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Using Evolutionary Algorithms in Layout Design of Sanitary Sewer Systems

LIN Shu [1], LIN Han [2], ZENG Fantang [1+] , FANG Huaiyang [1], HU Haofeng [1]

[1] South China Institute of Environmental Science, Ministry of Environmental Protection, Guangzhou, China
[2] School of Data and Computer Science, Sun Yat-sen University, Guangzhou, China

Abstract. The steps of using evolutionary algorithms in layout design of sanitary sewer systems are introduced. Two new techniques are developed. Randomly generating tree methods are used to generate initial layouts. “Or” operations are used in executing crossover operators. These two techniques are rarely used in this area. A real world example is used to illustrate the effectiveness of these steps. The results show that these steps can help to optimize the design of sanitary sewer systems.

Keywords: sanitary sewer system, evolutionary algorithm, initial layout.

1. Introduction

A sanitary sewer system is composed of sewers, pumping stations, manholes and other appurtenances. It costs much money for even a small city. Thus the design of this system has received much attention.

Until recently, most researches [1]-[9] are about detailed design of sewer system, i.e. the slope, the diameter and the invert elevation, with the layout having been determined. But few is done about the simultaneous optimization of the layout and the detailed design, except for the references [10]-[14]. And the methods are still not mature. Evolutionary algorithms are employed most often. In this paper, we will explore some innovation techniques of using evolutionary algorithms.

2. Model

2.1. Objective Function

The objective function is defined as the annual cost, which is comprised by the cost of the sewers, the pumping stations and the manholes. The cost of the pumping stations consists of the building cost and operation and maintenance cost. The annual cost can be expressed as the form

$$\min \mathrm{F} = \sum_{j=1}^{M}\{(\frac{1}{T}+e_s)C_s(D_j,H_j,LE_j)+\varphi_j[(\frac{1}{T}+e_{pu})C_{pu}(QP_j)+C_{puop}(QP_j,h_j)]+\sum_{k_j=1}^{L_j}(\frac{1}{T}+e_{man})C_{man}(D_j,hm_{k_j})\}$$

where

F annual cost of the whole wastewater system;

j, k_j index of sewers and manholes on sewer j;

e_s,e_{pu},e_{man} annual depreciation rate of sewers, pumping stations, and manholes;

M total number of the sewers;

T maturity, 20 years as default value;

D_j diameter of sewer j;

H_j average cover depth of sewer j;

+ Corresponding author. Tel.: + 862085558531; fax: +862085558531.
E-mail address:zengfantang@scies.org.

LE_j length of sewer j;

$C_s(D_j, H_j, LE_j)$ building cost of sewer j, which is the function of sewer diameter D_j, average cover depth H_j and sewer length LE_j;

φ_j a state variable, which denotes no pumping station at sewer j when it equals to 0, and denotes a pumping station at the upstream end of sewer j when it equals to l;

QP_j design flow rate of sewer j;

h_j lift height of pumping station j;

$C_{pu}(QP_j)$ building cost of pumping station at sewer j, which is the function of flow rate QP_j;

$C_{puop}(QP_j,h_j)$ operation and maintenance cost of pumping station at sewer j, which is the function of flow rate QP_j and lift height h_j;

L_j total number of the manholes on sewer j;

hm_{k_j} digging depth of manhole k_j;

$C_{man}\left(D_j, hm_{k_j}\right)$ building cost of manhole k_j, which is the function of pipe diameter D_j and digging depth hm_{k_j}.

2.2. Sewer Network Design Constraints

A good design of the sewer network can save a lot of money comparing to a bad design. For a certain sewer, when design flow rate is determined, several pairs of sewer diameter and its corresponding cover depth can be chosen. One pair of diameter and cover depth is chosen for upstream sewer can affect its immediately downstream sewer and all other mediately downstream sewers. So the sewer network design constraints are the important factor for this model. Referring to reference [9], those constraints are:

(1) Maintaining the proportional water depth under the specified maximum value. This constraint may be formulated as:

$$\left({hp_j}/{D_j} \right) \le \beta_{\max} \tag{2}$$

where hp_j = the water depth in sewer j; β_{max}= maximum proportional water depth for a certain sewer diameter.

(2) Keeping flow velocity between minimum and maximum bounds respectively for self-cleaning capability and preventing from scouring. These constraints may be formulated as:

$$V_{min} \le V_j \le V_{max} \tag{3}$$

where V_{min}= minimum flow velocity; V= flow velocity in sewer j; V_{max}= maximum flow velocity.

(3) Choosing sewer diameter from the commercial list defined as:

$$D_j \in D_s \tag{4}$$

where D_s=discrete set of commercially available sewer diameter.

(4) For each manhole, assigning the downstream sewer diameter not smaller than any upstream sewer diameter defined as:

$$D_{down} \ge D_{up} \tag{5}$$

where D_{down}= leaving sewer diameter; D_{up}= upstream sewer diameter.

(5) Maintaining the minimum sewer slope to avoid blockage and adverse slope caused by inaccurate construction. This constraint may be formulated as:

$$I_j \ge I_{min} \tag{6}$$

where I_j= the slope of sewer j; I_{min}= minimum sewer slope.

(6) Maintaining the cover depth between the minimum and maximum cover depth respectively for preventing damage from the traffic loads and local geological problems. This constraint may be formulated as:

$$DC_{min} \le DC_j \le D_{max} \tag{7}$$

where DC_{min}= minimum and maximum cover depth; D_j= cover depth of sewer j; D_{max}= maximum cover depth.

Equation (1) and constraints (2)-(7) constitute the optimization problem for sanitary sewer systems.

3. Optimization Algorithm

3.1. General Solution Procedure

The model described above can be solved by using the following procedure.

(1) Build a schematic graph for the sanitary sewer system.

(2) Generate several initial layouts of the sewer network. Every layout is denoted by a matrix, with a “1” in row m_i and column n_j meaning that vertex m_i and n_j are connected with a sewer.

(3) For each layout, call the genetic algorithm subroutine to decide the optimal size and slope of all the sewers.

(4) Evaluate all the layout generated and optimized above and choose the best one to store.

(5) Use evolutionary operators to generate next generation of the layouts. Then go back to step (3) until some termination criterion is reached.

For detail about step (1), (3) and (4), please refer to reference [9]. Step (2) and step (5), which two differ from other references, are described below.

3.2. Generate Initial Layouts of the Sewer Network

According to graph theory, a sewer network layout connected N_0 vertices with n final outlets have N_0-n edges. A layout with one final outlet is like a tree with the outlet like the root of the tree. A layout with n final outlets is like a forest comprised by n trees.

A structure array is used to store the two vertices of every edge. At the beginning, all the N_0 vertices are divided into N_0 groups. Randomly choose an edge, if the both vertices of the edge are in the same group or belong to two different trees, omit this edge. Otherwise, connect these two vertices and put them into the same group. Repeat this procedure until the termination criterion is reached. An example is shown in Fig. 1.

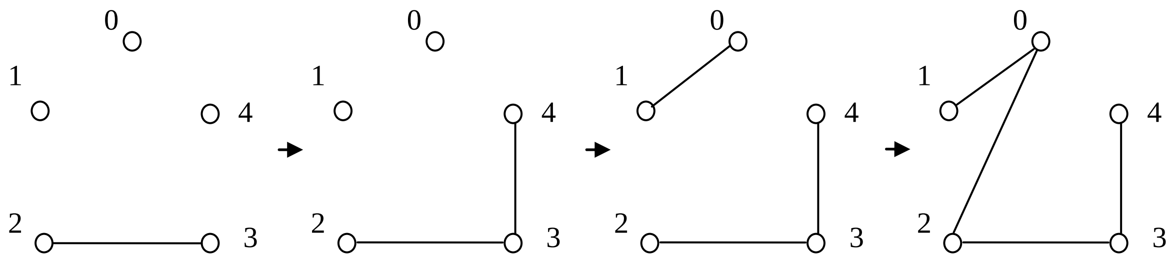

Fig. 1: An example of the implement of the randomly generating tree method（vertex 0 is assumed as the outlet）.

3.3. Crossover Operator

Selection operator, crossover operator and mutation operator are the three operators used in the research. A simple tournament selection is used.

For crossover operator, an “or” operator is executed for every two elements at the same position of the two matrices. The resulting matrix is still not a layout because there may be circles. So the method of generating initial layouts is used again to generate the two offspring layouts. Fig.2 is an example.

For mutation operator, when the randomly generated value is less than the mutation rate, an “or” operator is executed for the present element of the offspring matrix and the original matrix. Then, the method of generating initial layout need be used too.

3.4. Case Study

The example is based on a water pollution control system planning on Shiqiao River basin in Panyu district of Guangzhou, China. The schematic graph is represented in Fig.3 with 302 vertices. There are 3 available plots for the possible location of WWTPs. Outlet 1 has been chosen. Now a decision needs to be made about whether to choose outlet 2 or outlet 3 or both of them or none of them.

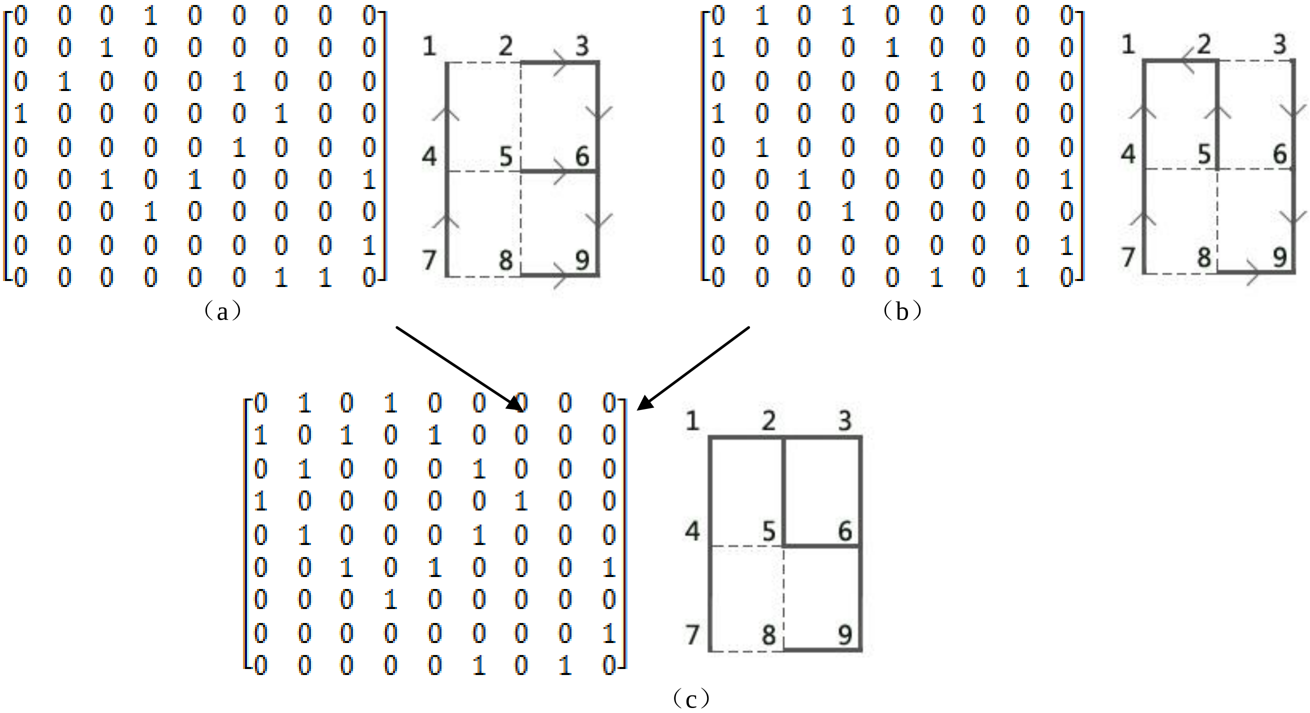

Fig. 2: The working of the crossover operator

Using the method described above, the costs corresponding to four scenarios are presented in Tab.1.

Table 1 Comparison of four scenarios（unit: 10^4 ￥）

No.	scenario	sewers	pumping stations		manholes	annual cost
			building	operation		
(1)	all three outlets	20703	4631	616	1751	3324
(2)	outlet 1+outlet 2	23174	4706	460	3203	3568
(3)	outlet 1+outlet 3	24081	4101	755	2285	3802
(4)	outlet 1	24292	5342	1021	3265	4311

In Table 1, the lowest annual cost occurs when all three outlets are chosen. The largest cost occurs when only one outlet is chosen. For 2 outlet scenarios, the annual cost for choosing outlet 1 and outlet 2 is lower than that for choosing outlet 1 and outlet 3. However, the cost of building pumping station for scenario (3) is the lowest, with that of pumping station operation and maintenance for scenario (2) the lowest. It means that scenario (2) tends to build more pumping station with little lift height, but scenario (3) tends to build less pumping station with large lift height. All these results show that the evolutionary algorithm we used can get to a satisfactory solution.

4. Conclusion

In this paper, several new techniques of evolutionary algorithms for sanitary sewer system design are developed. Randomly generating tree method can help to generate the initial layout for the sanitary sewer system. And the specified methods in executing evolutionary operators can help to generate the offspring layouts. A real world example is used to illustrate the effectiveness of these techniques. The results show that evolutionary algorithm can be used to optimize the sanitary sewer system design.

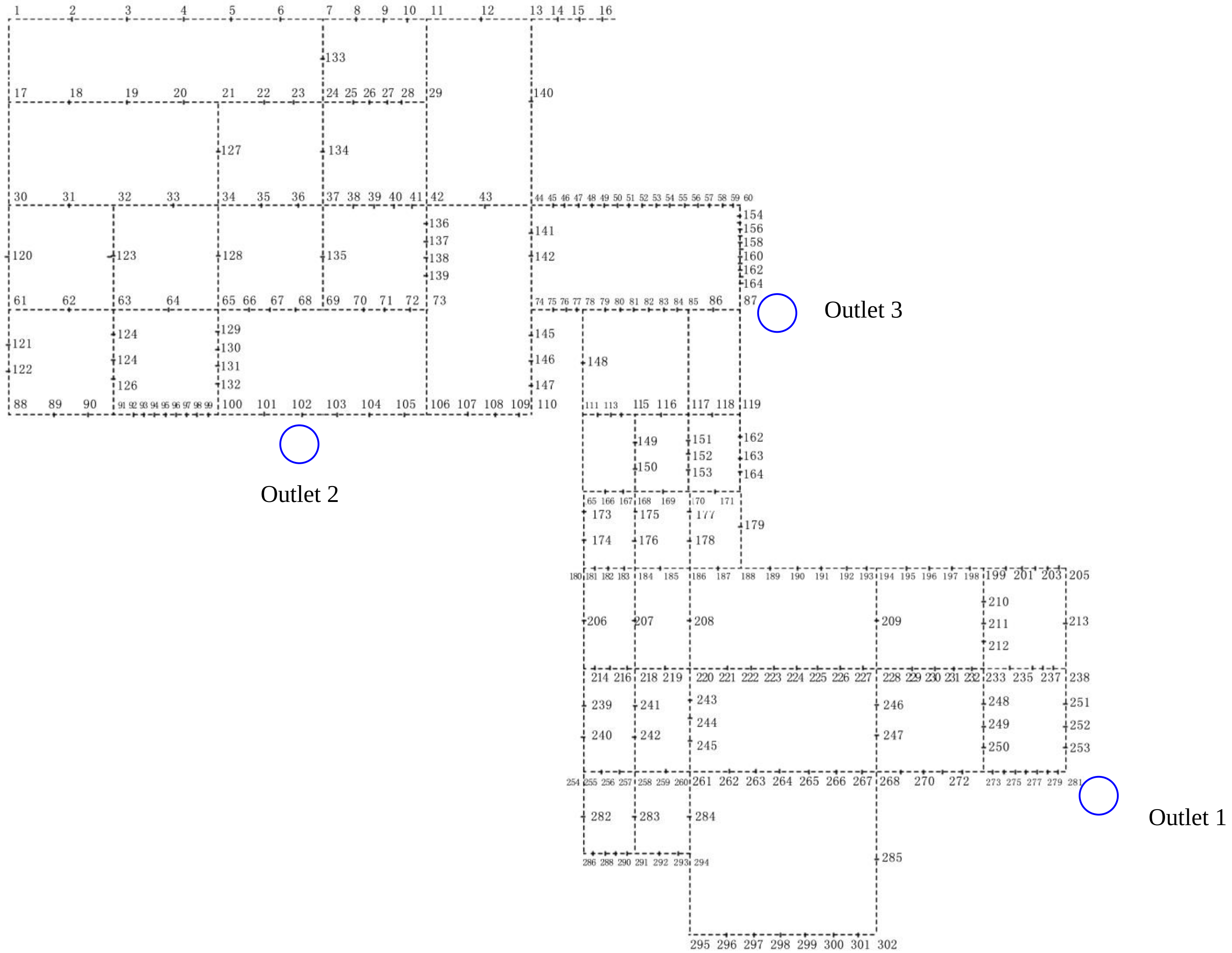

Fig. 3: Schematic graph of the case [15]

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