index	socio-demographic	0.34	59.77	19.92
11	Personal income tax for every 1,000 of population	socio-economic	1.02	100.00	33.33

Source: own elaboration

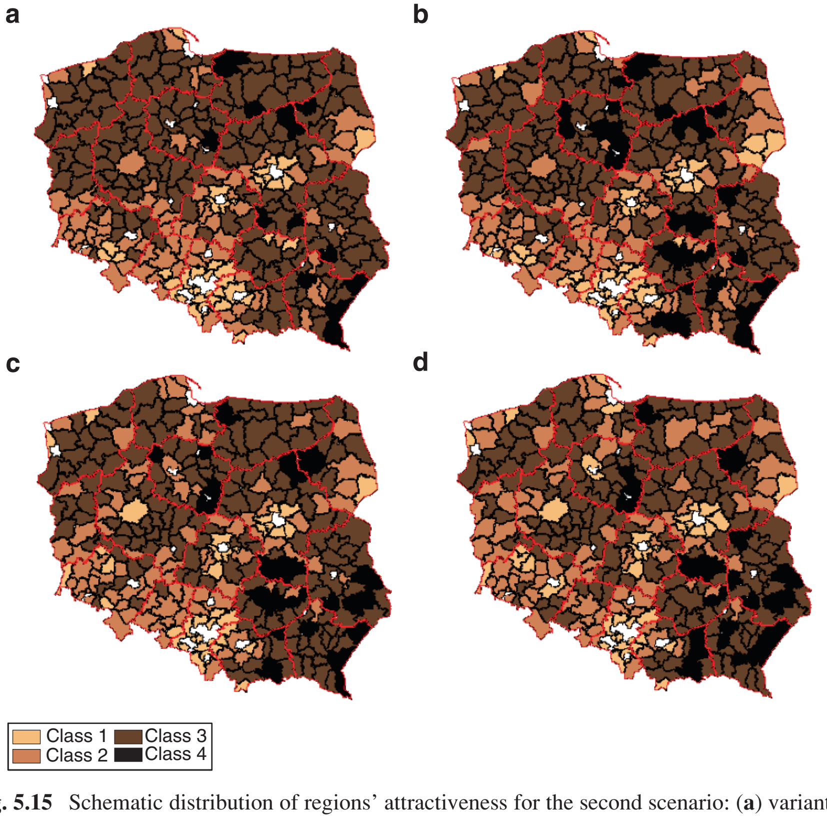

Fig. 5.15 Schematic distribution of regions' attractiveness for the second scenario: (**a**) variant 1; (**b**) variant 2; (**c**) variant 3; (**d**) variant 4. *Source:* own elaboration

Assumptions made with reference to the architecture of decision support system for regional development analysis, presented in this chapter, form a basis for the development of a fully functional computer system. For the purpose of verification of the method (measure) proposed and automation of obtaining decision-making variants, the prototype of a system with limited functionality has been built. Further design-implementation work should define current needs resulting from interest in the system from potential users.

Conclusions

The main objective formulated by the author of the present publication was to devise new methods and tools supporting regional and local development analysis. In order to meet this objective, three purposes had to be achieved: research purpose, methodical purpose and applied purpose.

Research purpose was attained via the literature study that allowed to get to know determinants of regional and local development in Poland. The analysis of statistical data, characterizing particular regions, enabled to state that objective reflection of the potential of particular territorial units was not possible without quantitative approach and statistical-mathematical methods. The review of methods hitherto used in the examination of regional development showed that they did not reflect regional reality fully.

Methodical purpose consisted in developing the concept of method based on vector calculus and premises as well as prototype of computer system aimed at the analysis of socio-economic data presented by statistical offices and other institutions. This system is supposed to facilitate investment decision-making to decision-makers and entrepreneurs at regional and local levels. For the sake of the system, methods used for regional development investigation were analyzed paying special attention to the fact if they allowed the manipulation of large data sets. Furthermore, attempt was made to record these methods in the notation of vector calculus or carry out such a modification that would make it possible.

In the publication, multi-variant computations were made with the use of method based on vector calculus and also in computer system into which the method was implemented. The results received confirmed research hypothesis according to which the method proposed reflected the development of particular regions more accurately than hitherto used methods based on distance measures.

It should be highlighted that multi-field results of computations provided by the method suggested may be presented for various decision-making scenarios in a cartographic way that enables people who do not know specialist quantitative methods used for decision-making to understand the problem solved in a more transparent way.

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