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Neural networks in economic analyses of wastewater systems

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ABSTRACT

During selection of optimum sewerage and wastewater treatment systems in rural settlements, often a large number of potential technical solutions is generated. The economic criterion is most frequently assigned the greatest importance which finally results that the solutions involving the lowest total costs are preferred. The conventional approach considerably complicates the choice of the optimum solution, because it requires great efforts in determining the size of considered solutions and preparing of corresponding cost estimates.

The paper analyzes the possibility of using of neural networks in economic analyses of wastewater systems. The neural network NENECOS (NEural Network for approximate Estimation of COsts of wastewater Systems) has been created, which allows simple, fast and adequately accurate estimation of total or unit costs of construction, operation and maintenance of sewerage systems, without the need for prior sizing and preparing of cost estimates. This allows simple and more efficient economic comparison of a greater number of alternative solutions. The limitation of the neural network NENECOS is the possibility of approximate estimation only for smaller rural settlements up to 500 population equivalents.

1. Introduction

Selection of the optimum wastewater collection and treatment system in rural areas is a complex and demanding process. This statement is the result of the fact that nowadays there is a large number of available technical solutions of wastewater collection and treatment applicable in small rural settlements. So far, practice has shown that in most cases it is possible to generate a large number of potential combinations of wastewater collection and treatment procedures, which makes the entire process of selection of the optimum solution more difficult (Hamilton, 2004; Pinkham, Magliaro, & Kinsley, 2004; Vouk, 2006; Vouk & Malus, 2007; Vouk, Malus, & Kesetovic, 2008).

Likewise, the practice has shown that in selection of the optimum solution the greatest importance is assigned to the economic criterion. Therefore, in discussing of a larger number of alternative solutions, determining of total costs of their construction, operation and maintenance is considered important. The conventional method of conducting of economic analyses is based on previous dimensioning of all considered wastewater collection and treatment technical solutions. Dimensioning of considered solutions represents the basis for working out of approximate cost estimates per individual items (construction of gravity sewers, construction of pressure sewers, number of pumping stations, operation costs, maintenance costs, etc.). Results of approximate cost estimates represent the basis for economic comparison of alternative solutions. Obviously, such procedure in most cases (larger number of alternative solutions) is very time-consuming, demanding larger efforts and a higher level of expertise.

The purpose of this paper is to offer the possibility of simple and quick economic analysis for different technical and technological solutions of wastewater collection and treatment. In this context, the authors consider the use of neural networks a useful and adequate solution.

Reviewing of recent worldwide experience and practice shows that in the few recent years the number of professional and scientific papers discussing the use of neural networks in the field of sanitary engineering has been constantly growing (Baruch, Georgieva, Barrera-Cortes, & de Azevedo, 2005; Bowers & Shedrow, 2000; Chen, Chang, & Shieh, 2003; Dandy, Loukas, & Davies, 1998; El-Din & Smith, 2002; Khalil, McKee, Kemblowski, & Asefa, 2006; Kunwar,

Abbreviations: NENECOS, neural network for approximate estimation of costs of wastewater systems; PE, population equivalents; CGS, conventional gravity sewerage; VS, vacuum sewerage; PS, pressurized sewerage; OST, onsite treatment; CTAS, conventional treatment with activated sludge process; CTSS, conventional treatment with simultaneous stabilization process; SBR, sequencing batch reactors; MBR, membrane technology; RBC, rotating biological contactors; TF, trickling filter; LN, lagoons; CWSF, constructed wetland with subsurface flow; OST-SF, onsite treatment with sand filters; OST-ATU, onsite treatment with aerobic treatment units; OST-SBR, onsite treatment with SBR technology; OST-MBR, onsite treatment with membrane technology; OST-TF, onsite treatment with trickling filter; OST-ST, onsite treatment with septic systems; GRNN, generalized regression neural network.

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Ankita, Amrita, & Gunja, 2009; Shukla, Kok, Prasher, Clark, & Lacroix, 1996; Sperac, 2004). However, the absence has been noticed of auxiliary tools that might be used for economic analyses of wastewater collection and treatment systems.

In the given framework of efforts, the neural network NENECOS (NEural Network for approximate Estimation of COsts of wastewater Systems) was created, which allows simple, fast and adequately accurate estimation of total or unit costs of construction, operation and maintenance of different wastewater collection and treatment systems, without the need for prior dimensioning and preparing of cost estimates. The procedure will enable the users to get, in a simple and quick manner, the insight into economic feasibility of individual solutions. This will enable the users to take an elimination step, i.e. to eliminate the solutions clearly deviating from the rest in the economic aspect.

The paper will describe the method of creating of the NENECOS neural network, with description of characteristic steps – preparing of the database, network training and testing. Also, the method of the network use, i.e. estimation of output parameters, will be shown.

2. Creating of neural network

2.1. General

In general, neural networks function on the principle of noticing and learning of certain relations between a larger number of different variables constituting the input database. Relations between input variables and values defined in the form of output result may be defined in the form of patterns or rules. On the basis of learned patterns (rules), neural networks offer the possibility of subsequent extrapolation of estimated output values for a new set of input data. In the process, the mentioned relations remain hidden within the structure of the neural network, which may be described as "black box model". However, along with presentation of the output result, the neural network offers the possibility of defining of the intensity of influence by input variables on the final result.

The aim of this paper is to develop integrated computer support in the form of neural network with unique and simply formulated user interface. As the database required for network training is created in MS Excel program package, the neural network should preferably be compatible with Excel interface. The program package selected was NeuralTools, version 1.0 Professional, of the American corporation Palisade.

NeuralTools contains the most recent algorithms of neural networks and allows good quality evaluations, regardless of whether the output variable (result) of classification or numeric nature. NeuralTools is created as the additional module of MS Excel program package. Direct integration of database is possible, previously prepared in MS Excel interface, which makes the use of NeuralTools simple and adjustable to various requirements of the final user.

In the use of the program package NeuralTools, the neural network NENECOS is defined with four basic steps, including evaluations related to output results:

- preparing of the database,
- network training,
- network testing,
- evaluation of output results.

All four characteristic steps are described in summarized form hereafter.

2.2. Preparing the database

A well prepared and comprehensive database, through which the neural network learns corresponding regularities (patterns or rules), aiming at maximum accuracy of evaluation of output results, is the basis of successful use of the network. Therefore, preparation of database is described in more detail compared to other elements.

A database was prepared by the authors, which contains a large number of settlements of up to 500 PE (population equivalent), analyzed according to all spatial characteristics. The database also contains a negligible number of settlements larger than 500 PE, which has been proved in practice as useful for better approximation of output values in the marginal zone. The total number of settlements contained in the database is about 600. Developing of the database is a part of analytic research, with the remark that the authors' own base of professional knowledge was used as well. For each settlement entered into the database, the procedure of previous dimensioning of all potential methods of wastewater collection and treatment was carried out, with preparing of corresponding approximate cost estimates. The database includes exclusively settlements in the territory of Croatia, covering however all typical geographic areas – continental, Mediterranean and mountain zones. This makes the available data applicable in the wider regional area, comprising the entire territory of Croatia.

In the absence of available basic data, in order to supplement the database, the authors also defined a certain number of hypothetic settlements. Defining of hypothetic settlements was considered necessary in order to define a better quality database which will ensure reaching of satisfactory results regarding approximate cost estimates. It should be noted that each of the hypothetic settlements simulates realistic conditions and describes actual situations.

The entire database is exceptionally extensive and contains the total of 64,490 scenarios. Each scenario represents a combination of solutions of wastewater collection and treatment for one or more interconnected settlements, i.e. for one system which may consist of one or several settlements. Likewise, for each scenario relevant local properties are defined, with approximate estimate of construction, operation and maintenance costs (Fig. 1). Local properties are selected in the way allowing inclusion of all relevant parameters in the process, in order to achieve as obvious differences between individual scenarios as possible, and higher level of accuracy of estimates of output values. The described database includes the following local properties (with description of the method of defining):

- size of the system (population equivalent – PE),
- climate characteristics (select one of three options – *Continental, Mountain, Mediterranean*),
- elongation factor (absolute number as ratio of length and width of the settlement encompassed by the system),
- dispersion factor (absolute number as ratio of number of households and length of sewerage network in the system),
- vertical disposition (choose one of three options – *flatland, hilly, mountainous*),
- uniformity of vertical disposition of terrain towards the plant (enter corresponding figure),
- vicinity of urban center (distance between settlement and nearest urban center),
- grouping of settlements (distance between neighboring settlements),
- soil permeability (choose one of three options – *low, moderate, high*)
- soil porosity (choose one of two options – *intergranular or fissure*),