PROSTORSKE, EKONOMSKE IN ČASOVNE SPREMENLJIVKE MEHKEGA MODELA DOSTOPNOSTI DO KOMUNALNIH STORITEV

SPATIAL, ECONOMIC, AND TIME VARIABLES FOR A FUZZY MODEL OF ACCESSIBILITY TO MUNICIPAL SERVICES

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IZVLEČEK

Za načrtovanje infrastrukturnih sistemov se lahko že v zgodnejših fazah prostorskega načrtovanja vzpostavijo modeli, ki zajemajo tudi ključne elemente načrtovanja dostopnosti do komunalnih storitev. Modeli za podporo odločanju v prostorskem načrtovanju, morajo omogočati ustrezno prostorizacijo rezultatov, ekonomske presoje in pravočasno načrtovanje infrastrukturnih sistemov. V prispevku je predstavljen model dostopnosti do komunalnih storitev, ki temelji na teoriji mehke logike. Obravnavane so prostorske, časovne in ekonomske lingvistične spremenljivke mehkega modela in predlagana metoda statistične analize prostorskih podatkov za določitev pripadnostnih funkcij. Metoda temelji na vzorčenju infrastrukturnih sistemov znotraj različnih razredov gostote poselitve. Statistična analiza 156 obstoječih stanovanjskih območjih v Republiki Sloveniji je zajela 10 do 20 % stanovanjskih površin v desetih lokalnih skupnostih. Izdelana je bila validacija ekonomske in verifikacija predlagane prostorske pripadnostne funkcije na 16 testnih območjih različne stopnje pozidanosti. Predlagana metoda prostorske analize je primerna za določanje pripadnostnih funkcij. Za predlagane spremenljivke se lahko razvije model dostopnosti do infrastrukturnih sistemov v Republiki Sloveniji. Za vzpostavitev celovitega modela so potrebne nadaljnje raziskave za vključitev zmogljivosti omrežij kot tudi okoljskih in družbenih vidikov zagotavljanja dostopnosti do komunalnih storitev.

ABSTRACT

For the planning of infrastructure systems, the models that include key elements of accessibility to municipal services in the early stages of spatial planning can be developed. Models for decision-making in spatial planning should enable suitable spatial presentation, economic assessments, and timely planning of infrastructure systems. This article describes the model of the accessibility to municipal services, which is based on the use of methods of fuzzy logic. Spatial, economic, and temporal variables of the fuzzy model are discussed, and a method for the determination of the membership functions is proposed. This method is based on sampling infrastructure systems within different classes of population density. A statistical analysis of 156 existing residential areas in the Republic of Slovenia has covered from 10 to 20% of the residential areas within 10 local communities. Validation of economic variables and verification of proposed spatial membership functions has been made within 16 residential areas of different settlement densities and level of urbanization. The proposed method of spatial analysis is suitable for determining membership functions. For the proposed variables, a model of accessibility to infrastructure systems within Slovenia can be developed. There is a need for further research to establish a comprehensive model related to the infrastructural capacity, as well as environmental and social aspects of accessibility to municipal services.

KLJUČNE BESEDE

prostorsko načrtovanje, mehko modeliranje, dostopnost, komunalne storitve

KEY WORDS

spatial planning, fuzzy modelling, accessibility, municipal services

1 INTRODUCTION

The access to municipal services is enabled through various infrastructure systems. Networks and facilities of infrastructure systems are a result of relatively advanced technical sciences; however, municipal activities in terms of organization, management, the relationship to the consumer and planning, are often left behind by technological solutions (Klemenčič, 1997). When planning the accessibility of municipal services, the orientations, resulting from spatial planning and relating to the efficient land use and the consideration of public and private interest in developing the land should be taken into account (ESDP, 1999; ZPNačrt, 2007). Policies, aimed at local communities, which are responsible for ensuring adequate accessibility to municipal services (MELLS, 1996), should also be taken into consideration. Alongside that, early integration of measures, dictated by the sustainable planning of infrastructure systems (Pitts, 2004) is also important, as well as adaptation to predicted climate changes (Seto et al., 2014).

Providing municipal services by infrastructure systems designers, planners and those responsible for the provision of municipal services, requires planning, which combines the land-use planning with infrastructure planning systems. Klemenčič and Pitts point out that already in the planning stages of the development of settlements, the phases, relating to the operation, maintenance, renovation and further development of infrastructure systems should be considered (Klemenčič, 1997; Pitts, 2004). It is important to plan the extent of municipal services in the early (strategic, initial) stages, as it is too late for a comprehensive solution of infrastructure systems in the implementation phases. Any partial solutions, which in themselves follow the progress of technology in a particular field of infrastructure, may even have negative effects on the entire system[1] (Pitts, 2004). Planning and management of infrastructure systems in construction-technical terms is in the domain of civil, mechanical, electro-technical and IT experts, and is based on various engineering methods, for which, in the early stages of land-use planning, there are usually no relevant input data for modelling available. Detailed simulations of various alternative solutions would be time-consuming and associated with high costs, and are therefore not implemented in practice. For the inclusion in the assessment in strategic phases of spatial planning, it is therefore necessary to make use of various generalizations and predictions.

The sectorial legislation of the Republic of Slovenia defines the concept of developing the land, which can with certainty be confirmed at the operational level of planning. For the assessment in the strategic stages this definition is not appropriate. Therefore we introduced the concept of accessibility[2] to municipal services, which means timely, long lasting and also economical long-term ability to provide adequate municipal services in the considered land.

For the actual use of the model results in spatial planning, appropriate localization of the model results is important (Preston, Yuen and Westaway, 2010) and the possibility of actual implementation and use of the models and tools in planning practice (Lichfield, 2006). The available spatial data on the settlement[3], data on existing municipal infrastructure networks and facilities[4] and digital data on land use, enable the assessment of accessibility to municipal services in implementing stages of spatial planning. In smaller areas, an individual assessment of each land plot can be made. For the assessment of larger areas, such

[1] *E.g. heat pump in the area with surplus heat in district heating system*

[2] *The original English term "accessibility" may be translated into Slovene as accessibility (e.g. Access to services in the physical sense) and as well as availability (e.g. Accessibility of in economic terms).*

[3] *Cadastre and Real Estate Register (GURS)*

[4] *Cadastre of public infrastructure (GURS)*

assessment is time-consuming, and it is therefore necessary to use methods, based on geographic information systems tools. The most commonly used are tools, based on buffer zones. In determining the width of the buffer zone, we typically utilize some general distances, within which the connection is technically possible, or acceptable by the network operators. However, since the arrangement of the buildings in the area is (generally) not adjusted to fit the distance from infrastructure systems, but rather vice versa, it is necessary, when determining the values of model variables, to take into account the dependencies between the expected distances of infrastructure systems and different characteristics of settlement. For an appropriate implementation of empirical economic data, it is also important to differentiate between built-up lands, where users are already using the services, and raw lands. Of key importance for the spatial part of the model is, of course, the integration of simulations of the new residential use and settlement in the area. The model must also allow the assessment, related to the existing land use.

From the economic point of view, the results of the model must allow the assessment of the costs of providing access to municipal services and the anticipated number of users who can use these services. These empirical data are crucial for further assessment by economic experts, where there are two main analytical directions present. The first is based on the theory of well-being and analyses of public services, which includes the assessment, related to the study of the land rent. The researches and models of the other analytical direction are mainly based on the assessment of the costs and benefits, gravity and accessibility models (Johansson and Leonard, 1986). Notwithstanding the long period of development of these analytical directions, the area is still characterized by high level of abstraction (Jäger, 2003; Park, 2014), idealization of the actual state (Alexander, 2014) and lack of empirical models (McDonald, 2003; Hortas- Rico, Ole Sole, 2008; Irwin, 2010). It is also necessary to carry out researches on the micro-empirical level, where the observation unit can be an individual investor (Ploegmakers, van der Krabben and Buitelaar, 2013). More researches should be aimed at developing more realistic dynamic spatial models (Irwin, 2010). If we actually want to take into account the results of the assessment of whether the society can handle the costs (Rakar, 2010), this assessment must be carried out timely, that is in the early stages of planning.

An important part of the assessments in the strategic stages is the prediction of future events. Typically, the assessments in spatial planning are focused on the future growth of the population and fluctuation of the population number. Less attention is focused on the future status of the infrastructure systems. Since one of the important topics in the recent years is the aging of infrastructure systems and associated high costs of renovations (Rakar, 2010), the assessments must include this aspect. Incorporation of time variables in the model must therefore allow for a distinction between 1) the existing, vital network 2) the network, the depreciation period of which is already or will soon expire and where costs of renovations or even restrictions for new buildings before reconstruction can be expected, 3) the networks under construction, which are associated with the current investment expenses and 4) the planned network, for which timely planning of funding sources is of crucial importance. The model should also allow for the distinction between the degree of accessibility, which already allows direct connection to infrastructure systems and the accessibility that requires further investment in terms of upgrading the secondary and / or primary[5] infrastructure systems.

[5] *Infrastructure networks are basically divided into primary, which are intended for connections between settlements or parts of settlements, and secondary networks, to which users connect with private connections.*

The collection and interpretation of the basic data on infrastructure and settlement 10 years ago accounted for the bulk of the time spent for such assessments. The data on the existing infrastructure systems are today quickly available, while the data on the planned systems are not systematically collected yet. In the absence of data, for which it is not realistic to expect that they may be supplemented, estimates can be used (Pergar and Polajnar, 2013). The available spatial data are, of course, not ideal, but with the awareness of the uncertainties of the input data and dependencies between variables, despite the uncertainties, the use of spatial data for purposes that go beyond simple localization (mapping) of the existing state in the area, should be used. Especially in strategic spatial models, these uncertainties are virtually ignored, which often leads to doubts related to the validity and accuracy of the results of such models (Preston, Yuen, andWestaway, 2011). With the inadequate incorporation of uncertainty in the models, it can be considered, or even shown, a significantly greater precision than actually exists in the real world (Krivoruchko, 2011). The reduction of uncertainty in spatial planning is possible especially with planned procedures and adequate preparation and processing of spatial data (Mlakar, 2009). Therefore, it is important that, prior to the establishment of a model of accessibility, we also ask ourselves about the suitability of the chosen method of modelling.

Spatial models, based on methods of geographic information systems, can basically be divided into overlay methods, multi-criteria evaluation methods and the methods of artificial intelligence (Collins et al., 2001; Malczewski, 2004). The overlay methods simplify too much the complexity of the process in determining land use, which we seek to eliminate by the use of multi-criteria evaluation methods. However, these with their complexity in terms of mathematical modelling of environmental geographical information systems reduce the commercial use of such models, which is a precondition for wider use in the practice of spatial planning (Malczewski, 2004). The solution is offered in the combining of multi-criteria decision-making models and methods of artificial intelligence, the main advantage of which is that they are, in contrast with traditional mathematical methods, tolerant of imprecision, ambiguity and uncertainty of input data, and dependencies between variables (Malczewski, 2004). After 2009, there is, in the development and use of models for the management of infrastructure systems, seen a big increase in multi-criteria decision-making models based on fuzzy decisions (Kabir, Sadiq andTesfamariam, 2013). Similarly, the analysis of the number of reports of using the method of fuzzy logic in the field of spatial planning indicates a doubling of the number of published scientific contributions after 2007[6]. The method of fuzzy logic has already proved to be an appropriate method, primarily in the manufacturing of complex models with high uncertainty and imprecise input data (e.g. Malczewski, 2006; Fernandez and Ruiz, 2009; Kabir, Sadiq andTesfamariam, 2013).

The method of fuzzy logic was introduced by Zadeh in 1956 and since then its use has spread into many professional and research fields. In the proposed model, the theory of fuzzy sets and fuzzy reasoning is applied, which is a narrower field of fuzzy logic. Based on the fuzzy logic, our and other empirical knowledge can be entered into the system, since it is based on fuzzy logic rules that are implemented by experts during the development of the model. The establishment of the input data requires, compared to other methods of the so-called artificial intelligence, intensive research work (Aliev and Aliev, 2001), while the use of such models is simpler and already built into some newer programs used for work in the geographic information systems (Boroushaki and Malczewski, 2010) and is as such more useful for other participants in the spatial planning process. By using the methods of fuzzy logic, the loss of information

[6] *The analysis was made in the database Web of Science publications according to keyword: "fuzzy logic" and "spatial planning".*

in the evaluation of the strategic phases as such can be significantly reduced, which can lead to different investment decisions, strategy developments and tax policies (Sui, 1992). The method is often used in this field in cases of evaluation of sustainability criteria (Han et al, 2006; Fernandez and Ruiz, 2009), as it can easily include a high number of criteria into the decision, which on the other hand can lead to the so-called information overload models (Virant, 2003). In the analysed studies (Sui, 1992; Han et al, 2006; Fernandez and Ruiz, 2009), there is little attention given to a more detailed determination of fuzzy sets or creation of individual membership functions, which are essential for the reduction of uncertainty of the results of the fuzzy model.

2 VARIABLES OF THE MODEL OF ACCESSIBILITY TO MUNICIPAL SERVICES

In order to be able to calculate with fuzzy statements, it is first necessary to determine their linguistic attributes, which are followed by the definition of their membership functions. For each variable, a basic premise (*X* is **term**) is created, wherein ***X*** is a fuzzy variable and **term** the linguistic value of this variable. There are different formats of fuzzy sets and various forms of membership functions. The most commonly used are triangular and trapezoidal forms of functions and the parametric manner of function recording[7] (Virant, 1998, 2003). If for the logistical connection we use a fuzzy implication, we obtain fuzzy rules on the basis of which we set the algorithms of functioning of fuzzy systems. The general example of the rule is (Virant 2003): IF (*X1* is **term1**) AND (*X2* is **term2**) AND THEN ... (*Y* is **term a**). The continuation of this article thus defines the linguistic values of spatial, economic and temporal variables (for example: **near, far, old, new**) and their membership functions (e.g. the function to integrate population density class $\mathbf{G_E}$ (50, 70, 90, 110) recorded in a parametric manner, Table 1).

The spatial part of the model is based on the distance between the existing or planned network and the considered land, as well as on the integration of the current state of the settlement in the model. For the integration of the distance between the existing or planned network and the considered land, the variable *distance* is determined with linguistic values **close**, $\mathbf{far_s}$ and $\mathbf{far_p}$ (Figure 1). At the distance from the infrastructure system, where the linguistic value **close** achieves the membership value 1, there is the highest level of accessibility to the particular infrastructure network possibility. Where the distance is coming closer to 0, the studied unit of land is located in the safety corridor of the infrastructure system, where construction usually is not possible, which is why the accessibility of these lands is not provided. In the range of values $\mathbf{far_p}$ the expansion of primary infrastructure system is previously required. Within the value $\mathbf{far_s}$, before connecting, an upgrading of the secondary systems is needed. For greater distances, the assessment of accessibility is associated with excessive uncertainty of the actual construction of the primary infrastructure system in the considered time frame, therefore the accessibility for this land is not provided within the model. In determining the value of the variable $\mathbf{far_p}$, it should be taken into consideration that there are, especially within the settlements, routes of primary systems related to the systems of infrastructure corridors, which usually run within the public roads. The determination of the distance from the primary system is therefore influenced, more than by the Euclidian distance, by the impact of the allocation of settlement and corridors of roads around the area. In addition, the long sections of primary networks are typically designed for several areas simultaneously, and therefore the cost of assuring accessibility should not be entirely the responsibility of the considered land.

[7] *Parametric manner of record for triangular functions: (a, b, c); for trapezoidal functions: (a, b, c, d).*

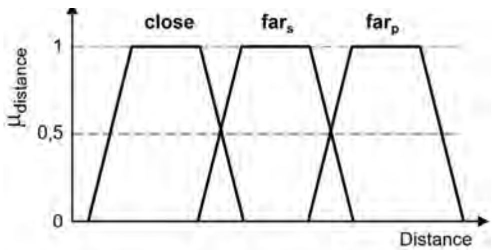

Chart 1: Fuzzy variable *distance* and its linguistic value for the inclusion of the distance from the network into the model.

The model must enable simulations of future settlements and also the assessment of the situation based on the current use of the land. With this in mind we have to consider the actual built-up land and population density, which are key elements for enabling further detailed economic assessments. For this purpose, a further fuzzy variable *built-up* is determined, with the fuzzy value **built**. The vacant (unbuilt) lands are defined as a fuzzy complement to the function with the value **built** $\mu_c(x) = 1 - \mu_A(x)$. For the incorporation of the existing land use into the model, it is necessary to take into account the fact that the area of building land is determined by the legally binding provisions, e.g. in the Spatial planning act. Therefore, the borders of the land for construction purposes can be included into the model only with crisp sets. The values to include the simulations of future use in the model can be fuzzy. The population density is incorporated into the model through fuzzy variables of classes of population density. The number and width of classes and the membership functions form depend on the settlement system in the considered land and on the accuracy of spatial analysis.

The output variable *costs* is determined by fuzzy numbers **S1, S2,... Sn**. In the case of major uncertainties in determining the costs, the trapezoidal membership functions are used to determine the fuzzy number, and if the predictions are more reliable and the differences between classes small, the triangular membership functions. Thus defined variable *costs* is used in the consequent part of the fuzzy logic process. The connection between the antecedent or premise and consequent part of the process is based on the fuzzy rules, such as: IF (*density of pop*. is **Gi**) AND (*age* is **new**) THEN (*cost* is **Si**). The values of the *costs* function are determined according to the cost which is assessed (the cost of the construction, the costs of annual depreciation, operating costs, renovation costs). In determining the value, the differences arising from the construction in different areas of settlement (a more dense building is associated with higher construction costs) must be taken into consideration, as well as variables related to different geological conditions for construction.

For the fuzzy variable *age,* four fuzzy values are determined, namely **old**, **new**, **under construction** and **planned** (Figure 2). The value **old** defines the infrastructure systems, for which a lower accessibility to municipal services as a result of the age of the systems can be expected. The function to the left is not bounded, in order to increase the tolerance to inadequate data on age[8], or if certain parts of the systems actually already significantly exceed the lifespan. The network within the expected life of the system is defined as **new**. The connecting of additional users to the system is in terms of age of the network in this part expected and optimal. In determining the value of the membership functions **new** and **old**, we should take into account the different depreciation periods of individual infrastructure systems. The network,

[8] *E.g. year of construction 1000*

which is during the time of the assessment in the phase of project documentation or under construction, shall be defined by the value **under construction**. The function in this case can be defined by a triangular function, because the construction is, in comparison with the rest of the time periods, carried out in a substantially shorter period of time. The membership function **planned** is bounded to the right, since the design of the new systems is only suitable for narrower and manageable time frames, for example 5 years. The delimitation between the old and the new network is dependent on the lifetime of the built-in materials, and is typically determined by the relevant regulations and standards, which is why this part of the study does not discuss it in detail. Since the actual integration of the data into the model requires availability of data on existing networks, the empirical part offers an analysis of the available data on the age of networks in the sample and a comparison with the data on the age of the connected buildings.

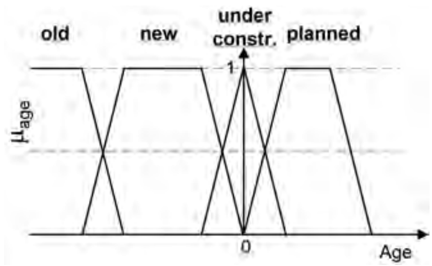

Chart 2: Fuzzy variable *age* and its linguistic value for the inclusion of age into the model

Method of determining membership functions

Of all the methods for evaluation of municipal infrastructure, into which we can directly include the relation to population density, the method of selection of typical spatial units, for example units of settlements or housing neighbourhoods, is appropriate (Rakar and Makuc, 1985). It is important that for a comprehensive assessment of the impact of population density on the costs of providing services, we include the population density from the lowest, which usually cause the highest costs per capita, to the highest densities in the studied area. The spatial analyses in the study are therefore based on the sample of existing housing settlements in the Republic of Slovenia within the selection of the local communities of different population densities. The selection[9] was based on the division of local communities in Slovenia on medium-sized and small cities (Zavodnik Lamovšek, Drobne and Žaucer, 2008). We also considered the criterion of the number of local communities in each group and the number of inhabitants. Thus, alongside two from the class of medium-sized cities, we included in the sample another 4 local communities from the group of small towns and 4 from the others. In the final selection, the greater diversity of the settlement was also taken into account. Based on the above criteria, the following have been selected: Municipality of Ljubljana, Municipality of Novo Mesto, Municipality of Idrija, Municipality of Črnomelj, Municipality of Naklo, Municipality of Ruše, Municipality of Vransko, Municipality of Turnišče, Municipality of Loški Potok and Municipality of Sveti Tomaž.

The sampling took place according to the classes of population density. The determination of the population density classes was based on the spatial analysis of the existing population density in 10

9 *Due to the prescribed uniform method of making digital content of Spatial planning acts, we selected the pattern within local communities that during the sampling already had adopted acts in accordance with the state legislation adopted after 2007. The sampling was conducted in 2012.*

selected local communities. For the graphical analysis, the population density was determined by the KernelDensity function in the programming environment ArcMap® (Figure 1). We took into account the number of residential parts of buildings (REN)[10] and the average number of household members within each local community[11]. Thus 6 classes, according to which the sampling was designed, were determined. The sample included the fully built residental zones[12]. For the final sample we determined 156 residential areas with 25 to 30 zones within each density class from A to F[13] (the classes are presented in more detail in Table 1) with over 7,000 existing housings. The sample covers a total area of 10 to 20% of the residential land use in 10 selected local communities. It is estimated that the percentage of the covered area is sufficiently representative. After the completion of the sampling, the data control on the distribution of apartments in buildings that are monitored within the register (Table 1) was done.

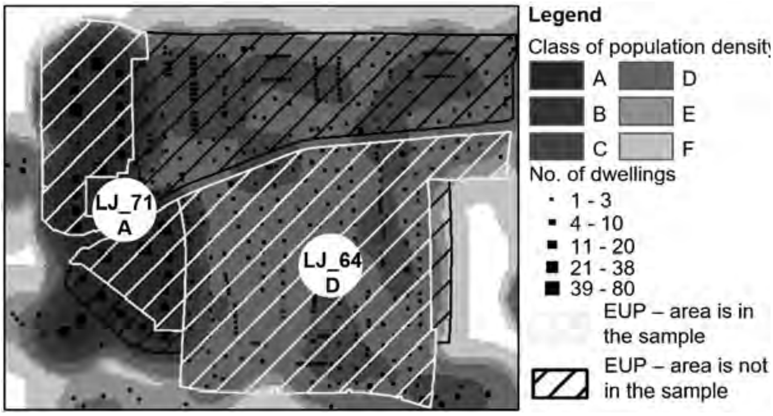

Figure 1: Review of the sampling of the existing residential areas within the proposed classes of population density.

During sampling it turned out that the selected classes of population density A, B, C and D are part of larger settlements and settlements of urban character, while the class E covers the smaller rural settlements and the class F scattered settlements in rural areas. The sample in addition to data on settlement also included information on existing infrastructure networks for water supply, waste water, local roads and electricity distribution, gas pipeline and the heating network[14]. When selecting the associated network infrastructure for individual residential area in the sample, we had to resolve the crucial dilemma of division of networks on the primary and secondary systems. The sample of classes of density, A, B, C and D cover only the secondary network, while the costs of building primary networks are based on the proportionate share of the primary network of the entire settlement. When sampling in classes E and F, the sample of the settlement already included the interconnected settlements or individual buildings, with which the additional lengths of the infrastructure systems, as a result of the distribution of the population in the area, were covered.

[10] *Data were taken from the register of real estate (REN, GURS).*

[11] *Average number of people per household in the year 2011 (www.stat.si).*

[12] *In case of individual empty areas within the sample, the sample was corrected with additional buildings and infrastructure networks.*

[13] *The designation of certain classes of population density was not the subject of research; further research need to determine an appropriate naming of the proposed classes.*

[14] *Data were taken from the Cadastre of public infrastructure (GURS), the sampling was done manually based on engineering knowledge of individual networks and connections to primary systems.*

The basis for estimating the costs of providing access to municipal services represent the lengths of the infrastructure systems. If we want to simultaneously assess the benefits in terms of number of customers, it is necessary to express the lengths in dependence on the parameters of population density. While the model parameters, which relate to the corresponding secondary network to an area, are relatively easy to determine, it is, mainly due to the simultaneous supply of several areas, the determining of the parameters of primary network harder. The study proposes a method based on a comparison of average costs to build a primary network in a particular sample, and the costs determined on the basis of the actual length of the primary systems in the area of each sample, at which point we included the lengths within the buffer zones of 100, 200, 300, 400 and 500m wide. To determine the average percentage of the primary water supply network, we included an additional sample within the dense settlement in 30 local communities in Slovenia, where the appropriate division of primary and secondary networks[15] is still recorded. The value of the fuzzy variable $\mathbf{far}_{\mathbf{p}}$ is determined according to the Euclidean distance, where both costs are the same.

When analysing actual spatial data, it is difficult to expect normally distributed samples, the statistical analyses are therefore based on nonparametric tests. In all cases, the Kruskal-Wallis test for hypotheses testing was used. If there were statistically significant differences between classes of population density for a given variable, we determined the value of fuzzy variables for each population density class. Based on the median and the 1st and 3rd quartile, membership functions are determined. For the trapezoid function a degree of membership increases to 1 in the 1st quartile, a degree of membership begins to decline in the third quartile. In the determining of the triangular function, the top represents the median of the class. Following recommendations, the functions then intersect with each other at the degree of membership of 0.5 (Virant, 2003). To facilitate the interpretation of the results of the fuzzy model and for greater intelligibility, are the values determined in such a manner converted from the fuzzy environment into the environment of crisp values by defuzzification. For spatial representation of the model results the method was tested with which the results obtained from the raster model are generalized into different spatial units (plot of land, unit of spatial planning, settlement). Thus generalized values can be presented in a simple and more understandable way.

The treatment of parameters, related to the determination of the economic variable, includes also the validation of the model. The spatial variables, in addition to the validation, already cover the verification, in the part that was enabled by the built-in features in the programming environment ArcMap®. The spatial and cost part of the model were verified on 16 residential areas of different population densities and rates of built-in, within the local communities, which were not included in the original sampling. The process of fuzzy modelling for one input and output was developed in the MS Excel programming environment, with triangular and trapezoidal membership functions, the Mamdani method of implications and the gravity method of defuzzification. The spatial analysis and verification of the spatial representation of the results were made in the ArcMap® programming environment, with built-in functions FuzzyMembership and FuzzyOverlay. The development of new tools has not been the subject of the research.

[15] Appropriate recording of networks, divided into primary and secondary systems, is getting lost in the public records.

3 RESULTS

Table 1 shows the proportions of each type of buildings from the sample in a research. Based on the population density classes that were defined in the sampling phase, we were already able to define membership functions for the inclusion of the population density in the fuzzy model (Table 1). Although by using the function KernelDensity we can define the current population density in the whole area, that is not appropriate for the inclusion of population density in the spatial part of the proposed model, as on the edges of the settlements the density, due to the inclusion of the empty areas in the calculation of density, drops all the way to the lowest class (shown in Figure 1), however, that does not mean that all the classes of population density actually occur at this location. It is more appropriate to include the population density into the spatial part of the model by taking into account the sharp boundaries of units of spatial planning or areas of simulation of new residential areas. The proposed membership functions (Table 1) are taken into account in the costs simulations (Chart 6).

Table 1: Proposed classes of population density, their membership functions and comparison with the proportions of the buildings according to the number of dwellings in the sample.

Class and population density (No./ha)	*Proposed membership function*	*No. of houses in the sample*	*Percentage according to the no. of houses in the sample*					
			Over 50	*21 to 50*	*6 to 20*	*3 to 5*	*Row house*	*1 to 2*
A - over 300	(280,300,500,500)	780	27%	36%	30%	2%	1%	4%
B - from 100 to 300	(90,110,280,300)	716	-	12%	30%	10%	40%	8%
C - from 60 to 100	(50,70,90,110)	1886	-	-	-	1%	89%	10%
D - from 20 to 60	(16,24,50,70)	2330	-	-	-	2%	41%	57%
E - from 10 to 20	(8,12,16,24)	958	-	-	-	-	2%	98%
F - less than 10	(0,0,8,12)	521	-	-	-	-	2%	98%

During the sampling of the infrastructure networks it turned out that in some areas, the data are lacking. The residential areas with lack of data are not covered in subsequent statistical analyses. According to the expectations, all the considered networks were not present in all classes of population density. Thus, the heating network appears only in classes A and B, the gas supply also in the class C and sewage network also in the class D, while public roads, water and electricity network as a mandatory infrastructure networks are present in all 6 classes. The dependency on the population density was comparable for all the addressed networks; however, the comparison of thus obtained distances between networks differs. This is due to the existence of certain networks outside of public areas (roads). According to the current practice, all new networks are designed within the public areas. Since most of the sampled water supply networks run in public areas, and the data were, compared with data on public roads, of better quality, we determined the value of the values of the membership function **close** according to the values of the sample of the water supply network. For the determination of dependency of distance on the networks of population density, we used the nonparametric Kruskal-Wallis test for hypothesis testing: H0 medians of samples are the same, while H1 medians of the sample are not. In all cases the hypothesis H1 was confirmed. On the basis of these findings, the membership function could be determined for each class, however, since the results of classes A, B and D were very close, we set a uniform function. All the discussed networks thus have determined membership functions $\mathbf{close}_{(A,\,B,\,D)}$ (0,10,20,30), $\mathbf{close}_{(C)}$ (0,10,15,25), $\mathbf{close}_{(E)}$ (0,10,35,45) and $\mathbf{close}_{(F)}$ (0,10, 55,65).

Based on the analysis of 30 major settlements with appropriate distribution of primary and secondary water supply networks, the expected costs of building of the primary network for classes A, B, C and D were determined in proportion of 45%[16]. For each class a comparison was then made with the costs established on the basis of the lengths of the primary network in the buffer zones of the samples. The costs are similar for the distance of 200 to 300 m for all classes. Thus determined distance was the basis for determining the value of the function $\mathbf{far}_p$. The values of the function $\mathbf{far}_s$ were determined as a value between the above-specified values of functions **close** and $\mathbf{far}_p$.

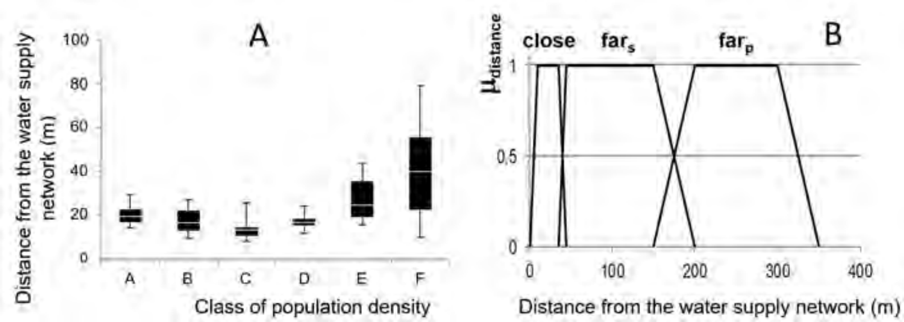

Chart 3: Quartile diagram of the analysis of the distance from the water supply network (A) and the membership function of the variable *Distance from the water supply network* for the population density class E (B).

The result of the statistical analysis of the distances between the buildings has shown that the differences between the medians of samples are statistically significant. Nevertheless, due to small differences in classes A, B, E and F, a uniform membership function was set. The membership functions for the value of the **built** are thus determined by using the three trapezoidal functions: μ_1(ABEF) = (25, 30, 40, 50); μ_2(C) = (0, 5, 10, 15); μ_3(D) = (10, 15, 25, 30).

Since the used ArcMap® program does not enable the inclusion of the consequent part of the process of fuzzy inference, the possibility of the spatial representation of the results could have been checked only in the antecedent part of the process with one value of the variable for each variable. The experiment thus tested the following premises: A) IF *population density* is **Gi** AND *distance from the water supply* is **close**[17] AND *land* is **buildable**, B) IF *population density* is **Gi** AND *build-up* is **built** AND *land* is **buildable** and C) IF *population density* is **Gi** AND *build-up* is **built** AND *distance from the network* is **close** AND *land* is **buildable**. In doing this we estimated the expected final population densities $\mathbf{G}_i$ for i = A, B, C, D, E and F per EUP[18]. For testing, the FuzzyMembership tool was used and a combination of two intermediate results thus obtained with FuzzyOverlay tool. The result is a part of the fuzzy process and represents only the degrees of membership. With

[16] *The statistical analysis of the lengths of networks in classes E and F already covers the primary network; therefore no additional assessment is required.*

[17] *The statements should include both the variable, in this case, "distance", as well as its value, in this case its close. As a result, some statements are inappropriate from the linguistic point of view. A linguistically correct statement would be as follows:* The distance from the water supply network is small *or* Water supply network is near.

[18] *The verification of the model takes into account boundaries of the defined units of spatial planning, the concept of the proposed method allows consideration of arbitrary spatial units, for example simulations of future land use in a certain population density.*

the ZonalStatistic tool the result thus obtained was averaged per plot of land. A test was done on 16 residential areas[19] of the total area of 641hectars, namely for 2-4 zones within each class of population density from A to F. The tested areas included build and larger vacant lands. A section of the experiment is shown in Figure 2.

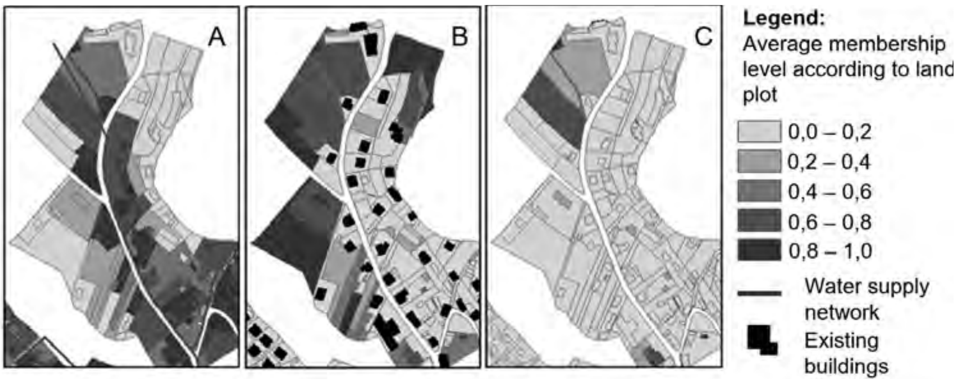

Figure 2: Section from the spatial representation of the test results for each premise A, B and C at the value of population density G_E, showing the average value of membership levels per land plots.

From the interpretation of the test results we can conclude that the reduction of the level of membership in the area of infrastructure corridors systems is well reflected in low values on the plots of existing roads. The highest values are achieved by parcels that are within the range of value of the function **close**. Low values show also large land parcels that are partly located near the infrastructure system. At the implemented phases of planning when some land plots will be divided, the values of the parcels at appropriate distances will significantly increase. The test also showed that the generalization of values per land plot shows various ranges of values, which are merely a consequence of the structure of plots. That allows for greater potential for detailed calibration of the model. In the developing of the application model, it is for Class C recommended to increase the value of the function **close**. When interpreting the results in the classes of population density A and B, it is necessary to pay attention to any possible major functional areas of existing buildings that do not represent free, available vacant lands for construction.

For the determination of the dependence between the lengths of the infrastructure systems and the settlement, the sum of net floor area of existing residential buildings, the number of housing units and the total area of the EUP was taken into account. Also in this case the comparison of the results revealed a high similarity of the results between infrastructure systems. The results of sampling for the density of water supply expressed in the number of housing units and the area of EUP for water supply network are shown in Chart 4. Due to extremely large differences between the classes, the logarithmic scale is used for a more appropriate presentation of the results (Chart 4, A). The differences are substantially lower, if the dependence is shown in relation to the area of the EUP[20] (Chart 4, B), where a high dispersion of the data in the class F is more visible.

[19] *Areas for verification of variables were selected in local communities, which were not included in the sample.*
[20] *EUP is, according to national legislation in republic of Slovenia, area of land with uniform spatial characteristics*

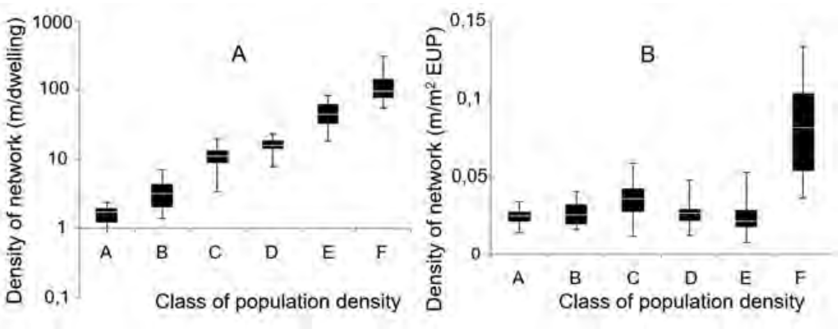

Chart 4: Quartile diagrams of the density of the water supply system expressed in meters per dwelling (A) and m per area of EUP in square meters (B).

Based on the expected length of the water supply network within each class of population density and assessment of the value of the investments[21] in the secondary water supply network, are on the basis of quartile diagrams (Chart 4) determined the costs membership functions for determining the value of the fuzzy variable *costs of construction for secondary water supply systems* (Chart 5).

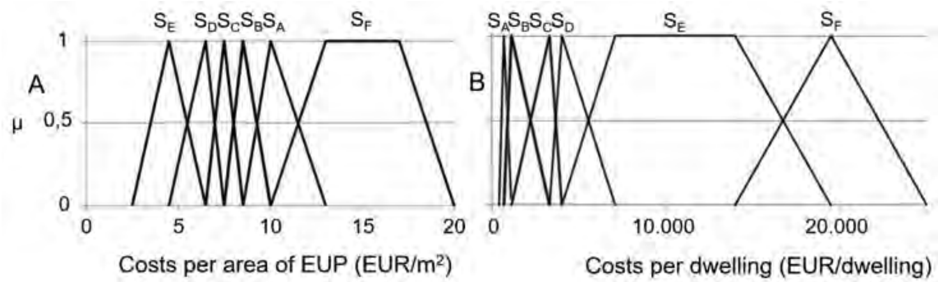

Chart 5: Membership functions of costs of water supply network expressed per surface of EUP (A) and the number of dwellings (B).

Taking into account antecedent and consequent part of fuzzy logic statement: IF (*pop. density* is $\mathbf{G_i}$) THEN (*cost* is Si), two fuzzy models for determining costs were formed. After the defuzzification of the results of the fuzzy model, simulations for different sizes of spatial units were done. Chart 6 presents the simulation, which is produced on the basis of the result of the fuzzy model cost estimates for the new construction of the secondary water supply network in all classes of population density in relation to the simulated number of housings (Chart 6, A) and the simulated EUP surfaces (Chart 6, B).

Thus designed model allows easy simulation of the costs of providing accessibility, based on the number of existing and / or planned housings (or surface of EUP) in a given population density within the subject area (e.g. local community). For the test areas of 16 residential areas, the verification of the fuzzy model, based on the input data of EUP area, was carried out (Chart 6, B). The result of the fuzzy model was compared to the values obtained according to the model, using the linear function obtained from the data within each class. The results of both models were comparable, larger deviations were in classes E and F, where the greatest scatters of the results of the sampling are present.

[21] *The assessment value is based on the author's professional experience in the field of cost evaluation of infrastructure systems.*

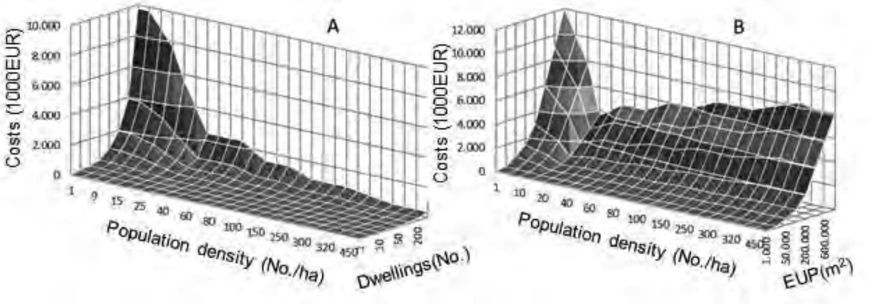

Chart 6: Simulation model of the costs of construction of the water supply network according to the model of the number of dwellings (A) and the surface of EUP (B).

The analysis of the available data on the age of networks in the samples revealed that the information on the age of networks in Slovenia is systematically monitored only in the field of drinking water supply and waste water systems. The analysis of data on the age of these systems showed a larger number of errors; often to meet the requirements of the data recorded, a flat year is entered (e.g. the year 1000 or 1800), making it impossible to directly use the data on age. The proposed method is, towards such errors that significantly overestimate the age of networks, namely tolerant, however, it is not possible to state with certainty that there is not a large number of errors even among the seemingly relevant data. We did a statistical comparison between the age of networks and buildings constructed after 1960 in particular areas, which showed that there are statistically significant differences only between the data of classes C, D, E and F in the water supply network. The water supply networks in classes C, D, E and F are on average for 10 to 20 years younger than the buildings. The reason is to be found in the extensive new constructions of water distribution networks in the 90s in areas with lower population density and is not a consequence of systematic errors in the records.

4 DISCUSSION

Based on the available spatial data in the Republic of Slovenia and according to the method proposed in this article, it was possible to determine the membership functions, which will enable the integration of spatial, economic and time variables in the further development of the model of accessibility to municipal services. In modelling on the basis of economic variables, the fuzzy modelling method proved to be appropriate also for the boundary areas (population density value near 0) and in the case of inclusion of non-linearity in the model. The validation of the spatial representation model for one variable showed the high stability of the model, easy interpretation of results and the possibility of establishing concrete measures on the networks. For the inclusion of all three proposed values of distance, the tools that will allow the output part of the process of fuzzy modelling need to be developed and checked. The age of buildings can, while lacking the historical data, which realistically will not be possible to acquire, be an appropriate basis for assessing the age of networks.

This article identifies the variables of accessibility to municipal services for which we already have the available spatial data, which satisfies the condition of the real accessibility of data for creation of models

(Geurs, van Wee, 2004). To increase the quality and coverage of some of the missing data, we can make use of the data for purposes that go beyond the mere mapping of the existing (state) situation of land development. We estimate that for the purposes of determining the proposed variables of the model, the existing data are of sufficient quality, and if there is interest in Slovenia for municipal land policy, supported by appropriate models, there is no reason not to make an approach towards developing an application model and appropriate tools. The used method of fuzzy logic has in modelling shown to be a sufficiently robust method to include in an appropriate manner the uncertainties arising from the available data. The small number of sufficiently detailed set of variables allows for a transparent and comprehensive monitoring of each discussed infrastructure individually, which in turn enables planning of concrete engineering measures in an area. Models, based on the fuzzy logic, enable the integration of various participants and the public, which Malczewski (2006) defines as the key factor that will define the future use of geographic information systems in spatial planning. The method of fuzzy logic goes in the direction of development of information technologies, which will be based on a calculation using words (Zadeh, 2008). Only a comprehensible model can enable different participants and the public also the "de facto" and not only "de iure" inclusion in the process of preparation of planning documents.

The basis of the inclusion of the proposed variables in the model of accessibility to municipal services will enable: 1) the assessment of the actual accessibility to certain municipal services, which enables timely planning of the missing infrastructure systems, 2) the assessment of the costs of providing adequate access and assessment of benefits in terms of the number of users of the services and 3) identification of areas with the renovation cost estimates for the renovation of existing systems. For a comprehensive assessment of providing adequate access to municipal services for existing and potential new users, further research should determine also the variables, related to the capacity and quality of the networks, the impact of new settlements on existing users of services, potentials for the development of additional municipal services and environmental and social aspects of the provision of access to municipal services, which requires inclusion of experts from other scientific, technical and engineering disciplines. Only the development of applicative tools, testing of models of planning in practice and appropriate standardization of the preparation of the input data will lead to the implementation of the relevant provisions. Only thus will the local communities, which are responsible for the provision of public services, be given its 'own' spatial layer, with which they will be able to actually argue the efficient land use and budgetary resources.

5 ACKNOWLEDGMENTS

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PROSTORSKE, EKONOMSKE IN ČASOVNE SPREMENLJIVKE MEHKEGA MODELA DOSTOPNOSTI DO KOMUNALNIH STORITEV

OSNOVNE INFORMACIJE O ČLANKU:

GLEJ STRAN 201

1 UVOD

Zagotavljanje dostopa do komunalnih storitev je omogočeno prek različnih infrastrukturnih sistemov. Omrežja, objekti in naprave infrastrukturnih sistemov so rezultat že razmeroma visoko razvitih tehničnih ved, vendar pa komunalne dejavnosti glede organizacije, načina upravljanja, razmerja do potrošnika in planiranja pogosto zaostajajo za tehnološkimi rešitvami (Klemenčič, 1997). Pri načrtovanju dostopnosti do komunalnih storitev je treba upoštevati usmeritve, ki izhajajo iz prostorskega načrtovanja ter se nanašajo na gospodarno rabo prostora in tehtanje javnega in zasebnega interesa pri opremljanju stavbnih zemljišč (EPRP, 1999; ZPNačrt, 2007). Upoštevati je treba tudi usmeritve, namenjene lokalnim skupnostim (MELLS, 1996), ki so odgovorne za zagotavljanje ustrezne dostopnosti do komunalnih storitev. Pomembno je tudi zgodnje vključevanje ukrepov, ki jih narekuje trajnostno načrtovanje infrastrukturnih sistemov (Pitts, 2004) ter prilagajanje na napovedane podnebne spremembe (Seto in sod., 2014).

Zagotavljanje komunalnih storitev od načrtovalcev infrastrukturnih sistemov, prostorskih načrtovalcev in odgovornih za zagotavljanje komunalnih storitev zahteva načrtovanje, v katerem se združuje načrtovanje rabe prostora z načrtovanjem infrastrukturnih sistemov. Klemenčič in Pitts izpostavljata, da je treba že v fazah planiranja razvoja poselitve upoštevati tudi faze, ki se nanašajo na delovanje, vzdrževanje, obnove in nadaljnji razvoj infrastrukturnih sistemov (Klemenčič, 1997; Pitts, 2004). Pomembno je, da se obseg komunalnih storitev načrtuje že v zgodnjih (strateških, začetnih) fazah, ker je v izvedbenih fazah že prepozno za oblikovanje celovitih rešitev infrastrukturnih sistemov. Morebitne parcialne rešitve, ki same po sebi sicer sledijo napredku tehnike na posameznem infrastrukturnem področju, imajo lahko celo negativne učinke na celoten sistem[1] (Pitts, 2004). Načrtovanje in upravljanje infrastrukturnih sistemov v gradbeno-tehničnem smislu je v domeni strokovnjakov gradbenega, strojnega, elektrotehničnega ter informacijskega področja in temelji na različnih inženirskih metodah, za katere v zgodnejših fazah načrtovanja rabe prostora običajno še ni na voljo ustreznih vhodnih podatkov. Podrobne simulacije različnih variantnih rešitev bi bile dolgotrajne in povezane z visokimi stroški, zato se v praksi ne izvajajo. Za vključitev v presoje v strateških fazah je zato treba posegati po različnih posplošitvah in napovedih.

V področni zakonodaji v RS je opredeljen pojem opremljenosti zemljišč za gradnjo, ki pa se z gotovostjo lahko potrdi šele na izvedbeni ravni prostorskega načrtovanja. Za obravnavane presoje v strateških fazah

[1] *Na primer ogrevanje s toplotnimi črpalkami na območju vročevodnega sistema z viški toplotne energije.*

ta opredelitev ni primerna, zato vpeljemo pojem dostopnosti[2] do komunalnih storitev, ki pomeni pravočasno, trajno in tudi dolgoročno ekonomsko vzdržno možnost zagotavljanja ustreznih komunalnih storitev na obravnavanem zemljišču.

Za dejansko uporabo rezultatov modela v prostorskem načrtovanju je pomembna ustrezna prostorizacija (alokacija) rezultatov modela (Preston, Yuen in Westaway, 2010) ter možnost dejanske implementacije in uporabe modelov v praksi prostorskega načrtovanja (Lichfield, 2006). Razpoložljivi prostorski podatki o poselitvi[3], podatki o obstoječi gospodarski javni infrastrukturi[4] in digitalni podatki o namenski rabi prostora že omogočajo presoje opremljenih zemljišč za gradnjo v izvedbenih fazah prostorskega načrtovanja. Na manjših območjih obdelave se lahko izdela posamična presoja na posamezno parcelo natančno. Za obravnavo večjih območij je takšna presoja dolgotrajna, zato je treba uporabiti drugačne postopke. Najpogosteje so v uporabi prostorske analize, ki temeljijo na določanju vmesnih območij[5]. Pri določanju širine vmesnih območij se običajno uporabijo splošne oddaljenosti, znotraj katerih je še tehnično mogoča ali po navodilu upravljavcev sprejemljiva priključitev. Ker pa se razporeditev stavb v prostoru (praviloma) ne prilagaja primerni oddaljenosti od infrastrukturnih sistemov, ampak nasprotno, je pri določitvi vrednosti spremenljivk modela treba upoštevati tudi odvisnosti med pričakovanimi oddaljenostmi od infrastrukturnih sistemov in načinom poselitve. Za ustrezno oblikovanje ekonomskih empiričnih podatkov je pomembno tudi razlikovanje med pozidanimi zemljišči, kjer uporabniki storitve že uporabljajo, in nepozidanimi zemljišči. Ključnega pomena pri prostorskem delu modela je seveda vključitev simulacij nove stanovanjske rabe in poselitve v prostoru. Model pa mora omogočati tudi presoje, vezane na obstoječo namensko rabo prostora.

Iz ekonomskega vidika morajo rezultati modela omogočiti oceno stroškov za zagotavljanje dostopnosti do komunalnih storitev ter pričakovanega števila uporabnikov, ki te storitve na preučevanem zemljišču lahko izkoriščajo. Navedena empirična podatka sta ključnega pomena za nadaljnje presoje ekonomskih strokovnjakov, pri čemer sta na obravnavanem področju prisotni dve glavni analitični smeri. Prva temelji na teoriji blaginje in analizah javnih storitev, vanjo spadajo tudi presoje, vezane na proučevanje rente za rabo zemljišč. Raziskave in modeli druge analitične smeri večinoma temeljijo na presoji stroškov in koristi, gravitacijskih modelih in modelih dostopnosti (Johansson in Leonardi, 1986). Čeprav sta se navedeni analitični smeri razvili že dolgo nazaj, je za področje še vedno značilna visoka stopnja abstrakcije (Jäger, 2003; Park, 2014), idealiziranje dejanskega stanja (Alexander, 2014) in pomanjkanje empiričnih modelov (McDonald, 2003; Hortas-Rico in Sole Ole, 2008; Irwin, 2010). Potrebne so tudi raziskave na mikro empirični ravni, kjer je enota opazovanja lahko posamezen investitor (Ploegmakers, van der Krabben in Buitelaar, 2013). Več raziskav mora biti usmerjenih v izdelavo realnejših dinamičnih prostorskih modelov (Irwin, 2010). Če želimo tudi dejansko upoštevati rezultate presoje, ali družba stroške lahko prenese (Rakar, 2010), mora biti ta presoja izvedena pravočasno, torej v zgodnejših fazah prostorskega načrtovanja.

Pomemben del presoj v strateških fazah je tudi napovedovanje prihodnjih dogodkov. Običajno so presoje v prostorskem načrtovanju osredotočene na prihodnjo rast poselitve in gibanje števila prebivalcev. Manj pozornosti je namenjene prihodnjemu stanju infrastrukturnih sistemov. Ker je ena izmed pomembnih

[2] *Izvirni angleški izraz accessibility lahko v slovenščino prevajamo kot dostopnost (na primer dostopnost do storitev v fizičnem smislu) in tudi kot dosegljivost (na primer dosegljivost v časovnem in ekonomskem smislu).*
[3] *Kataster stavb in register nepremičnin (GURS).*
[4] *Zbirni kataster gospodarske javne infrastrukture (GURS).*
[5] *Angl. buffer zone.*

tem v zadnjem obdobju staranje infrastrukturnih sistemov in s tem povezani visoki stroški obnov (Rakar, 2010), morajo presoje vključevati tudi ta vidik. Vključitev časovnih spremenljivk v model mora zato omogočiti razlikovanje med 1) obstoječim, vitalnim omrežjem, 2) omrežjem, ki mu je že ali mu bo v kratkem pretekla amortizacijska doba in na katerem lahko pričakujemo stroške obnov ali celo omejitve priključevanja novih objektov do obnove, 3) omrežja v gradnji, ki so povezana s trenutnimi investicijskimi odhodki, in 4) načrtovanim omrežjem, za katero je ključnega pomena pravočasno načrtovanje virov financiranja. Model mora omogočiti tudi razlikovanje med stopnjo dostopnosti, ki že omogoča neposredno priključevanje načrtovanih objektov na sisteme, in dostopnostjo, ki pred dejansko možnostjo priključitve narekuje še dodatne investicije v smislu dograditve sekundarnih in/ali primarnih[6] infrastrukturnih sistemov.

Še pred desetimi leti se je v tovrstnih presojah največ časa namenilo za zbiranje in interpretacijo osnovnih podatkov o infrastrukturi in poselitvi. Podatki o stanju prostora so danes že hitro dosegljivi, medtem ko se podatki o načrtovanih ureditvah še ne zbirajo sistematično. Ob odsotnosti podatkov, za katere ni realno pričakovati, da bi jih lahko dopolnili, lahko uporabimo tudi ocene (Pergar in Polajnar, 2013). Razpoložljivi prostorski podatki seveda niso idealni, a je ob zavedanju negotovosti vhodnih podatkov in odvisnosti med spremenljivkami navkljub negotovostim treba spodbujati uporabo prostorskih podatkov za namene, ki presegajo zgolj prikaze stanja v prostoru. Še posebej v strateških prostorskih modelih so negotovosti skoraj prezrta tema, kar pogosto povzroča dvome, povezane z veljavnostjo in natančnostjo rezultatov takšnih modelov (Preston, Yuen in Westaway, 2011). Z neustrezno vključitvijo negotovosti v modele lahko upoštevamo, ali celo prikazujemo, bistveno večjo natančnost, kot obstaja v realnem svetu (Krivoruchko, 2011). Zmanjšanje negotovosti v prostorskem načrtovanju je mogoče predvsem z načrtovanimi postopki ter ustrezno pripravo in obdelavo prostorskih podatkov (Mlakar, 2009). Zato je pomembno, da se že pred vzpostavitvijo modela dostopnosti vprašamo tudi o primernosti izbrane metode modeliranja.

Prostorske modele, ki temeljijo na metodah v okolju geografskih informacijskih sistemov, lahko v osnovi razdelimo na metode prekrivanja, večkriterijske metode vrednotenja in metode umetne inteligence (Collins in sod., 2001, v: Malczewski, 2004). Metode prekrivanja preveč poenostavljajo kompleksnost procesov pri določanju rabe prostora, kar se skuša odpraviti z uporabo večkriterijskih metod vrednotenja. Te pa s svojo kompleksnostjo v smislu matematičnega modeliranja v okolju geografskih informacijskih sistemov zmanjšujejo komercialno rabo takšnih modelov, kar je osnovni pogoj za širšo uporabo v praksi prostorskega načrtovanja (Malczewski, 2004). Rešitev se ponuja v združitvi večkriterijskih odločitvenih modelov in metod umetne inteligence, pri katerih je bistvena prednost, da so v nasprotju s tradicionalnimi matematičnimi metodami tolerantne do nenatančnosti, dvomnosti in negotovosti vhodnih podatkov ter odvisnosti med spremenljivkami (Malczewski, 2004). Po letu 2009 je na področju razvoja in uporabe modelov za upravljanje infrastrukturnih sistemov opaziti veliko povečanje večkriterijskih odločitvenih modelov, ki temeljijo na mehkem odločanju (Kabir, Sadiq in Tesfamariam, 2013). Podobno tudi analiza števila objav o uporabi metode mehke logike na področju prostorskega načrtovanja kaže na podvojitev števila objavljenih znanstvenih prispevkov po letu 2007[7]. Metoda mehke logike (angl. *fuzzy logic*) se je

[6] *Infrastrukturna omrežja v osnovi delimo na primarna, ki so namenjena povezavi med naselji oziroma njihovimi deli, ter sekundarna, na katera se končni uporabniki priključujejo z zasebnimi priključki.*

[7] *Analiza je bila izdelana v bazi objav Web of Science po ključnih besedah: »fuzzy logic« in »spatial planning«.*

že izkazala za primerno predvsem na področju izdelave kompleksnih modelov z visokimi negotovostmi in nepreciznimi vhodnimi podatki (npr. Malczewski, 2006; Fernandez in Ruiz, 2009; Kabir, Sadiq in Tesfamariam, 2013).

Metodo mehke logike je vpeljal Zadeh v letu 1956 in od takrat se je njena uporaba razširila na številna strokovna in raziskovalna področja. V predlaganem modelu je uporabljena teorija mehkih množic in mehkega sklepanja, ki je ožje področje mehke logike. Na podlagi mehke logike lahko v sistem vnašamo svoja in druga izkustvena znanja, saj temeljijo na mehkih logičnih pravilih, ki jih ob razvoju modela posredujejo nosilci izkustvenih (ekspertnih) znanj. Vzpostavitev vhodnih podatkov zahteva v primerjavi s preostalimi metodami tako imenovane umetne inteligence intenzivno znanstveno-raziskovalno delo (Aliev in Aliev, 2001), medtem ko je uporaba tako oblikovanih modelov enostavnejša in že vgrajena v nekatere novejše programe za delo v okolju geografskih informacijskih sistemov (Boroushaki in Malczewski, 2010), in je kot takšna lahko bolj uporabna za preostale deležnike v procesu prostorskega načrtovanja. Z uporabo metode mehke logike se lahko bistveno zmanjša izguba informacij pri vrednotenju v strateških fazah, kar na primer lahko vodi v drugačne investicijske odločitve, razvojne strategije in davčne politike (Sui, 1992). Na obravnavanem področju je pogosto uporabljena pri vrednotenju trajnostnih kriterijev (Han s sod., 2006; Fernandez in Ruiz, 2009), ker omogoča preprosto vključevanje visokega števila kriterijev v odločitve, kar pa na drugi strani lahko vodi do tako imenovane preinformiranosti modelov (Virant, 2003). V analiziranih raziskavah (Sui, 1992; Han in sod, 2006; Fernandez in Ruiz, 2009) je malo pozornosti posvečene podrobnejšemu določanju mehkih množic oziroma oblikovanju posameznih pripadnostnih funkcij, ki pa so ključnega pomena za zmanjševanje negotovosti rezultatov mehkega modela.

2 SPREMENLJIVKE MODELA DOSTOPNOSTI DO KOMUNALNIH STORITEV

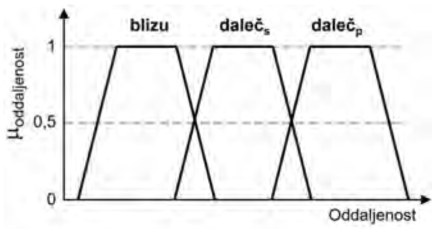
Za računanje z mehkimi izjavami je treba najprej določiti njihove lingvistične atribute, sledi opredelitev njihovih pripadnostnih funkcij. Za posamezno spremenljivko se oblikuje osnovna premisa (*X* je **term)**, pri čemer je *X* mehka spremenljivka in **term** lingvistična vrednost te spremenljivke. Mogoči so različni zapisi mehkih množic in različne oblike pripadnostnih funkcij. Najpogosteje se uporabljajo trikotniške in trapezoidne oblike funkcije in parametrski način zapisa funkcij[8] (Virant, 1998, 2003). Če za logično povezavo uporabimo mehko implikacijo, dobimo mehka pravila, na podlagi katerih postavljamo algoritme delovanja mehkih sistemov. Splošen primer pravila je (Virant, 2003): IF (*X1* je **term1**) AND (*X2* je **term2**) AND … THEN (*Y* je **term a**)[9]. V nadaljevanju prispevka so tako določene lingvistične vrednosti prostorskih, ekonomskih in časovnih spremenljivk (kot so v nadaljevanju na primer: **blizu**, **daleč**, **staro**, **novo**) in njihove pripadnostne funkcije (na primer funkcija za vključitev gostote poselitve razreda $\mathbf{G_E}$ (50,70,90,110), zapisana na parametričen način, preglednica 1).

Prostorski del modela temelji na oddaljenosti med obstoječim ali načrtovanim omrežjem in obravnavanim zemljiščem ter na vključitvi obstoječega stanja poselitve v model. Za vključitev oddaljenosti med obstoječim ali načrtovanim omrežjem in obravnavanim zemljiščem se določi spremenljivka *oddaljenost* z lingvističnimi vrednostmi **blizu**, $\mathbf{daleč_s}$ in $\mathbf{daleč_p}$ (graf 1). Na oddaljenosti od infrastrukturnega sistema, kjer dosega lingvistična vrednost **blizu** stopnjo pripadnosti 1, je največja možnost dejanske priključitve

[8] *Parametričen zapis trikotne funkcije: (a, b, c), trapezoidne funkcije: (a, b, c, d).*

[9] *Po priporočilih (Virant, 1998, 2003) se tudi za zapise v slovenskem jeziku zaradi večje jasnosti uporabljajo izvirni angleški izrazi IF, AND, OR, THEN, min, max.*

prek terciarnega sistema oziroma priključka. Kjer se oddaljenost bliža vrednosti 0, je proučevana enota zemljišča v varovalnem koridorju infrastrukturnega sistema, kjer gradnja praviloma ni mogoča, zato se dostopnost na teh zemljiščih ne določa. V območju vrednosti **daleč$_p$** so zemljišča, na katerih je predhodno treba širiti primarni infrastrukturni sistem. V vmesnem območju **daleč$_s$** je pred priključitvijo treba le dograditi sekundarne sisteme. Na večjih oddaljenostih je zagotovitev dostopnosti povezana s previsoko negotovostjo dejanske izgradnje primarnega infrastrukturnega sistema v obravnavanem časovnem okvirju, zato se za ta zemljišča dostopnost ne določa. Pri določitvi vrednosti spremenljivke **daleč$_p$** je treba upoštevati, da so predvsem v naseljih trase primarnih sistemov vezane na sisteme infrastrukturnih koridorjev, ki praviloma potekajo znotraj javnih cest. Na določanje oddaljenosti od primarnih sistemov zato bolj kot evklidska razdalja vpliva razporeditev poselitve in koridorjev cest po prostoru. Poleg tega so daljši odseki primarnih omrežij običajno namenjeni več območjem hkrati, zato strošek zagotavljanja dostopnosti ne sme biti v celoti v breme obravnavanega zemljišča.



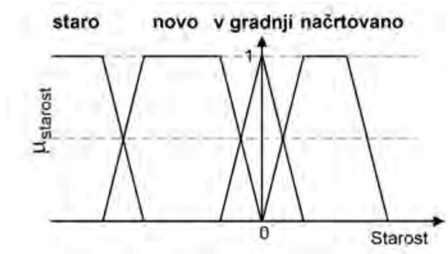
Graf 1: Mehka spremenljivka *oddaljenost* in njene lingvistične vrednosti za vključitev oddaljenosti od omrežja v model.

Model mora omogočiti simulacije prihodnje poselitve in tudi presoje stanja glede na trenutno namensko rabo zemljišč. Pri tem je treba upoštevati dejansko pozidanost zemljišč in gostoto poselitve kot ključen element, ki omogoča nadaljnje podrobnejše ekonomske presoje. V ta namen se določi še mehka spremenljivka *pozidano* z mehko vrednostjo **pozidano**. Nezazidana zemljišča se opredelijo kot mehki komplement funkciji z vrednostjo **pozidano** $\mu_c(x) = 1 - \mu_A(x)$. Za vključitev obstoječe namenske rabe prostora v model je treba upoštevati, da je območje stavbnega zemljišča vezano na pravno zavezujoča določila prostorskega akta. Zato se meje že veljavnega zazidljivega območja v model lahko vključijo le z ostrimi vrednostmi. Vrednosti za vključitev simulacij prihodnje rabe v model so lahko mehkejše. Gostota poselitve se v model vključi prek mehkih spremenljivk razredov gostote poselitve. Število in širina razredov ter oblika pripadnostnih funkcij so odvisni od sistema poselitve v obravnavanem okolju in natančnosti obravnave.

Izhodna spremenljivka *stroški* se določi z mehkimi števili **S1, S2 … Sn**. Ob večjih negotovostih pri določanju stroškov se za določitev mehkega števila uporabijo trapezne pripadnostne funkcije, če so napovedi bolj zanesljive in razlike med razredi majhne, se uporabijo trikotne pripadnostne funkcije. Tako opredeljena spremenljivka *stroški* se uporabi v sklepni logiki mehkega procesa. Povezava med pogojno in sklepno logiko procesa nato temelji na posameznih logičnih izjavah, na primer: IF (*gostota pos.* je **G$_i$**) AND (*starost* je **novo**) THEN (*strošek* je **S$_i$**). Vrednost funkcije *stroški* se določi glede na strošek, ki se presoja (stroški prve gradnje, stroški letne amortizacije, stroški obratovanja, stroški obnov). Pri določitvi vrednosti je treba upoštevati tudi razlike, ki izhajajo iz gradnje na različnih območjih poselitve (gostejša zazidava je povezana z višjimi stroški gradnje), ter spremenljivke, vezane na terenske razmere gradnje.

Za mehko spremenljivko *starost* se opredelijo štiri mehke vrednosti, in sicer **staro, novo, v gradnji** in

načrtovano (graf 2). Z vrednostjo **staro** se opredelijo infrastrukturni sistemi, pri katerih se lahko pričakuje nižja dostopnost do komunalnih storitev, ki je posledica starosti sistemov. Funkcija v levo ni zamejena, s čimer je povečana toleranca do neustreznih podatkov o starosti[10] ali pa nekateri deli sistemov dejansko že bistveno presegajo življenjsko dobo. Omrežje znotraj pričakovane življenjske dobe sistema se opredeli kot **novo**. Priključevanje dodatnih uporabnikov na sistem je z vidika starosti omrežja v tem delu pričakovano in optimalno. Pri določitvi vrednosti pripadnostnih funkcij **staro** in **novo** je treba upoštevati različne amortizacijske dobe posameznih infrastrukturnih sistemov. Omrežje, ki je ob presoji v fazi izdelave projektne dokumentacije ali gradnje, se opredeli z vrednostjo **v gradnji**. Funkcija je v tem primeru lahko definirana s trikotno funkcijo, ker je gradnja v primerjavi s preostalimi časovnimi obdobji bistveno krajša. Pripadnostna funkcija **načrtovano** je v desno zamejena, ker je načrtovanje novih sistemov smiselno le v ožjih in časovno obvladljivih okvirjih, na primer pet let. Razmejitev med starim in novim omrežjem je odvisna od življenjske dobe vgrajenih materialov ter je praviloma določena z ustreznimi predpisi in standardi, zato v raziskavi ta del ni bil podrobneje obravnavan. Ker je za dejansko vključitev podatkov v model ključnega pomena razpoložljivost podatkov o obstoječih omrežjih, je bila v empiričnem delu izdelana analiza razpoložljivih podatkov o starosti omrežij v vzorcu in izdelana primerjava s podatki o starosti priključenih stavb.



Graf 2: Mehka spremenljivka *starost* in njene lingvistične vrednosti za vključitev starosti v model.

Metoda določitve pripadnostnih funkcij

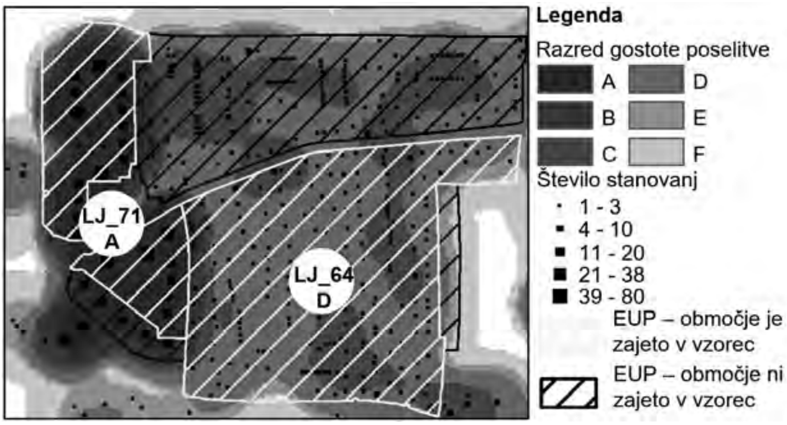
Od metod vrednotenja komunalne infrastrukture, v katere lahko neposredno vključimo tudi relacijo do gostote poselitve, je primerna metoda izbora tipičnih prostorskih enot, na primer vzorčnih naselij ali stanovanjskih sosesk (Rakar in Makuc, 1985). Pomembno je, da za celovito presojo vpliva gostote poselitve na stroške zagotavljanja storitev v presojo zajamemo gostote poselitve od najnižjih, ki praviloma povzročajo najvišje stroške na prebivalca, do najvišjih gostot v preučevanem prostoru. Prostorske analize v raziskavi so zato temeljile na vzorcu obstoječe stanovanjske poselitve v Republiki Sloveniji v izboru lokalnih skupnosti različne gostote poselitve. Pri izboru[11] je bila najprej izdelana delitev vseh lokalnih skupnosti v Republiki Sloveniji na srednje velika in majhna mesta (Zavodnik Lamovšek, Drobne in Žaucer, 2008). Upoštevano je bilo tudi merilo števila lokalnih skupnosti v posamezni skupini in število prebivalcev. Tako so bile poleg dveh iz razreda srednje velikih mest v vzorec vključene še po štiri lokalne skupnosti iz skupine majhnih mest in štiri izmed preostalih. Pri dokončnem izboru je bila upoštevana

[10] *Na primer leto izgradnje 1000.*

[11] *Zaradi predpisane enotne metode izdelave digitalnih vsebin prostorskih aktov je bil izbran vzorec v lokalnih skupnostih, ki so v času vzorčenja že imele sprejete prostorske akte v skladu z novejšo prostorsko zakonodajo, sprejeto po letu 2007. Vzorčenje je potekalo v letu 2012.*

tudi čim večja raznolikost poselitve. Na podlagi zgornjih meril so bile izbrane: mestna občina Ljubljana, mestna občina Novo mesto, občina Idrija, občina Črnomelj, občina Naklo, občina Ruše, občina Vransko, občina Turnišče, občina Loški Potok in občina Sveti Tomaž.

Vzorčenje je potekalo po razredih gostote poselitve. Določitev razredov je temeljila na prostorski analizi gostote obstoječe poselitve v izbranih desetih lokalnih skupnostih. Za grafično analizo je bila določena gostota poselitve s funkcijo KernelDensity v programskem okolju ArcMap® (slika 1). Upoštevano je bilo število stanovanjskih delov stavb[12] ter povprečno število članov gospodinjstva v posamezni lokalni skupnosti[13]. Tako je bilo določenih šest razredov, po katerih je bilo izdelano vzorčenje. V vzorec so bile vključene že v celoti pozidane enote urejanja prostora[14]. Za končen vzorec je bilo določenih 156 stanovanjskih območij s po 25 do 30 območji v posameznem razredu gostote poselitve od A do F[15] (razredi so podrobneje predstavljeni v preglednici 1) z več kot 7000 obstoječimi stanovanjskimi objekti. V skupni površini vzorec zajema od 10 do 20 % stanovanjske namenske rabe prostora v izbranih desetih lokalnih skupnostih. Ocenjujemo, da je delež tako zajetih površin dovolj reprezentativen. Po izvedenem vzorčenju je bila izdelana kontrola podatkov o deležih stanovanj v stavbah, ki se spremljajo v okviru REN (preglednica 1).



Slika 1: Prikaz načina vzorčenja obstoječe stanovanjske zazidave v predlaganih razredih gostote poselitve.

Med vzorčenjem se je izkazalo, da so izbrani razredi gostote poselitve A, B,C in D praviloma del večjih naselij in naselij mestnega značaja, razred E zajema manjša podeželska naselja in razred F območja razpršene poselitve. V vzorec so bili poleg podatkov o poselitvi vključeni podatki o obstoječih infrastrukturnih omrežjih za oskrbo s pitno vodo, odvajanje odpadnih komunalnih voda, lokalnih cestah ter distribucijskem elektroenergetskem, plinovodnem in vročevodnem omrežju[16]. Pri izboru pripadajočega infrastrukturnega omrežja k posameznemu stanovanjskemu območju v vzorcu je bilo treba razrešiti še ključno dilemo delitve omrežij na primarne in sekundarne sisteme. V vzorec razredov gostote poselitve

[12] *Podatki so bili povzeti po Registru nepremičnin (GURS).*
[13] *Povprečno število prebivalcev na posamezno gospodinjstvo v letu 2011 (www.stat.si).*
[14] *V primeru posameznih praznih zemljišč v vzorcu je bil vzorec korigiran z dodatnimi stavbami in infrastrukturnim omrežjem.*
[15] *Poimenovanje tako določenih razredov gostote poselitve ni bilo predmet raziskave, v nadaljnjih raziskavah je treba določiti ustrezno poimenovanje predlaganih razredov.*
[16] *Podatki so bili povzeti po Zbirnem katastru javne gospodarske infrastrukture (GURS), vzorčenje je potekalo ročno na podlagi inženirskega poznavanja posameznih omrežij in navezav na primarne sisteme.*

A, B, C in D je zajeto le sekundarno omrežje, stroški izgradnje primarnega omrežja pa temeljijo na sorazmernem deležu primarnega omrežja celotnega naselja. Pri vzorčenju v razredih E in F je že v vzorec poselitve hkrati zajetih več med seboj povezanih naselij oziroma posameznih stavb, s čimer so že zajete tudi dodatne dolžine infrastrukturnih sistemov, ki so posledica razporeditve poselitve v prostoru.

Podlaga za oceno stroškov zagotavljanja dostopnosti do komunalnih storitev so dolžine infrastrukturnih sistemov. Če želimo hkrati presojati koristi v smislu števila odjemalcev, je treba dolžine izraziti v odvisnosti od parametrov gostote poselitve. Medtem ko je parametre modela, ki se nanašajo na pripadajoče sekundarno omrežje k posameznemu območju, razmeroma enostavno določiti, je predvsem zaradi sočasnega napajanja več območij hkrati določanje parametrov primarnih omrežij težavnejše. V raziskavi je predlagana metoda, ki temelji na primerjavi povprečnega stroška za gradnjo primarnih omrežij v posameznem vzorcu in stroška, določenega na podlagi dejanske dolžine primarnih sistemov v okolici posameznega vzorca. Pri tem so bile zajete dolžine vmesnih območij širine 100, 200, 300, 400 in 500 metrov. Za določitev povprečnega deleža primarnega vodovodnega omrežja je bil zajet dodaten vzorec znotraj zgoščene poselitve v tridesetih lokalnih skupnostih v Republiki Sloveniji, kjer je še evidentirana ustrezna delitev na primarno in sekundarno omrežje[17]. Vrednost mehke spremenljivke $\mathbf{dale\check{c}_p}$ se določi na evklidski oddaljenosti, kjer sta oba stroška enaka.

Pri analizah dejanskih prostorskih podatkov je težko pričakovati normalno porazdeljene vzorce, zato statistične analize temeljijo na neparametričnih testih. V vseh primerih je bil za testiranje hipotez uporabljen test Kruskal-Wallis. Če so za posamezno spremenljivko obstajale statistično značilne razlike med razredi gostote poselitve, se nato določijo vrednosti mehkih spremenljivk za posamezen razred gostote poselitve. Na podlagi mediane ter 1. in 3. kvartila se določijo pripadnostne funkcije. Za trapezoidne funkcije se določi stopnja pripadnosti 1 pri 1. kvartilu, stopnja pripadnosti se začne zmanjševati pri vrednosti 3. kvartila. Pri določitvi trikotne funkcije vrh predstavlja mediano razreda. Po priporočilih se funkcije nato med seboj sekajo pri stopnji pripadnosti 0,5 (Virant, 2003). Za lažjo interpretacijo rezultatov mehkega modela in večjo razumljivost se tako opredeljene vrednosti pretvorijo iz mehkega okolja v okolje običajnih vrednosti z ostrenjem[18]. Za prostorske prikaze je v prispevku predlagana in preizkušena tudi metoda, pri kateri se tako dobljeni rezultati rastrskega modela posplošijo na različne prostorske enote (zemljiško parcelo, enoto urejanja prostora, naselje). Tako določene posplošene vrednosti je mogoče enostavno in bolj razumljivo tudi prikazati.

Obravnava parametrov, vezanih na določitev ekonomskih spremenljivk, zajema tudi validacijo modela. Prostorske spremenljivke poleg validacije zajemajo že tudi verifikacijo, in sicer v delu, ki so ga omogočale že vgrajene funkcije v programskem okolju ArcMap. Prostorski in stroškovni del modela je verificiran na 16 stanovanjskih območjih različne gostote poselitve in stopnje zazidanosti, in sicer iz lokalnih skupnosti, ki niso bile zajete v osnovno vzorčenje. Proces mehkega modela za en vhod in izhod je bil razvit v programskem okolju MS Excel. Pri tem so upoštevane trikotniške in trapezoidne oblike pripadnostnih funkcij, metoda implikacije Mamdani in težiščna metoda ostrenja. Prostorske analize in verifikacije prostorskega prikaza rezultatov so bile izdelane v programskem okolju ArcMap®, z vgrajenima funkcijama FuzzyMembership in FuzzyOverlay. Razvoj novih orodij ni bil predmet raziskave.

[17] *Ustrezna delitev in evidentiranje omrežij ločeno na primarne in sekundarne sisteme se v javnih evidencah izgublja.*
[18] *Izvirni angleški izraz je defuzzification.*

3 REZULTATI

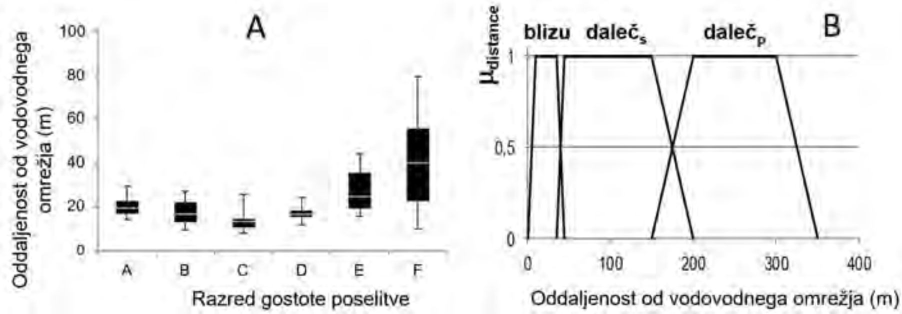
V preglednici 1 so prikazani deleži posameznega tipa stavb iz izdelanega vzorca. Na podlagi razredov gostote poselitve, ki so bili določeni že v fazi vzorčenja, so bile že lahko opredeljene pripadnostne funkcije za vključitev gostote poselitve v mehki model (preglednica 1). Čeprav na primer lahko s funkcijo *KernelDensity* na celotnem prostoru opredelimo trenutno gostoto poselitve, za vključitev gostote poselitve v prostorski del predlaganega modela to ni primerno. Na robovih poselitve namreč gostota, zaradi vključitve praznih zemljišč v preračun gostote, upade vse do najnižjega razreda (razvidno s slike 1), kar pa še ne pomeni, da se na tej lokaciji dejansko pojavijo vsi razredi gostote poselitve. Gostoto poselitve je v prostorski del modela ustrezneje vključiti ob upoštevanju ostre meje enote urejanja prostora ali območij simulacije novih stanovanjskih območij. Predlagane pripadnostne funkcije (preglednica 1) so upoštevane v simulacijah (graf 6).

Preglednica 1: Predlagani razredi gostote poselitve, njihove pripadnostne funkcije in primerjava z deleži stavb glede na število stanovanj v vzorcu.

Razred in gostota (preb/ha)	*Predlagana pripadnostna funkcija*	*Število stavb v vzorcu*	*Odstotek stavb glede na število stanovanj in vrstnih hiš v vzorcu*					
			nad 50	*od 21 do 50*	*od 6 do 20*	*od 3 do 5*	*vrstne hiše*	*od 1 do 2*
A – več kot 300	(280,300,500,500)	780	27 %	36 %	30 %	2 %	1 %	4 %
B – od 100 do 300	(90,110,280,300)	716	-	12 %	30 %	10 %	40 %	8 %
C – od 60 do 100	(50,70,90,110)	1886	-	-	-	1 %	89 %	10 %
D – od 20 do 60	(16,24,50,70)	2330	-	-	-	2 %	41 %	57 %
E – od 10 do 20	(8,12,16,24)	958	-	-	-	-	2 %	98 %
F – manj kot 10	(0,0,8,12)	521	-	-	-	-	2 %	98 %

Med vzorčenjem infrastrukturnih omrežij se je izkazalo, da so na nekaterih območjih podatki še pomanjkljivi. Stanovanjska območja s pomanjkljivimi podatki niso bila zajeta v nadaljnje statistične analize. Vsa obravnavana omrežja po pričakovanjih niso bila prisotna v vseh razredih gostote poselitve. Tako se vročevodno omrežje pojavi le v razredih A in B, plinovodno omrežje še v razredu C in kanalizacijsko omrežje še v razredu D, omrežje javnih cest, vodovodno in elektroenergetsko omrežje je kot obvezno seveda prisotno v vseh šestih razredih. Odvisnosti od gostote poselitve so bile za vsa obravnavana omrežja med seboj primerljive. Primerjava tako dobljenih oddaljenosti pa se med omrežji razlikuje. Vzrok je v poteku nekaterih obstoječih omrežij tudi zunaj javnih površin (cest). Po sedanji praksi se vsa nova omrežja načrtujejo znotraj javnih površin. Ker večina vzorčenega vodovodnega omrežja poteka po javnih površinah in so bili podatki v primerjavi s podatki o javnih cestah kakovostnejši, so bile za določitev vrednosti pripadnostne funkcije **blizu** privzete vrednosti iz vzorca vodovodnega omrežja. Za opredelitev odvisnosti oddaljenosti od omrežij od gostote poselitve je bil uporabljen neparametričen test Kruskal-Wallis za testiranje hipoteze: H0-mediane vzorcev so enake, H1-mediane vzorcev niso enake. V vseh primerih je bila sprejeta hipoteza H1. Na podlagi te ugotovitve bi lahko za vsak razred določili svojo pripadnostno funkcijo, ker pa so si bili rezultati v razredih A, B in D zelo blizu skupaj, je zanje določena enotna funkcija. Tako so za vsa obravnavana omrežja določene pripadnostne funkcije $\mathbf{blizu}_{(\mathbf{A, B, D})}$(0, 10,20,30), $\mathbf{blizu}_{(\mathbf{C})}$(0,10,15,25), $\mathbf{blizu}_{(\mathbf{E})}$(0,10,35,45) in $\mathbf{blizu}_{(\mathbf{F})}$(0,10,55,65).

Na podlagi analize tridesetih večjih naselij z ustrezno razdelitvijo na primarno in sekundarno vodovodno omrežje so bili pričakovani stroški gradnje primarnega omrežja za razrede A, B, C in D določeni v deležu 45 %[19]. Za vsak posamezen razred je bila nato izdelana primerjava s stroški, določenimi na podlagi dolžin primarnih omrežij v vmesnih območjih ob vzorcih. Stroška sta za vse razrede podobna na oddaljenosti od 200 do 300 metrov. Tako določena oddaljenost je bila podlaga za določitev vrednosti funkcije **daleč$_p$**. Vrednosti funkcije **daleč$_s$** so določene kot vrednost med zgoraj določenimi vrednostmi funkcij **blizu** in **daleč$_p$**.



Graf 3: Kvartilni diagrami analize oddaljenosti od vodovodnega omrežja (A) in pripadnostne funkcije spremenljivke *Oddaljenost od vodovodnega omrežja* za razred gostote poselitve E (B).

Rezultat statistične analize oddaljenosti med stavbami je pokazal, da so razlike med medianami vzorcev statistično značilne. Kljub temu je zaradi majhnih razlik za razrede A, B, E in F določena enotna pripadnostna funkcija. Pripadnostne funkcije za vrednosti **pozidano** so tako določene s tremi trapezoidnimi funkcijami: μ_1(ABEF) = (25, 30, 40, 50); μ_2(C) = (0, 5, 10, 15); μ_3(D) = (10, 15, 25, 30).

Ker uporabljeno programsko okolje ArcMap® še ne omogoča vključitve sklepnega dela procesa mehkega sklepanja, je bila možnost prostorskega prikaza rezultatov lahko preverjena le v pogojnem delu procesa z eno vrednostjo spremenljivke pri posamezni spremenljivki. V preizkusu so bile tako preverjene naslednje premise: *A) IF gostota poselitve* je **G$_i$** AND *oddaljenost od vodovoda* je **blizu**[20] AND *zemljišče* je **zazidljivo**, B) *IF gostota poselitve* je **G$_i$** AND *zazidanost* je **pozidano** AND *zemljišče* je **zazidljivo** in C) *IF gostota poselitve* je **G$_i$** AND *zazidanost* je **pozidano** AND *oddaljenost od omrežja* je **blizu** AND *zemljišče* je **zazidljivo**. Pri tem so bile ocenjene pričakovane končne gostote poselitve **G$_i$** za i=A, B, C, D, E in G na enoto urejanja prostora[21]. Pri preveritvi je bilo uporabljeno orodje *FuzzyMembership* in kombinacija dveh tako dobljenih vmesnih rezultatov z orodjem *FuzzyOverlay*. Rezultat je del mehkega procesa in predstavlja zgolj stopnje pripadnosti. Z orodjem *ZonalStatistic* je bil tako dobljen rezultat povprečen na posamezno zemljiško parcelo. Izdelan je bil preizkus na 16 stanovanjskih območjih[22] skupne površine 641 hektarov, in sicer za od 2 do 4 območja v posameznem razredu gostote poselitve od A do F. Na testiranih območjih so bila tako zazidana kot večja nezazidana območja. Izsek iz preizkusa je na sliki 2.

[19] *V statistično analizo dolžin omrežij v razredih E in F je že zajeto tudi primarno omrežje, zato dodatna ocena ni potrebna.*

[20] *Izjave morajo zajemati tako spremenljivko, v tem primeru »oddaljenost«, kot njeno vrednost, v konkretnem primeru je njena vrednost blizu. Posledično so nekatere izjave neustrezne iz jezikovnega vidika. Jezikovno pravilna izjava bi se na primer glasila:* Oddaljenost od vodovoda je majhna *ali* Vodovod je blizu.

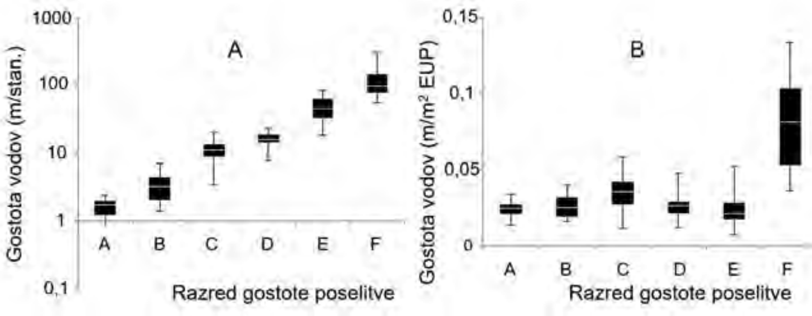
[21] *V verifikaciji modela so bile upoštevane meje že določenih enot urejanja prostora, koncept predlagane metode omogoča upoštevanje poljubnih prostorskih enot, na primer simulacije prihodnje rabe prostora v določeni gostoti poselitve*

[22] *Območja za verifikacijo spremenljivk so bila izbrana v lokalnih skupnostih, ki niso bile zajete v vzorec.*

Slika 2: Izsek iz preizkusa prostorskega prikaza rezultatov za posamezne premise A, B in C pri vrednosti gostote poselitve G_E, s prikazom povprečnih vrednosti pripadnostnih stopenj na zemljiško parcelo.

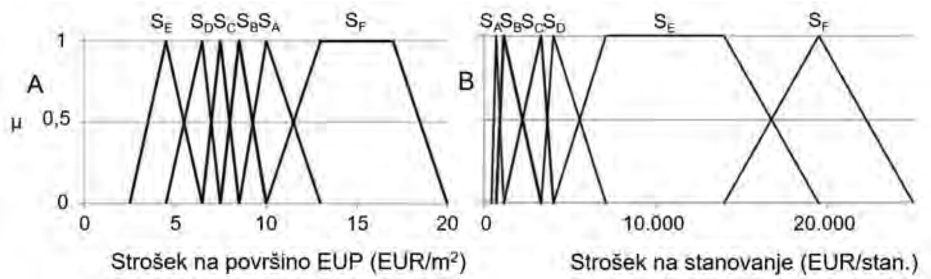
Iz interpretacije rezultatov preizkusa sledi, da se zmanjšanje stopnje pripadnosti na območju koridorjev infrastrukturnih sistemov dobro odraža v nizkih vrednostih na parcelah obstoječih cest. Najvišje vrednosti dosegajo parcele, ki so v vsej širini znotraj območja vrednosti funkcije **blizu**. Nizke vrednosti izkazujejo tudi velike zemljiške parcele, ki se v delu sicer nahajajo v neposredni bližini infrastrukturnega sistema. Ob parcelaciji, ki se izvede šele v izvedbenih fazah prostorskega načrtovanja, se bodo vrednosti parcelam na primerni oddaljenosti bistveno zvišale. Preizkus je tudi pokazal, da posplošitev vrednosti na zemljiško parcelo izkazuje različne razpone vrednosti, ki so zgolj posledica strukture parcel. Navedeno omogoča večje možnosti pri podrobnejšem umerjanju modela. Pri razvoju aplikativnega modela je za razred C priporočljivo povečanje vrednosti funkcije **blizu**. Pri interpretaciji rezultatov v razredu gostote poselitve A in B je treba biti pozoren na morebitne večje funkcionalne površine obstoječih stavb, ki ne predstavljajo prostih, razpoložljivih zemljišč za gradnjo.

Za določitev odvisnosti med dolžinami infrastrukturnih sistemov in poselitvijo je bila za enoto poselitve lahko upoštevana vsota neto tlorisnih površin obstoječih stanovanjskih stavb, število stanovanj in skupna površina enote urejanja prostora. Primerjava rezultatov je tudi v tem primeru pokazala na visoke podobnosti rezultatov med infrastrukturnimi sistemi. Rezultati vzorčenja za gostoto vodov, izraženo v številu stanovanj in površine enote urejanja prostora za vodovodno omrežje, so na grafu 4. Zaradi izredno velikih razlik med razredi je zgolj zaradi ustreznejšega prikaza rezultatov uporabljeno logaritmično merilo (graf 4, A). Kot bistveno nižje se izkazujejo razlike, če se odvisnosti izkazujejo glede na površino EUP (graf 4, B), kjer je bolje razviden tudi visok raztros podatkov v razredu F.



Graf 4: Kvartilni diagrami gostote vodov vodovodnega omrežja, izražene v m/stanovanje (A) in v m/površino EUP (B).

Na podlagi pričakovanih dolžin vodovodnega omrežja v posameznem razredu gostote poselitve in strokovne ocene vrednosti investicij[23] v sekundarno vodovodno omrežje so na podlagi kvartilnih diagramov (graf 4) nato določene stroškovne pripadnostne funkcije za določitev vrednosti mehke spremenljivke *stroški izgradnje sekundarnih vodovodnih sistemov* (graf 5).

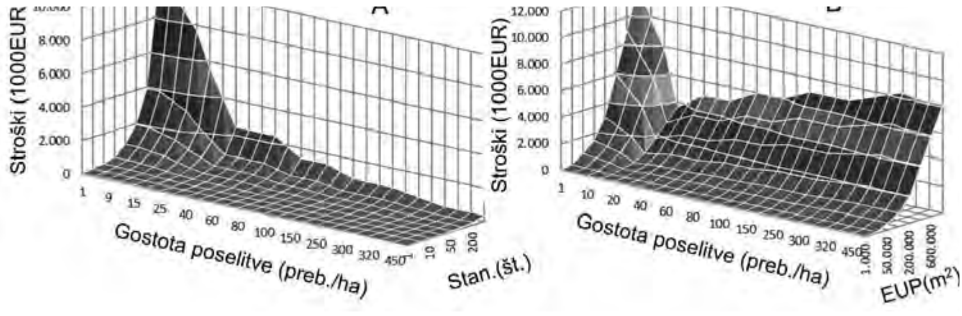


Graf 5: Pripadnostne funkcije stroškov izgradnje vodovodnega omrežja, izraženih na površino EUP (A) in število stanovanj (B).

Ob upoštevanju mehke izjave pogojne in sklepne logike: IF (*gostota pos.* je $\mathbf{G}_i$) THEN (*strošek* je $\mathbf{S}_i$) sta oblikovana dva mehka modela za določitev stroškov. Po ostrenju rezultatov mehkega modela so bile izdelane simulacije za različne velikosti prostorskih enot. Na grafu 6 je predstavljena simulacija, ki je izdelana na podlagi rezultata mehkega modela ocene stroškov novogradnje sekundarnega vodovodnega omrežja po vseh razredih gostote poselitve glede na simulirano število stanovanj (graf 6, A) in glede na simulirane površine EUP (graf 6, B).

Tako oblikovan model nam omogoča enostavno simulacijo stroškov opremljanja glede na število obstoječih in/ali načrtovanih stanovanj (ali površine EUP) v posamezni gostoti poselitve na obravnavanem prostoru (na primer lokalne skupnosti). Za testna območja 16 stanovanjskih območij je bila izdelana tudi verifikacija mehkega modela, ki temelji na vhodnih podatkih površine EUP (graf 6, B). Rezultat mehkega modela je bil primerjan z vrednostmi, ki jih dobimo po modelu z uporabo linearne funkcije, pridobljene iz podatkov v posameznem razredu. Rezultati obeh modelov so bili med seboj primerljivi, večja odstopanja so bila v razredih E in F, kjer so prisotni največji raztrosi rezultatov vzorčenja.

[23] *Ocena vrednosti temelji na avtoričinih strokovnih izkušnjah s področja vrednotenja infrastrukturnih sistemov.*



Graf 6: Simulacije modela stroškov izgradnje vodovodnega omrežja po modelu števila stanovanj (A) in površine EUP (B).

Analiza razpoložljivih podatkov o starosti omrežij v vzorcih je pokazala, da se podatki o starosti omrežij v Republiki Sloveniji sistematično spremljajo le za področje oskrbe s pitno vodo ter odvajanje komunalnih odpadnih in padavinskih voda. Analiza podatkov o starosti teh sistemov je pokazala na večje število napak, pogosto je za izpolnitev zahteve po podatku vpisano pavšalno leto (na primer leto 1000 ali 1800), kar onemogoča neposredno uporabo podatkov o starosti. Predlagana metoda je do tovrstnih napak, ki bistveno precenijo starost omrežij, sicer tolerantna, ni pa mogoče z gotovostjo trditi, da tudi med na videz ustreznimi podatki ni večjega števila napak. Izdelana je bila statistična primerjava med starostjo omrežij in stavb, zgrajenih po letu 1960, ki je pokazala, da obstajajo statistično značilne razlike le med podatki v razredih C, D, E in F pri vodovodnem omrežju. Vodovodna omrežja v razredih C, D, E in F so v povprečju od 10 do 20 let mlajša kot stavbe. Razlog je iskati v obsežnih novogradnjah vodovodnih omrežij v 90. letih na območjih nižjih gostot poselitve, ne gre za sistematične napake v evidencah.

4 RAZPRAVA

Na podlagi razpoložljivih prostorskih podatkov v Republiki Sloveniji je bilo po predlagani metodi v prispevku mogoče določiti pripadnostne funkcije, ki bodo omogočile vključitev prostorskih, ekonomskih in časovnih spremenljivk v nadaljnji razvoj modela dostopnosti do komunalnih storitev. Pri modeliranju na podlagi tako oblikovanih ekonomskih spremenljivk se je metoda mehkega modeliranja izkazala kot ustrezna tudi na robnih območjih (vrednosti gostote poselitve blizu 0) in pri vključevanju nelinearnosti v model. Validacija prostorskega prikaza modela za eno spremenljivko je pokazala na visoko stabilnost modela, enostavno interpretacijo rezultatov in možnost določitve konkretnih ukrepov na omrežjih. Za vključitev vseh treh predlaganih vrednosti oddaljenosti je treba razviti ali preveriti že razpoložljiva orodja, ki bodo omogočala tudi izhodni del procesa mehkega modeliranja. Starost stavb je ob pomanjkanju zgodovinskih podatkov, ki jih, realno gledano, ne bo mogoče več pridobiti, lahko ustrezna podlaga za oceno starosti omrežij.

V pričujočem prispevku so opredeljene spremenljivke modela dostopnosti do komunalnih storitev, za katere že imamo na voljo razpoložljive prostorske podatke, s čimer zadostimo tudi pogoju realne dosegljivosti podatkov za izdelavo modelov (Geurs in van Wee, 2004). K večji kakovosti in zajemu nekaterih manjkajočih podatkov pa bo lahko pripomogla prav uporaba podatkov v namene, ki presegajo zgolj prikaz stanja v prostoru. Ocenjujemo, da so za potrebe določitve predlaganih spremenljivk modela obstoječi podatki že dovolj kakovostni, in če v Republiki Sloveniji obstaja interes po komunalni zemljiški politiki, podprti z ustreznimi modeli, ni razlogov, da ne bi začeli razvijati aplikativnega modela in ustreznih orodij.

Uporabljena metoda mehke logike se je pri modeliranju izkazala za dovolj robustno metodo, ki primerno vključuje tudi negotovosti, izhajajoče iz razpoložljivih podatkov. Manjše število dovolj podrobno določenih spremenljivk omogoča transparentno in razumljivo spremljanje vsake obravnavane infrastrukture posebej, kar nam šele omogoča tudi načrtovanje konkretnih inženirskih ukrepov v prostoru. Modeli, ki temeljijo na mehki logiki, omogočajo tudi vključevanje različnih deležnikov in javnosti, kar Malczewski (2006) opredeli kot ključni dejavnik, ki bo v prihodnosti določal uporabo geografskih informacijskih sistemov v prostorskem načrtovanju. Metoda mehke logike gre v smeri razvoja informacijskih tehnologij, ki bodo temeljile na računanju z besedami (Zadeh, 2008). Šele razumljiv model lahko različnim deležnikom in javnosti omogoči tudi »de facto« in ne le »de iure« vključevanje v procese priprave prostorskih aktov.

Že na podlagi vključitve predlaganih spremenljivk v model dostopnosti do komunalnih storitev bodo lahko omogočene: 1) presoje dejanske dostopnosti do posameznih komunalnih storitev, kar omogoča pravočasno načrtovanje manjkajočih infrastrukturnih sistemov, 2) ocene stroškov zagotavljanja ustrezne dostopnosti in presoje koristi v smislu števila uporabnikov storitev ter 3) določitev območij prenove z ocenami stroškov prenove obstoječih sistemov. Za celovito presojo zagotavljanja ustrezne dostopnosti do komunalnih storitev obstoječim in potencialnim novim uporabnikom je treba v nadaljnjih raziskavah opredeliti tudi spremenljivke, ki se nanašajo na zmogljivost in kakovost omrežij, vplive nove poselitve na obstoječe porabnike storitev, potenciale za razvoj dodatnih komunalnih storitev ter okoljske in družbene vidike zagotavljanja dostopnosti do komunalnih storitev, za kar pa je v raziskave treba vključiti tudi strokovnjake z drugih znanstvenih, strokovnih in inženirskih področij. Šele razvoj aplikativnih orodij, testiranje modelov v praksi prostorskega načrtovanja in ustrezna standardizacija priprave vhodnih podatkov bodo lahko vodili v implementacijo v ustrezne predpise. Šele s tem bodo tudi lokalne skupnosti, ki so sicer odgovorne za zagotavljanje javnih storitev, dobile »svoj« prostorski sloj, s katerim bodo lahko dejansko argumentirale gospodarno ravnanje s prostorom in proračunskimi sredstvi.

5 ZAHVALA

V prispevku je predstavljen del rezultatov raziskave, izdelane v okviru doktorskega študija avtorice na Fakulteti za gradbeništvo in geodezijo Univerze v Ljubljani, ki ga je sofinancirala Javna agencija za raziskovalno dejavnost Republike Slovenije. Nadaljevanje raziskave in razvoj aplikativnega modela bo deloma potekal v okviru projekta Water4Cities, ki je financiran iz programa Horizon 2020.

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