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SUSTAINABLE CITY COMPACTNESS EVALUATION ON THE BASIS OF GIS AND BAYES RULE

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ABSTRACT. For a long period in Lithuania there was a tendency to build extensively leaving huge wasteland insertions in the urban fabric of the cities. As a result cities overspread such a big territory that the edges of the cities and location of provision centers are almost inconceivable. In this paper the method of game theory fitted for Geographic Information System (GIS) is given to evaluate and calculate the rate of city compactness. This methodology can help city planners to determine and localize problems of urban fabric density, to enhance motivation and versatility of decisions. For evaluation of city compactness efficiency attributes and the weights of it based on expert judgment are established. This model is applied to Kaunas city. On the basis of GIS the data bank of population, public transport stops and places of public attraction is prepared. Area of the city was divided by rectangular grid and analysis was made calculating efficiency attributes for each sector, applying Bayes rule. The results were visualized as diagrams showing most problematical areas.

KEYWORDS: Bayes rule; City compactness; Evaluation; Attributes weights; Attributes of efficiency

1. INTRODUCTION

The debates on sustainable urban development in the world are going on now very intensively and compact city appears to be one of the best realizations for a sustainable development (Livingstone and Rogers, 2003). A lively discussion of the appropriate form for sustainable urban development has been stimulated by the European Commission's green paper on the urban environment, by a number of recent planning policy guidance notes issued by the department of the environment in Britain, by general urban policy changes in Australia and by series of urban design proposals for new forms of suburban development in the United States. Incrasing city compactness is the most effective measure to deal with the main problems of European cities today. The new attempts made in recent years attain criticism like in the case of Great Britain Environment Department decision to build not less than 25 % af new housing in previously developed land (using converted vacant industry zones and other "brown field" land). Increasing city compactness is complex and long term process (it must take ~50 years to make the best) which supposes flexible law system and support of local politics (Chinyio *et al.,* 1998; Urban Task Force, 1999; Commission of the European Communities, 2005).

Nickel *et al.* (2005) stated that Locational

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Analysis has become a very active field of research in the last decades among both practitioners and academia. He presents a survey of the most representative multi-attribute location problems.

Munda (2005) states that sustainable development is a multidimensional concept, including various perspectives. He showed that multi-attribute decision analysis is an adequate approach for dealing with sustainability conflicts at both micro and macro levels of analysis. For example Barbier (1987) writes that sustainable development implies: "to maximise simultaneously the biological system goals (genetic diversity, resilience, and biological productivity), economic system goals (satisfaction of basic needs, enhancement of equity, increasing useful goods and services), and social system goals (cultural diversity, institutional sustainability, social justice, participation)". This definition correctly points out that sustainable development is a multidimensional concept, but as our everyday life teaches us, it is generally impossible to maximise different objectives at the same time, and as formalised by multi-attribute decision analysis, compromise solutions must be found.

Development trends of Lithuanian cities are almost identical with European and we can perfectly use the experience of their planners and try to realize this knowledge in practice. By preliminary information Lihuanian cities now cover from 5 times (Vilnius city) to 2 times (Panevezys city) bigger areas than it is possible according to compact city theory.

It is inadmissible to leave abandoned land in the cities and to steer development to the adjacent territories not taking care of existing situation. There is a lot of wasteland inside the cities and the boundaries of cities are stretching forward and ruining countryside. The city provision centers became difficult to localize because the level of spatial organization is now very minimal and based mostly on access by automobile (Urban Task Force, 1999; Rogers and Power, 2000).

There must be taken measures to calculate damaging impact of city sprawl; the careful way of economic development and using land resources more effectively must be found. The filling of wastelands must be underlying option as well as bigger population density, mixed-use adaptive environment, balanced planning and maximum dependence on public transport (Frey, 1999).

Gradual and more concentrated development is more effective. It gives opportunity to use existing infrastructure and makes it possible to use city wastelands. Clever planning of inner areas leads to minimizing hard covering per citizen and greening of an environment. Several examples of European cities show that development can be targeted to the inside city. It is enough to develop existing unused territories if planning is good. Such planning minimizes amount of land taken, creates sustainable environment with population density sufficient for normal functioning, gives benefit to the city and protects the countryside (Commission of the European Communities, 2004).

The object of the compact city theory is the density of the cities and finding optimal density values. City density can be interpreted as a built-up and green area crossrate but here the discussion will go on about population density and territorial distribution of population because this rate characterizes the city as a developing and changing system.

The analysis of the city form in the aspect of compactness is quite new subject of research. This is the reason why there are no steady methods of analysis. For the evaluation of city compactness different statistical analysis methods are applied, the main difference between these methods is the way how the area of the city is divided and what attributes are used. Using these methods different subsystems of the city can be explored – street network, public transportation, infrastructure, built-up area, population density, location of the working places, etc. It can be calculated how these characteristics change in the teritorry and during periods of time. Usually the territory is divided in concentric circles, segments of concentric circles or simply by dividing territory by rectangular grid (Thingh *et al.,* 2001).

Typical example of recent researches is the estimation of German cities compactness acomplished by Dresden regional ecological development department in 2001 (Thingh *et al.,* 2001).

In the first stage urban form is covered by 500x500 m grid. The value of used land for each cell is evaluated. For the each pair of cells i and j with their used land areas z_i and z_j, mutual gravitation is counted acording to the law of gravitation:

$$a_{ij} = \frac{1}{c} \cdot \frac{z_i \cdot z_j}{d_{ij}^2} \qquad (1)$$

where d_{ij} is Euclidean distance between the centers of the cells and $c = 100\text{m}^2$ is proportional factor.

A degree of compactness G is established as a mean value in the gravitation matrix A:

$$G = \frac{\sum a_{ij}}{n(n-1)/2} \qquad (2)$$

where n is amount of all cells of an analysed theritory which have more than 5 m^2 of used land.

G is a measure of average spatial gravitation between the cells of teritory. The more built-up land is dispersed the less is spatial gravitation. The more structure is compact the spatial interaction between cells is greater and the measure displays it (Thingh *et al.,* 2001).

In most sources it is agreeed that the best population density in European type cities is around 60 people per hectare (pph). Social and economic conditions are changing and so changes the urban fabric of city or district, city macrostructure and land-use. But basic necessities of human life are mostly the same. These necessities can be based on fullfilling daily needs, and special needs of different importance. The reach-out of provision centers with diferent levels of services and equipment is always necessary. Reach-out of open countryside is also one of the constant neccesities. The mobility is even more constant and essential need – in the city and city region it must be achieved without congestion and degradation of environment. Compact city theory gives the solution – how to deal with these necessities. Thereby applying compact city planning pricipies for more sustainable city functioning can be attained in almost all situations of nowaday European cities (Frey, 1999; Commission of the European Communities, 2004).

It is obvious that the compact city has environment and energy consumption advantages and gives social benefit. The main arguments for the compact city are as follows (Rogers and Power, 2000):

- The utilization of previously derelict land and developed infrastructure, rejuvenation of it;
- Effectiveness of public transport, overall decrease of transport routes and overall decrease of polution, increase of mobility;
- Increased vitality due to higher population density;
- Possibility of social mix.

There are a lot of possibilities to densify urban fabric of the cities and before concerning which measures to take detail analysis of city compactness is needed.

There are three ways of dealing with the mismatch between population and built-up area:

- Strategy one: increase the population in those areas with a population density below the city average. This strategy is based on the assumption that people will be attracted to move from the countryside or from the outside the the city into under-populated areas of the city.
- Strategy two: increase the population in those areas below the threshold average by redistribution of population from areas with densities above average.
- Strategy three: decrease the size of built-up area of the city in those districts below the population average. This is based on assumption that the population in higher density area will not be reduced

> and population in the lower density areas needs to be more concentrated into a considerably smaller area to achieve the required gross density.

Traditional decision support techniques lack the ability to simultaneously take into account these factors and conditions. The opinions are uncertain and preferences appear for possible consequences or outcomes. Utility theory has been developed by Von Neumann and Morgenstern (1947), it give us the elements that we need, for to make a quantification of preferences in the process of making decision under uncertainty.

Similarly, GIS, while recognized as useful decision support technologies, do not provide the means to handle multiple decision factors. Jun (2000) provided a framework for integrating the strengths of GIS, expert systems, and the analytic hierarchy process to incorporate the decision maker's preferences on a range of factors used in finding optimally suitable sites.

Kitsiou *et al.* (2002) presents a study, in which a methodology was developed for the multi-dimensional evaluation and ranking of coastal areas using a set of attributes and based on the combination of multi-attribute choice methods and GIS.

Store and Jokimäki (2003) presents a method based on the combined use of empirical evaluation models and models based on expertise in GIS environment. GIS was used to produce the data needed in the models, and as a platform to execute the models and to present the results of the analysis. Furthermore, multi-attribute evaluation methods provide the technical tools for modeling the expertise and for connecting (standardizing, weighting, and combining) the habitat needs of different species.

Lant *et al.* (2005) examines the policy implications of the analysis conducted using this spatial decision support system (SDSS). The structure of SDSS more in-depth is described by Beauleu *et al.* (2000), Sengupta *et al.* (2000), Sengupta (2003), Sengupta and Benett (2003), Bennett *et al.* (2000, 2004).

Different elements can be extracted that are supporting one decision rather than another. The indices can be modified after the relative evaluation of each of them has been estimated. Many methods have been proposed to model the decision making phase. Here, more particularly, we are concerned by Bayes rule (Raiffa, 1970; Keeney and Raiffa, 1976; Cocquerez and Philipp, 1995; Baundry, 2000, 2001a, 2001b). Zanakis *et al.* (1998) states that several methods have been proposed for solving multi-attribute decision making problems (MADM). A major criticism of MADM is that different techniques may yield different results when applied to the same problem. In simulation experiment they investigated the performance of eight methods: ELECTRE, TOPSIS, Multiplicative Exponential Weighting (MEW), Simple Additive Weighting (SAW), and four versions of AHP (original vs. geometric scale and right eigenvector vs. mean transformation solution). Dissimilarities in weights produced by these methods become stronger in problems with few alternatives; however, the corresponding final rankings of the alternatives vary across methods more in problems with many alternatives. Although less significant, the distribution of attributes weights affects the methods differently. In general, all AHP versions behave similarly and closer to SAW than the other methods. ELECTRE is the least similar to SAW (except for closer matching the top-ranked alternative), followed by MEW. TOPSIS behaves closer to AHP and differently from ELECTRE and MEW, except for problems with few attributes. A similar rank-reversal experiment produced the following performance order of methods: SAW and MEW (best), followed by TOPSIS, AHPs and ELECTRE. It should be noted that the ELECTRE version used was adapted to the common MADM problem and therefore it did not take advantage of the method's capabilities in handling problems with ordinal or imprecise information.

2. INITIAL DATA FOR MULTI-ATTRIBUTE ANALYSIS

The data used for the analysis is characterizing intensity of land use. There were three groups of data – living places, working places and places of strongest public attraction (provision, service, market and trading centers). For the description of this data the GIS was used.

Living places were appointed from unification of Kaunas city geo-adressing data base and table of registered citizens with their living adresses. The GIS that was made contains point objects for the each building with aditional data about number of people living in the building. Operations required to calculate these values were programmed using Oracle DBMS. The objects selected from innitial data and is used in calculation were 87 % of total. Prepared data was processed in ArcGIS program medium.

Locations of working places were calculated using the data kindly given by social insurance information service. These are very dynamic and quicly changing type of data and the precision is less than data about living places. In calculations some presumptios and undirect analytical methods were used also.

Information about public attraction centers was obtained from recently developed specialized plan of big market-places dislocation in Kaunas city and the data about visitors of such centers.

Another group of data that experts recognized as important in the compact city is the level of public transport network development. To estimate this data the discused data of land use intensity and a plan of public transport routes and stops were used.

The results of the comparative analysis of districts are presented as a grouped decision making matrix where columns contain n alternative districts, while all quantitative and conceptual information pertaining to them is found in Table 1.

In order to perform a complete study of the district a complex evaluation of its land use intensity, public transport development level and other aspects is needed. Quantitative descriptions provide this information.

Quantitative information is based on attributes systems and subsystems, units of measure, values and initial weights of the projects' alternatives. Quantitative information is more accurate and reliable than conceptual and allows to use multi-attribute decision making methods.

The grouping of information in the matrix should be performed so as to facilitate the calculation process and to express their meaning. The attributes system here is formed from attributes describing the city compactness as expressed in a quantitative form (quantitative attributes) and the attributes describing the sustainability of the city land use which can not be expressed in a quantitative form (qualitative attributes).

The values of qualitative attributes must be put into a numerical and comparable form. They must be comparable because a "medium" value for one qualitative attribute must receive approximately the same numerical values as "medium" values of other qualitative attributes.

3. THE PROBLEM OF CITY COMPACTNESS ANALYSIS

In our case study built-up territory is divided into n x squares which are called cells (Figure 1). The analysis is performed with the data of each cell. Attributes of sustainable city compactness have been selected on the basis of interrogation of competent experts on planning territories. 35 experts participated in this process. As a result of the analysis of interrogation data the most important attributes have been selected.

The different characteristics of the cells are counted and the level of matching to the compact city model is calculated by Bayes rule method. The obtained results are displayed in diagram with cells colored in different intensity to show the most problematic areas. The approximation method is used – at first stage territory of the city is divided into bigger cells (2x2 km), when problematic areas are found

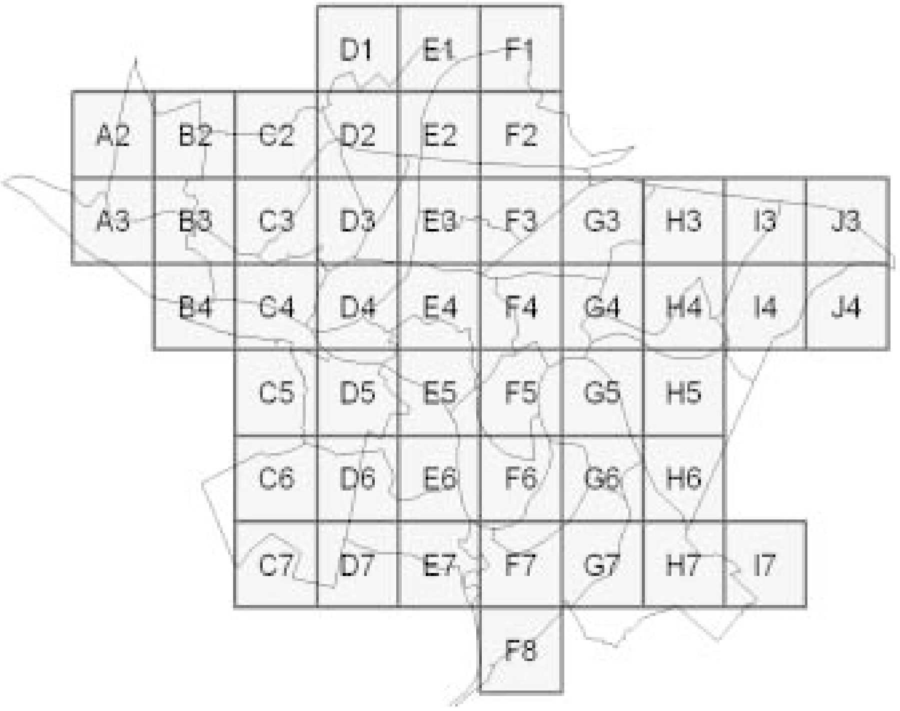

Figure 1. Division of Kaunas city into rectangular cells

these areas are analyzed dividing them by the grid of 500x500 meters.

Five attributes to characterize properties of the district were selected as follows:

1. Population density.
2. Level of even distribution of population.
3. Population and working places ratio.
4. Population and objects of public attraction ratio.
5. Density of public transport network.

In the future developing this methodology will include additional attribute from the rules and regulations of territorial planning documents.

Population density **(x_1)** has an optimal value, which is 60 people/ha and is dimensioned by points (1–10 interval). Relation between population density in people/ha and point value is drawn in the Figure 2. In Lithuanian cities population density varies from 0 to ~220 people/ha. From the position of compact city theory bigger population density is better than less compared to optimal.

In the Kaunas city territory population density varies from 12 to 95 people per hectare. The biggest population density is in block housing areas built up in Soviet Union period. In these districts live around 65 % of city inhabitants. Other areas have population density much less than optimal for a compact city. The values were taken from GIS database made from Kaunas city municipality inhabitant registry (Figure 3).

Level of even distribution of population **(x_2)** is second strongest factor showing how the district is built-up. The best building style in the terms of compactness is of constantly changing density, and building with intervals or sharp change in density shows less sustainable development of a district.

Level of even distribution of population in city cell is measured by arithmetical average of squared values differences sum of lines and columns (Equation 3 and Figure 4).

$$x_{2i} = \frac{1}{4}\sum_{j=1}^{4}\frac{(a_{j1}-a_{j2})^2+(a_{j2}-a_{j3})^2+(a_{j3}-a_{j4})^2+(a_{1j}-a_{2j})^2+(a_{2j}-a_{3j})^2+(a_{3j}-a_{4j})^2}{6} \qquad (3)$$

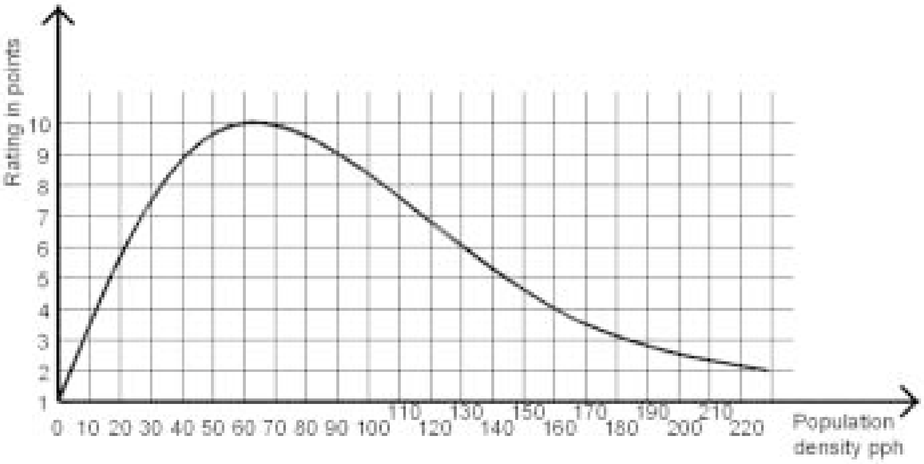

Figure 2. Scale for attribute of population density in the city cell value determining (our graphical interpretation of population density rate in the cities according to Frey, 1999)

Figure 3. Population density in Kaunas city cells (x_1)

	1	2	3	4
1	a_{11}	a_{12}	a_{13}	a_{14}
2	a_{21}	a_{22}	a_{23}	a_{24}
3	a_{31}	a_{32}	a_{33}	a_{34}
4	a_{41}	a_{42}	a_{43}	a_{44}

Figure 4. Territorial distribution of population in city cell

It is assumed that the less value of x_2 of the city cell is better for evaluation of city compactness.

The most even distribution of population in Kaunas city is found in the private house territories without nature objects and green belts (Figure 5). Data was taken from GIS.

Population and working places ratio **(x_3) shows** possibilities to work near the living place for the citizens and in this way to make shorter daily trips (Figure 6). According to the data given by Lithuanian Department of Statistics 56 % of the citizens are of employable age. When calculation of relation between living places and working places is done it is confirmed that the best value is when population have all the working places in their district. If there are more working places than people living in the district it is also problem in compact city because it creates the need for other people to come and produces longer distances also. The same situation takes place when the number working places is less than 56 % of number of living places – the people from this district will have to migrate to other places. Of course there is no such a fact that everybody is working in the place near from their living place, but it is an objective to be reached in the compact city at least in theory.

In Kaunas city working places are situated mostly in city center and industrial zones. Most of city districts are very mono-functional and

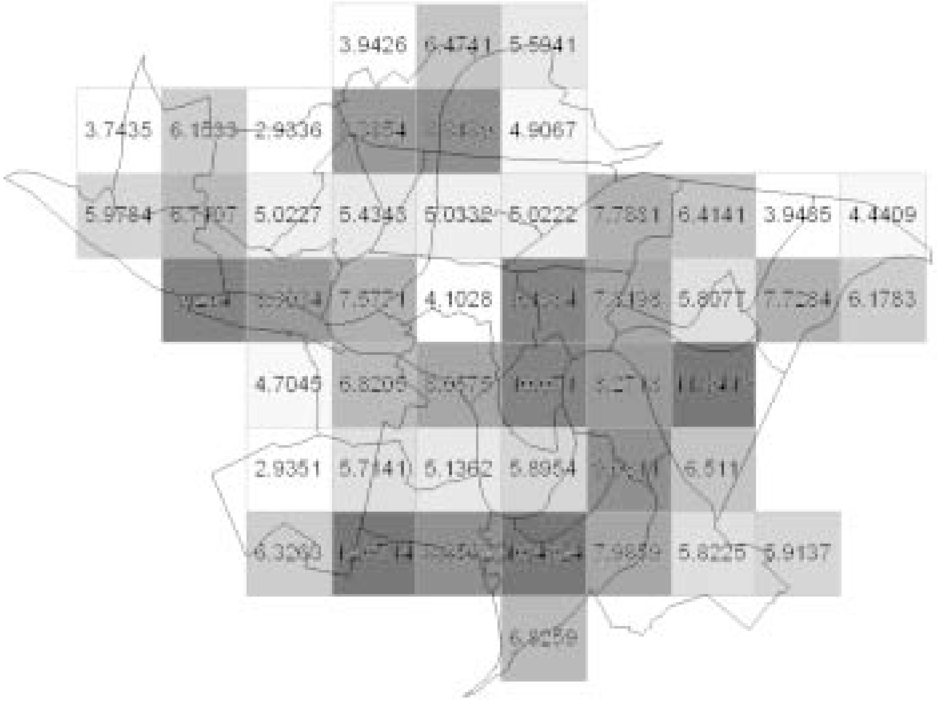

Figure 5. Even distribution level of population in the Kaunas city cells (x_2)

Figure 6. Population and working places ratio in the Kaunas city cells (x_3)

the results show bad distribution and locations of working places. The data about working places was taken from Lithuanian social insurance institution and put to GIS database.

Population and the objects of attraction ratio **(x_4)** shows the possibilities for the citizens to find provision objects, services, fulfill daily needs near the living place and in this way to make daily trips shorter (Figure 7).

When calculations are made it is reputed that the more such provision center are nearby the better is development of the district. There is one theoretical problem in this case if there are very little people living in the district and there are huge objects that attract thousands of people. In this case there is maximum barrier for this ratio and if it expands this limit it is stated that district meets the compact city requirements at a medium level.

In Kaunas city the objects of public attraction are located nearby popular living and working areas. In peripheral areas there are no such objects and it gives bad valuation. City center has too little provision objects compared to the number of people working there. The data about public attraction objects was taken from plan of trade and commerce objects recently developed by Kaunas municipality enterprise for planning. The objects that attract most people today are the biggest supermarkets, shopping centers, shopping malls.

Public transport network development level, as experts state it, is also one of the most important points in compact city. This category in our case is defined by ***Public transport network density*** **(x_5)** in the district (Figure 8). Public transport stops and number of routes are calculated and divided by the sum of living places, working places and public attraction places. In Kaunas city public transport is developed sufficiently in the eastern and northern sides of a city. In city center and western side development is not sufficient. There are three main types of public transport –

Figure 7. Population and the objects of attraction ratio in the Kaunas city cells (x_4)

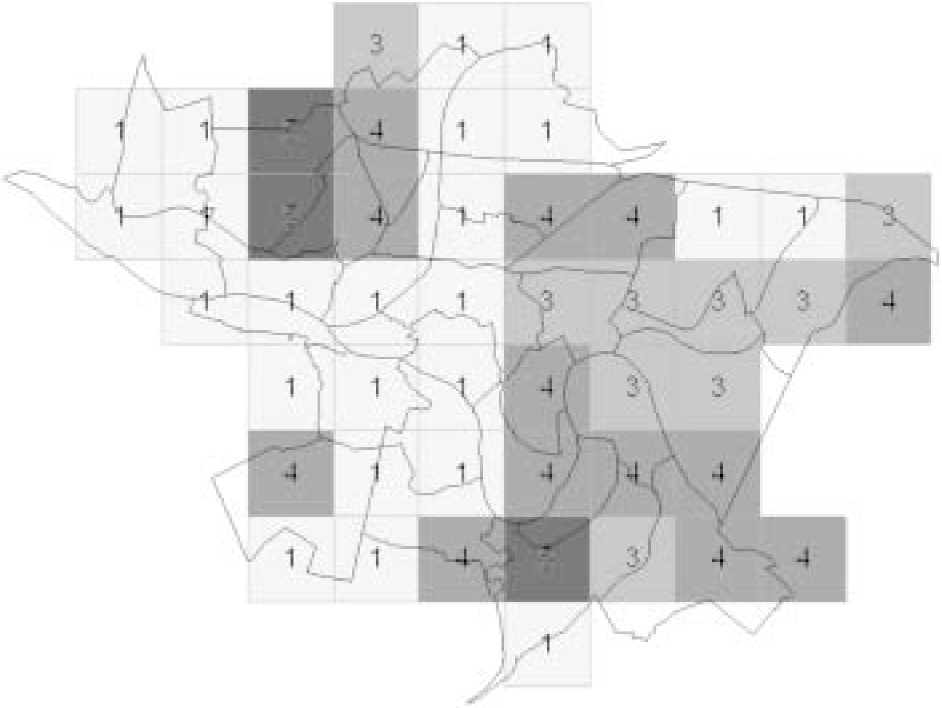

Figure 8. Public transport network density in the Kaunas city cells (x_5)

trolleybuses, buses, private micro-buses. The data about public transport routes was taken from general Kaunas city plan confirmed in year 2004.

4. DETERMINATION OF THE ATTRIBUTES WEIGHTS

Multi-attribute analysis is widely used in selecting the best alternative from a finite set of decision alternatives with respect to multiple, usually conflicting attributes. A special feature of the model is the determination of attributes weights. Many methods in multi-attribute decision making require information about the relative importance of each attribute (Hwang and Yoon, 1981). Multi-attribute analysis methods that generate a cardinal preference of the alternatives require the decision maker to provide information in specific ways on:

- Relative importance (weights) of the attributes with respect to the objectives of the decision problem;
- Performance ratings of the alternatives in relation to each attribute (Keeney and Raiffa, 1976; Hwang and Yoon, 1981; Zeleny, 1982; Colson and de Bruyn, 1989; Chen and Hwang, 1992; Vincke, 1992).

A number of methods for determining attributes weights in multi-attribute analysis have been developed. It is usually given by a set of weights which is normalized to sum to 1. Eckelrode (Eckenrode, 1965) suggests six techniques for collection of the judgements of decision makers concerning the relative value of attributes. Keeney and Raiffa (1976) first present a value trade off approach. This approach requires the decision maker to compare pairs of alternatives with respect to each pair of attributes, with the assumption that both alternatives have identical values on the remaining attributes. The high value of one alternative is traded off for the low value of the other through a series of adjustments until indifference value is achieved. The attributes weights are determined after numerous value tradeoff processes. Erlandson (1978) investigated combined multidimensional scaling and ordering techniques. Hwang and Yoon (1981) stated that they are simple, but to a single decision maker, we need more elegant methods to substitute a small (single) statistical sample for a large one. They dealt with four techniques recently developed: eigenvector method, weighted least square method, entropy method and LINMAP. Entropy method and LINMAP need decision making matrix as a part of input. In eigenvector method the Saaty (1977) scale ratio gives an intensity of importance. A weighted least square method is proposed by Chu *et al.* (1979) to obtain the weight. This method has the advantage that it involves the solution of a set of simultaneous linear algebraic equations and it is conceptually easier to understand than Saaty's (1977) eigenvector method. When the data of the decision matrix are known, instead of the Saaty's pairwise comparison matrix, the entropy method and the LINMAP (Linear programming techniques for Multidimensional Analysis of Preference) (Srinivasan and Shocker, 1973) method can be used for evaluating weights. Srinivasan and Shocker developed LINMAP for assessing the weights of attributes as well as for selecting the alternative. Saaty (1980) develops a pairwise comparison approach based on the hierarchical structure of the problem. A reciprocal pairwise comparison matrix is constructed based on a subjective scale of 1 – 9. Attributes weights are obtained by synthesising various assessments in a systematic manner. This approach is generalised by Takeda *et al.* (1987) to reflect the decision maker's uncertainty about the estimates in the reciprocal matrix. Barzilai (1997) analyses properties of acceptable solutions of this approach. Laarhoven and Pedrycz (1983), Buckley (1985) and Juang and Lee (1991) further extend this approach to accommodate the subjectiveness and imprecision inherent in the pairwise comparison process using fuzzy set theory (Zadeh, 1965, 1973, 1975a, 1975b, 1979). However, in certain situations this approach may cause the rank reversal phenomenon (Perez, 1995). Von Winterfeldt and Edwards (1986) and Tabucanon (1988) propose a direct ranking and rating approach. The decision maker is required first to rank all attributes according to their importance, and then give each attribute an estimated numerical value to indicate its relative degree of importance. Attributes weights are obtained by normalising these estimated values. Zavadskas (1987) describes and applies methods of weight assessment based on the Entropy method, evaluating the weights of attributes on the basis of the relative losses method and weight assessment according to expert opinion.

Mareschal (1988) uses a mathematical programming model with sensitivity analysis to determine the intervals of attributes weights, within which the same ranking result is produced. The range sensitivity of attributes weights using different weight assessment methods is examined by Fischer (1995). The sensitivity analysis approach is also used by Bana e Costa (1988) to deal with the uncertainty associated with the attributes weights in a municipal management decision environment. Sensitivity analysis gives decision maker's flexibility in judging attributes weights and helps decision makers understand how attributes weights affect the decision outcome, thus reducing their cognitive burden in determining precise weights. However, this process may become tedious and difficult to manage as the number of attributes increases.

By recognising the fact that attributes weights are context-dependent, Ribeiro (1996) reviews and proposes preference elicitation techniques for use by the decision maker at run time to determine weights. In actual applications, the same decision maker may elicit different weights using different approaches, and no single approach can guarantee a more accurate result (Barron and Barrett, 1996). This may be mainly due to the fact that the decision maker cannot always provide consistent value judgements under different quantifying procedures. Different decision makers using the same approach may give different weights due to their subjective judgements (Diakoulaki *et al.*, 1995). As a result, inconsistent ranking outcomes may be produced, leading to ineffective decisions being made. Figueira and Roy (2002) explain a very simple procedure proposed by Simos (1990), using a set of cards, allowing to determine indirectly numerical values for weights. Smolíková and Wachowiak (2002) discussed a heuristic method for determining weights for Multi Expert-Multi Attribute decision-making.

A comparison of some weight assessment techniques is given by Hobbs (1980), Hwang and Yoon (1981), Schoemaker and Waid (1982), Zavadskas (1987), Barron and Barrett (1996). Approaches to attribute weighting for multi-attribute analysis models based on outranking methods (Roy, 1996) are well discussed by Voogd (1983), Vansnick (1986), Solymosi and Dombi (1986) and Zavadskas (1987). In addition, to solve the multi-attribute analysis selection problem for accomplishing a specific task, existing approaches virtually require the decision maker to consider all task requirements simultaneously for assessing attributes weights. This often places a heavy cognitive burden on the decision maker due to the limitations on the amount of information that humans can effectively handle (Miller, 1956; Morse, 1977). The presence of imprecision and subjectiveness in describing the task requirements further complicates the attributes weighting process.

In order to find the best and worst areas, the group decision-making matrix is calculated to perform comparative multi-attribute analysis of the districts. Comparing attributes values and weights leads to making a selection. The compactness of an area can be described on the basis of an attributes system including many attributes with different meanings and dimensions. One of the major problems is to determine the weights of the attributes. This is most often done by means of expert methods. Theoretical and practical aspects of expert methods have been dealt with in various research papers by many authors (Arditi and Gunaydin, 1998; Kale and Arditi, 2001; Bana e Costa and Vansnick, 1997; Bana e Costa *et al.,* 1999; Chinyio *et al.,* 1998; Ustinovichius, 2001, 2004; and others). To determine the significances of the attributes, the expert judgement method proposed by Kendall (1970) was used. Zavadskas *et al.* (1994), Kaklauskas *et al.* (2005, 2006), Vilutiene and Zavadskas (2003) discussed the application of this method in the construction field. This expert judgement method was implemented at the following stages:

- Calculation of values t_{jk};
- Calculation of weights q_j;
- Calculation of values S;
- Calculation of values T_k;
- Calculation of values W;
- Calculation of values $\chi^2_{\alpha,v}$;
- Testing the statement $\chi^2_{\alpha,v} > \chi^2_{tbl}$.

The values for statistical processing were obtained by interviewing the highly skilled urban planning specialists (Table 1).

The algorithm of attributes weight establishment and process of calculation (Zavadskas, 1987) is presented in Table 2. After performed

Table 1. Attributes weights determined by the experts

Expert $k=1,\ldots,35$	Efficiency attributes ranks values, t_{jk}; $j=1,\ldots,n$; $n=5$.				
	x_1	x_2	x_3	x_4	x_5
1	4	5	3	1	2
2	4	5	2	1	3
3	5	4	3	2	1
4	5	3	4	2	1
5	5	4	3	1	2
6	5	3	4	1	2
7	5	4	2	3	1
8	4	5	1	3	2
9	5	3	4	1	2
10	5	4	1	2	3
11	5	4	1	3	2
12	3	5	4	1	2
13	4	5	2	3	1
14	5	3	4	1	2
15	5	4	2	3	1
16	5	4	3	2	1
17	5	4	3	2	1
18	4	3	5	2	1
19	5	3	4	1	2
20	4	5	1	2	3
21	5	4	2	3	1
22	5	4	3	2	1
23	5	4	3	2	1
24	5	4	1	3	2
25	5	4	3	1	2
26	5	3	1	2	4
27	5	3	4	1	2
28	5	4	2	3	1
29	5	4	2	3	1

(*continued*)

Expert $k = 1,...,35$	Efficiency attributes ranks values, t_{jk}; $j = 1,...,n$; $n = 5$.				
	x_1	x_2	x_3	x_4	x_5
(*continued*)					
30	3	4	5	1	2
31	5	4	3	2	1
32	5	4	3	1	2
33	5	4	2	3	1
34	5	4	1	2	3
35	5	3	2	1	4

Table 2. Algorithm of attributes weights establishment (Zavadskas, 1987)

Process of calculation	Efficiency attributes x_j; $j = 1,...,n$; $n = 5$.				
	x_1	**x_2**	**x_3**	**x_4**	**x_5**
Sum of ranks $\bar{t}_j = \sum_{k=1}^{r=35} t_{jk}$	165	137	93	67	63
The average attribute rank value $\bar{t}_j = \frac{\sum_{k=1}^{r=35} t_{jk}}{r}$	4.71	3.91	2.66	1.91	1.80
Attribute rank	1	2	3	4	5
Attribute weight $q_j = \frac{\bar{t}_j}{\sum_{j=1}^{n=5} t_j}$	**0.31**	**0.26**	**0.18**	**0.13**	**0.12**
$\sum_{k=1}^{r=35} \left(t_{jk} - \bar{t}_j\right)^2$	11.42	14.81	47.46	22.81	25.60
Dispersion of experts ranking values $\sigma^2 = \frac{1}{r-1} \sum_{k=1}^{r=35} \left(t_{jk} - \bar{t}_j\right)^2$	0.34	0.44	1.40	0.67	0.75
Variation $\beta_j = \frac{\sigma}{\bar{t}_j}$	0.12	0.17	0.44	0.32	0.48
Ranking sum average	$V = \frac{1}{r} \sum_{j=1}^{n=5} \sum_{k=1}^{r=35} t_{jk} = 165 + 137 + 93 + 67 + 63 = 105$				
The total square ranking deviation	$S = \sum_{j=1}^{n=5} \left(\sum_{k=1}^{r=35} t_{jk} - V \right)^2 = (165-105)^2 + (137-105)^2 + (93-105)^2 + (67-105)^2 + (63-105)^2 = 8061$				
The coefficient of concordance	$W = \frac{12S}{r^2\left(n^3 - n\right)} = \frac{12 \cdot 8061}{35^2\left(5^3 - 5\right)} = 0.66$				
The significance of the concordance coefficient (no related ranks) $\chi^2_{\alpha,v}$	$\chi^2_{\alpha,v} = \frac{12S}{rn(n+1) - \frac{1}{n-1} \sum_{k=1}^{r} T_k} = \frac{12 \cdot 8061}{35 \cdot 5(5+1)} = 92.1$, where $\frac{1}{n-1} \sum_{k=1}^{r} T_k = 0$				
Rank of table concordance χ^2_{tbl} when the importance equal to 1 %.	The freedom degrees value of a solved problem $v = n - 1 = 5 - 1 = 4$; $\chi^2_{tbl} = 13.3$				
Compatibility of expert judgement (Kendall, 1970).	$\chi^2_{\alpha,v} = 92.1 \succ \chi^2_{tbl} = 13.3$ - The hypothesis about the consent of experts in rankings is accepted				

calculations we established attributes weights.

Kendall (1970) has shown that, when $n > 7$, the value $\chi^2 = Wr(n-1)$ has a distribution with degrees of freedom $v = n-1$, where n is the number of attributes considered and r the number of experts. It has been proved that if the calculated value χ^2 is larger than the critical tabular value χ^2_{tbl} for the pre-selected level of significance is $\alpha = 0.01$, therefore the above mentioned conditions should be satisfied. If the $\chi^2_{\alpha,v} > \chi^2_{tbl}$ is obtained, the respondents' opinions are not in agreement, which implies that they differ substantially and the hypothesis on the rank's correlation can not be accepted. The concordance coefficient based on the criteria weights is $W = 0.66$. In this case the tabular value was taken from Fisher and Yates (1963) statistical tables. When the degrees of freedom is $v = n-1 = 5-1 = 4$ and pre-selected level of significance is $\alpha = 0.01$ (or error probability $P =$ 1 %), in that case we have the value $\chi^2_{tbl} = 13.3$. Since $\chi^2_{\alpha,v} > \chi^2_{tbl}$, then, the assumption is made that the coefficient of concordance is significant and expert rankings are in concordance with 99 % probability.

Having determined the weights of attributes by expert methods, we learn how much one of the attribute is more significant than another one.

5. DESCRIPTION OF BAYES METHOD AND APPLYING IT TO CALCULATE COMPACTNESS OF KAUNAS CITY DISTRICTS

Decision maker using the expert methods determines the system of attributes and calculates the values (Table 3) and initial weights of qualitative attributes (Table 2). Following Table 3 decision matrix if formed in which values of the attribute are measured in points using scale presented in Figure 2. The weighted normalized decision making matrix is formed (Table 4). The purpose here is to receive dimensionless weighted values from comparative indexes. When the dimensionless values of the indexes are known, all attributes can be compared.

Various decision methods can be applied to the decision of such problems. One of such methods is the criterion of optimality. If parameters of efficiency q_j are not equivalent, but the importance of these parameters is known, the best variant can be determined by average success criterion of the decision made under the equation:

$$K_i = \left\{ v_i \middle| \max_i \left(\frac{1}{n} \sum_{j=1}^{n} q_i \bar{x}_{ij} \right) \right\}. \qquad (4)$$

where: v_i alternative; $\bar{x}_{ij}$ – normalized attribute values of j-th parameter for i-th variant.

The given criterion refers K_i to Bayes rule or Bayes-Laplace principle (Arrow, 1947). Most often parameters of the importance pay off in such a manner that $\sum_{j=1}^{n} q_j = 1$, therefore the variant with the greatest weighed sum of parameters values in this case gets out. Criterion K_i in the literature is named on a miscellaneous. Hwang and Yonn (1981) refer to Bayes rule or Bayes - Laplace principle as a Simple Additive Weighting method (SAW) and Zavadskas (1987) – average success criterion of the made decision.

In this method for the final choice the values of efficiency parameters describing compared cells are used. Values of parameters should be always cardinal (numerical) and comparable. In the given method efficiency parameters become comparable due to normalization. High value of one parameter receives the numerical expression close on size to high value numerical expression of other parameter.

In applying the method SAW (Zavadskas, 1987; Zavadskas *et al.*, 2002, 2003, 2004; Zavadskas and Kaklauskas, 1996; Bauer *et al.*, 1999) the decision matrix elements are normalized according to the equation (5) or (6) (Table 4):

$$b_{ij} = \frac{a_{ij} - \min_i a_{ij}}{\max_i a_{ij} - \min_i a_{ij}}, \qquad (5)$$

when preferable value $a_{ij} = \min_i a_{ij}$;

Table 3. Determined initial data for multi-attribute analysis of Kaunas city territory cells

Cell number	Population density	Level of even distribution of population	Population and working places ratio	Population and the objects of attraction ratio	Public transport network density
	x_1	x_2	x_3	x_4	x_5
D1	15.4000	3.9426	46.2000	693.0000	1
E1	1.1886	6.4741	208.0000	208.0000	1
F1	4.3769	5.5941	569.0000	569.0000	1
A2	0.5892	3.7435	2.8684	10.90000	1
B2	3.3312	6.1533	1066.0000	71.0666	1
C2	0.1038	2.9336	27.0000	27.0000	1
D2	36.8852	8.3854	17.1315	0.5561	2
E2	8.2525	8.8189	132.0400	3301.0000	3
F2	3.3117	4.9067	1275.0000	1275.0000	2
A3	2.2946	5.9784	4.9423	15.4200	1
B3	12.7125	6.7107	6.8438	3.1781	4
C3	13.3700	5.0227	10.3243	2.4874	4
D3	87.2400	5.4343	6.8063	1.9033	2
E3	56.4800	5.0332	53.4090	0.9036	2
F3	116.8850	5.0222	3.8591	1.1688	2
G3	97.5400	7.7881	5.2553	1.3934	2
H3	0.3158	6.4141	0.0400	0.8000	3
I3	3.6548	3.9485	0.6107	22.6600	3
J3	3.6476	4.4409	0.6192	766.0000	3
B4	2.2143	9.2840	2.8181	0.2480	2
C4	9.4080	8.3034	1.3781	1.7640	2
D4	0.7200	7.5771	0.1020	0.0115	2
E4	49.5700	4.1028	0.5161	0.1652	2
F4	63.7425	9.1384	3.7276	1.2748	2
G4	46.4725	7.8198	3.3798	0.5311	2
H4	4.0050	5.8077	0.2625	0.5340	4
I4	5.6571	7.7284	1.7678	1.2375	3
J4	18.6000	6.1783	13.6764	930.0000	3
C5	8.4250	4.7045	674.0000	674.0000	2
D5	17.2725	6.8205	1.3142	3.4545	5
E5	17.6650	8.0575	1.4635	0.4710	2
F5	27.6125	10.0710	74.6283	4.4180	4
G5	3.4775	8.2718	0.5743	6.9550	5
H5	18.9250	11.9419	4.0159	5.0466	4
C6	6.7171	2.9351	40.5344	19.5916	4
D6	12.7050	5.7141	5.0068	1.6940	5
E6	20.3800	5.1362	3.3966	16.3040	5
F6	28.3425	5.8954	3.7764	4.5348	5
G6	6.7000	9.0811	39.4117	12.1818	2
H6	1.9875	6.5110	19.8750	0.3180	2
C7	3.8778	6.3263	87.2500	698.0000	1
D7	8.8133	12.0714	24.0363	1322.0000	3
E7	4.2304	8.8562	973.0000	19.4600	2
F7	8.1625	10.4924	21.7666	32.6500	3
G7	0.8775	7.9859	29.2500	351.0000	1
H7	4.7571	5.8225	111.0000	83.2500	4
I7	5.3600	5.9137	5.9555	5.3600	2
F8	10.3000	6.8259	1030.0000	2060.0000	1

$$b_{ij} = \frac{\max\limits_{i} a_{ij} - a_{ij}}{\max\limits_{i} a_{ij} - \min\limits_{i} a_{ij}}, \qquad (6)$$

when preferable value $a_{ij} = \max\limits_{i} a_{ij}$.

The rationality of the alternatives is obtained by the equation (4) (Table 4). The solution results show that sustainable Kaunas city compactness is not even and K_i varies from 0.030 to 0.195.

Table 4. Initial decision-making matrix for evaluation of Kaunas city territory cells and linear normalized matrix

Initial decision- making matrix							Normalized decision- making matrix					Result
Cell	Var.	Values of attributes in points										K_i
		x_1	x_2	x_3	x_4	x_5	x_1	x_2	x_3	x_4	x_5	
D1	1	5	3.943	1	1	1	0.138	0.231	0.000	0.000	0.000	0.103
E1	2	1	6.474	1	1	1	0.000	0.159	0.000	0.000	0.000	0.041
F1	3	3	5.594	1	1	1	0.069	0.184	0.000	0.000	0.000	0.069
A2	4	1	3.744	2	3	1	0.000	0.237	0.045	0.065	0.000	0.078
B2	5	2	6.153	1	1	1	0.034	0.168	0.000	0.000	0.000	0.054
C2	6	1	2.934	1	3	1	0.000	0.260	0.000	0.065	0.000	0.076
D2	7	7	8.385	1	4	2	0.207	0.105	0.000	0.098	0.030	0.108
E2	8	3	8.819	1	1	3	0.069	0.093	0.000	0.000	0.060	0.053
F2	9	2	4.907	1	1	2	0.034	0.204	0.000	0.000	0.030	0.067
A3	10	2	5.978	2	3	1	0.034	0.179	0.045	0.065	0.000	0.074
B3	11	4	6.711	2	5	4	0.103	0.153	0.045	0.130	0.090	0.107
C3	12	4	5.023	1	5	4	0.103	0.201	0.000	0.130	0.090	0.112
D3	13	9	5.434	2	5	2	0.276	0.189	0.045	0.130	0.030	0.163
E3	14	10	5.033	1	5	2	0.310	0.200	0.000	0.130	0.030	0.169
F3	15	8	5.022	2	5	2	0.241	0.201	0.045	0.130	0.030	0.155
G3	16	9	7.788	2	5	2	0.276	0.122	0.045	0.130	0.030	0.146
H3	17	1	6.414	1	5	3	0.000	0.161	0.000	0.130	0.060	0.066
I3	18	2	3.948	5	3	3	0.034	0.231	0.180	0.065	0.060	0.119
J3	19	2	4.441	5	1	3	0.034	0.217	0.180	0.000	0.060	0.107
B4	20	2	9.284	2	2	2	0.034	0.079	0.045	0.033	0.030	0.047
C4	21	3	8.303	3	5	2	0.069	0.107	0.090	0.130	0.030	0.086
D4	22	1	7.577	2	1	2	0.000	0.128	0.045	0.000	0.030	0.045
E4	23	10	4.103	5	2	2	0.310	0.227	0.180	0.033	0.030	0.195
F4	24	10	9.138	2	5	2	0.310	0.083	0.045	0.130	0.030	0.146
G4	25	10	7.820	2	4	2	0.310	0.121	0.045	0.098	0.030	0.152
H4	26	3	5.808	3	4	4	0.069	0.178	0.090	0.098	0.090	0.107
I4	27	3	7.728	3	5	3	0.069	0.124	0.090	0.130	0.060	0.094
J4	28	5	6.178	1	1	3	0.138	0.168	0.000	0.000	0.060	0.091
C5	29	3	4.704	1	1	2	0.069	0.210	0.000	0.000	0.030	0.079
D5	30	5	6.820	3	5	5	0.138	0.149	0.090	0.130	0.120	0.129
E5	31	5	8.058	3	2	2	0.138	0.114	0.090	0.033	0.030	0.096
F5	32	6	10.071	1	5	4	0.172	0.057	0.000	0.130	0.090	0.096
G5	33	2	8.272	5	4	5	0.034	0.108	0.180	0.098	0.120	0.098
H5	34	5	11.942	2	4	4	0.138	0.004	0.045	0.098	0.090	0.075

(*continued*)

Initial decision- making matrix							Normalized decision- making matrix					Result
Cell	Var.	Values of attributes in points										K_i
		x_1	**x_2**	**x_3**	**x_4**	**x_5**	**x_1**	**x_2**	**x_3**	**x_4**	**x_5**	
(*continued*)												
C6	35	3	2.935	1	3	4	0.069	0.260	0.000	0.065	0.090	0.108
D6	36	4	5.714	2	5	5	0.103	0.181	0.045	0.130	0.120	0.118
E6	37	6	5.136	2	3	5	0.172	0.197	0.045	0.065	0.120	0.136
F6	38	6	5.895	2	5	5	0.172	0.176	0.045	0.130	0.120	0.138
G6	39	3	9.081	1	3	2	0.069	0.085	0.000	0.065	0.030	0.056
H6	40	1	6.511	1	2	2	0.000	0.158	0.000	0.033	0.030	0.049
C7	41	2	6.326	1	1	1	0.034	0.163	0.000	0.000	0.000	0.053
D7	42	3	12.071	1	1	3	0.069	0.000	0.000	0.000	0.060	0.029
E7	43	3	8.856	1	3	2	0.069	0.091	0.000	0.065	0.030	0.057
F7	44	3	10.492	1	2	3	0.069	0.045	0.000	0.033	0.060	0.044
G7	45	1	7.9859	1	1	1	0.000	0.116	0.000	0.000	0.000	0.030
H7	46	3	5.822	1	1	4	0.069	0.178	0.000	0.000	0.090	0.079
I7	47	3	5.914	2	4	2	0.069	0.175	0.045	0.098	0.030	0.091
F8	48	4	6.826	1	1	1	0.103	0.149	0.000	0.000	0.000	0.071
Optimum		***max***	***min***	***max***	***max***	***max***						

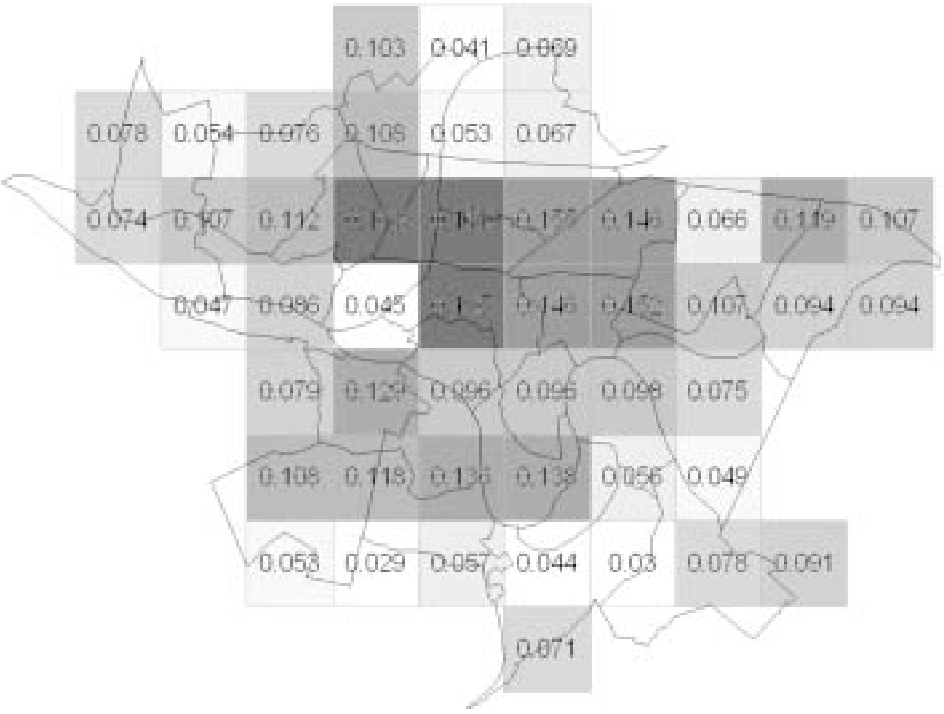

Figure 9. Kaunas city cells compactness

According to solution results K_i Figure 9 is drawn that represents sustainable Kaunas city compactness. The most compact areas are darkest and not sustainable areas are light. According to this chart the lightest areas are problematic from the point of view of sustainable compactness.

6. CONCLUSIONS

Estimating city compactness and sustainability is complex problem. The method described in this article can be used as a basis for further development. A simple set of five attributes describing basic structure and functionality of a city was used. City sustainability must to be described by many attributes. Attributes weights and sets can vary according to different situations and character of research. Additional attributes and different sets can be applied for this universal method.

When science is used for policy making, an appropriate management of decisions implies including the multiplicity of participants and perspectives. This also implies the impossibility of reducing all dimensions to a single unity of measure. Our concern is with the assumption that in any dialogue, all valuations or 'numeraires' should be reducible to a single one-dimension standard. It is noteworthy that this call for citizen participation and transparency, when science is used for policy making, is more and more supported institutionally inside the European Union, where perhaps the most significant examples are the White Paper on Governance and the Directive on Strategic Environmental Impact Assessment. Multi-attribute evaluation supplies a powerful framework for the implementation of the incommensurability principle. In fact it accomplishes the goals of being multi-disciplinary (with respect to the research team), participatory (with respect to the local community) and transparent (since all attributes are presented in their original form without any transformations in money, energy or whatever common measurement rod). As a consequence multi-attribute evaluation looks as an adequate assessment framework for (micro and macro) sustainability policies.

In this work graphical charts of different attributes were made to indicate problematic areas. These charts can be used by planners as a motivation for decisions to deal with specific problem. GIS gives powerful tools to visualize results, here we used simple graduated colour charts. However, results can be shown in more complex way putting some attributes together and raster overlaying techniques.

Only by calculating the values of different attributes such a compound subject as sustainability of the city can be measured. Multi - attributes analysis methods can give numerical expression to the sustainability of regions, cities, city districts. In this case we used rectangular city cell as a unit but whole regions, cities or city districts of complex form can be chosen as well. Numerical expression of sustainable city compactness puts more light on the concept of city sustainability and also gives opportunity to visualize results with graphical charts.

The case study of Kaunas city has shown the most problematic areas. Mostly problems occur in the peripheral zones, but there is a big problem in the area of one cell near the city center also. Problem near the center occurs mainly because there are very little living places here. The best ranked areas are mainly block-housing areas to the north of city center where around 70 % of city population lives.

This work presents a universal methodology and simplified practical model for measuring sustainable city compactness. According to the model calculations can be made using any geographical data; and the methodology can be expanded and adjusted to specific environments.

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SANTRAUKA

DARNAUS MIESTO KOMPAKTIŠKUMO ĮVERTINIMAS, TAIKANT GIS IR BAYESO TAISYKLĘ

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Lietuvoje ilgą laiką vyravo tendencija statyti ekstensyviai, paliekant didžiulius laisvus plotus mieste. Dėl to miestai užima tokią didelę teritoriją, kad miesto pakraščiai ir aprūpinimo centrai tapo beveik nepasiekiami. Šiame straipsnyje lošimų teorijos metodas kartu su Geografine informacine sistema (GIS) pritaikytas miesto kompaktiškumo normai nustatyti. Miestų planavimo specialistai straipsnyje pateiktą metodiką gali taikyti miesto užstatymo tankiui nustatyti ir sprendimo motyvams išsamiai pagrįsti. Miesto kompaktiškumui įvertinti reikalingi efektyvumo rodikliai ir jų svarba nustatyti pagal ekspertų apklausų duomenis. Uždavinio sprendimo modelis ir metodika pritaikyta Kauno miesto subalansuotam kompaktiškumui nustatyti. GIS pagrindu sudarytas duomenų bankas, kuriame surinkti gyventojų, visuomeninio transporto stotelių ir visuomeninės paskirties objektų duomenys. Miesto teritorija suskirstyta į kvadratinį tinklelį. Iš duomenų banko surinkti duomenys, priklausantys kiekvienam tinklelio elementui ir pateikti sprendimo matricoje. Uždavinys išspręstas taikant Bayeso taisyklę. Rezultatai pateikiami diagramomis nurodančiomis problemines miesto ląsteles – tinklelio elementus. Pagal gautus rezultatus miesto planavimo specialistai nesunkiai gali priimti sprendimus, kurie pagerintų kompleksiškai darnų miesto vystymąsi.