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Research on the Leakage Problems of a Campus Water Supply System

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ABSTRACT
In this study, it is researched four problems in relation to the leakage of water pipe network within a campus water supply system and established mathematical models. Firstly, superior water meters without corresponding subordinate water meters were removed at first, and then the tiered relationship model of campus water meters is established. Secondly, the total flow of water meters at night between 2:00 to 5:00 in the morning is regarded as the amount of leakage water of the water pipe network, with the relationship model of monthly water leakage change and monthly leakage rate provided. Third, by using the conclusion of Question II, screening is carried out in other months except March and May, and the serial numbers of principal leakage water meters is given for each month. Fourth, by using the conclusion of Question III, combined with the usage of work force and the caliber size of the water pipes under maintenance, the corresponding labor cost and material cost are given, so that water meters at the main leakage locations were repaired, thereby determined the model of minimum maintenance cost within the school annual expenditure. Lastly, suggestions are proposed to improve the leakage issue of the water pipe network of the school.
Keywords: *campus water supply system, tiers of water meters, leakage rate, water pipe network maintenance.*

1. INTRODUCTION

As the material basis for the existence of organisms on Earth, water resources are the primary condition for the sustainable development of the Earth’s ecological environment; therefore, protection of water resources is the greatest and most sacred vocation of mankind. China is a country with limited water resources, and has a large population, that the per capita fresh water resources only account for a quarter of the world’s per capita fresh water resources[1]. With the growth of population and the rapid development of economy and society, the contradiction between water shortage and economic & social development has become prominent. Therefore, people must establish a sense of water crisis and regard water conservation as our conscious code of conduct from individual level. From the point of view of a campus water supply system, it is researched in this study the leakage issues of its water pipe network, which would be of great significance to the improvement of campus service and management and the enhancement of water-saving consciousness of the students.

2. INTRODUCING OF THE QUESTIONS

Campus water supply system is an indispensable part of campus public facilities. owing to the improvement of science and technology, although intelligent water meters have been widely used in the campus to obtain a great number of real-time operation data from the water supply system, the leakage of water pipe network, especially the hidden leakage of underground water pipes is still not easy to be found. Data show that in a well-maintained public water supply network, the average water loss is around 5 %; while in more outmoded pipeline networks, there will be more water loss. Therefore, in order to ensure the normal operation of the campus water supply system, it is still necessary for the school to make substantial investment of manpower, material and financial resources to detect, locate, and repair the leakage of the water supply pipelines, so as to reduce the degree of leakage of the pipeline network to control the waste of water resources. In this study, the following problems will be addressed through mathematical modeling and data mining by using the data of Test E of the 2020 Contemporary Undergraduate Mathematical Contest in Modeling (CUMCM)[2].

Question I: Based on the tiered relationship of water meters in the campus, to establish the relationship model between the water meter data, and to analyze the error of the model by using the existing data.

Question II: Please analyze the status of leakage of the campus water supply network.

Question III: Please find and determine the locations of leakage in time from the real-time data of the water meters.

Question IV: Please determine the best repair decision plan for pipeline network leakage based on the above results and current water price and maintenance cost.

3. MODEL ESTABLISHING AND SOLVE THE QUESTIONS

Indications are given as the following: x_i : total amount of water used by the tiered water meters, $i = 1,2,3,4$; s_i : monthly water leakage at 2:00 A. M. - 5:00 A. M. , $i = 1,2,...,12$; a_i : the total monthly water supply, $i = 1,2,...,12$; H_i : monthly leakage rate, $i = 1,2,...,12$; b : unit price of water supply; Q: maintenance costs; g : the total number of maintenance workers; t : the number of days required to repair a leak point; l: number of leaky water meters to be repaired; d : maintenance workers' daily wages; c_i : the unit price per meter of the required maintenance material, $i = 1,2,...$; e : the length of the required maintenance material; m: months.

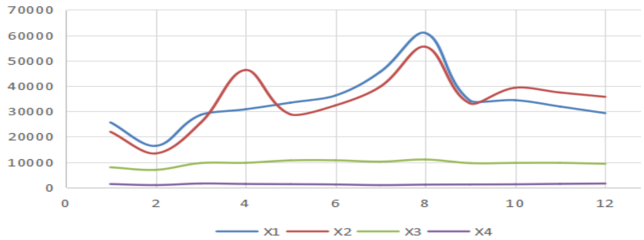
3.1 Problem I

3.1.1 Based on the data, the monthly total water consumption table and total water consumption graph of each tier are given respectively.

Table 1. STotal water consumption per month of the first, second, third, and fourth-tiers

m	X1	X2	X3	X4
JAN	25615. 95	21907. 48	7916. 63	1317. 32
FEB	16368. 18	13385. 09	6915. 71	906. 22
MAR	28565. 3	25446. 63	9586. 87	1515. 8
APR	30806. 31	46304. 33	9696. 44	1343. 38
MAY	33416. 96	28815. 37	10636. 75	1262. 8
JUN	36219. 34	32327. 45	10678. 77	1155. 94
JUL	45593. 78	39736. 87	10141. 61	884. 87
AUG	60923. 47	55486. 61	10980. 2	1086. 64
SEP	34189. 97	33119. 07	9578. 37	1159. 37
OCT	34400. 51	39303. 79	9654. 23	1214. 18
NOV	31895. 35	37429. 11	9677. 42	1381. 68
DEC	29295. 85	35738. 63	9301. 88	1520. 15

Fig. 1. Graph of total monthly water consumption in the first, second, third and fourth-tiers



The relationship model between the first-tier water meters and second-tier water meters, third-tier water meters, and fourth-tier water meters is fitted by Figure 1 by using the SPSS19 software (1):

$$x_1 = -1.5920 \times 10^3 + 0.5085\, x_2 + 4.0658\, x_3 - 16.8290\, x_4 \quad (1)$$

The analysis results suggest that $R^2 = 0.8468$, the significance test of the regression equation F = 14. 7427, that the fitting degree of the model is desirable. Among them, the second-tier water meters have a significant influence on the first-tier water meters [3]; The error ratio range is (-0.2585, 0.2362).

3.1.2 Only the first level water meters with second-tier water meters are retained, the other first-tier water meters without second-tier water meters are eliminated; and the relationship model between the first-tier water meters and the second-tier water meters is fitted out by using the Excel software (2):

$$x_1 = -10^{-6} x_2^{\,2} - 0.641 x_2 + 7391.9 \quad (2)$$

The analysis results suggest that $R^2 = 0.7292$, that the fitting degree of the model is desirable. The error ratio range is (- 0.3527, 0.1202).

3.1.3 Only the second-tier water meters with third-tier water meters are retained, while the other second-tier water meters without third-tier water meters are eliminated; and the relationship model between the second-tier water meters and the third-tier water meters is obtained by Excel fitting (3).

$$x_2 = -3 \times 10^{-5} x_3^{\,2} - 4.0042\, x_3 + 17428 \quad (3)$$

The results of the analysis suggest that $R^2 = 0.2953$, that the fitting degree of the model is ordinary. The error ratio range is (-0.4034, 0.4607).

3.1.4 Only the third-tier water meters with fourth-tier water meters are retained, and the other third-tier water meters without fourth-tier water meters are eliminated. The relationship model between third-tier water meters and fourth-tier water meters is obtained by Excel fitting (4)

$$x_3 = -0.0068\,x_4^{\ 2} + 17.981 x_4 + 7575.7 \qquad (4)$$

The results of the analysis suggest that R^2 = 0. 6386, that the fitting degree of the model is desirable. The error ratio range is (- 0.3338, 0.1666).

Lastly, through the relationship model of water meters at all tiers, it is found that the total amount of water used in water meters of the subordinate tiers is higher than that in a superior tier, although the difference is not significant, which is consistent with the fact that when there are less water flow, a meter at the subordinate tier may not able to drive the meter at the superior tier.

3. 2 Question II

Next, the total flow of water meters at night from 2: 00 am to 5: 00 am is taken as the amount of leakage of the water pipe network, and it is defined that : Monthly leakage rate = The total amount of monthly leakage / the total amount of monthly water consumption , that is:

$\mathrm{Trace}_M^{\sigma}$, and the probability space can know the probability of the adversary σ.

$$H_i = \frac{s_i}{a_i} \qquad (5)$$

Meanwhile, the monthly leakage rate is regarded as the monthly water loss rate of the school water pipe network. The results are as follows in Table 2:

Table 2. Annual leakage status of the school

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
s	3758. 5	2702. 08	4050. 99	5513. 28	3409. 99	3749. 75	5710. 33	6554. 43	4665. 24	4840. 43	5320. 43	4657
a	52041. 79	34818. 9	60072. 63	83034. 46	68982. 23	73312. 3	85624. 43	110410. 28	72722. 89	79667. 98	75674. 39	71334. 45
H	0. 07222	0. 0776	0. 000674	0. 066397	0. 04943	0. 05114	0. 06669	0. 05936	0. 06415	0. 060757	0. 0703	0. 06528

The monthly leakage rates that exceeds 7 % include January, February and November; The monthly leakage rates that range from 5 % to 7 % include April, May, June, July, August, September, October and December; The monthly leakage rates that are less than 5 % only include March and May.

Then, MATLAB software is used for gathering data statistics, and it is obtained the relationship model of water leakage from 2: 00 to 5: 00 in the morning of each month is as follows:

$$m = 0.0638s^9 - 3.7541s^8 + 93.8016s^7 - 1.2957\times10^3 s^6 + 1.0808\times10^4 s^5 - 5.5848\times10^4 s^4$$
$$+1.7648\times10^5 s^3 - 3.2399\times10^5 s^2 + 3.0888\times10^5 s - 1.1136\times10^5$$

(6)

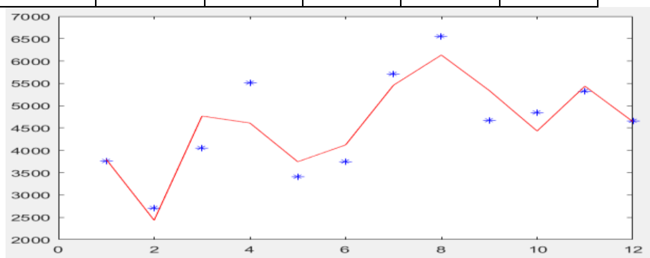


Fig. 2 Annual leakage water amount

The analysis results suggest that R^2 = 0. 9905, indicating that the fitting rate of the model is desirable and it could be used to predict the amount of water leakage in this period of time in the following year.

3. 3 Question III

Hidden leakage of underground water pipe is not easy to be found. Next, the total water meter flow at 2: 00 to 5: 00 in the morning with small flow of water will be taken as the hidden leakage amount of water pipe network. Therefore, the water meters with relatively obvious leakage amount (more than 100 cubic meters) in one month are defined as the major leakage positions; the water meters with total monthly leakage amount (more than 20 cubic meters and less than 100 cubic meters) are defined as the ordinary leakage positions; while the water meters with minor total m onthly leakage amount (less than 20 cubic meters) are defined as the leakage positions not to be addressed. By using the results of question 2, screening is conducted within months excluding March and May, and to list the serial numbers of major leakage meters in each month.

Table 3. Serial numbers of water meters with a monthly leakage amount of more than 100 cubic meters

Table 3 Sensor network experimental results

JAN	3620300300	3620301400	3620300400	3320100500	1836718629	3620300500	3320100400	3620300200						
FEB	3620300300	3620300400	3620301400	3620301700	3320100500	1836718629								
MAR	3620300400	3620301500	3620300500	3320100700	1836718629	3620300300	3320100600	3320100900	3363000100	3313800500				
APR	3620301400	3620300300	1836718629	3320100500	3620300400	3620300200	3320100700	3312800100	3320100100					
MAY	3620300300	3620301400	3620300400	3320100500	1836718629	3620300200	3320100700	3620300500	3620300100	3320100100	3320100900			
JUN	3620300300	3620301400	3620300400	3363000100	3620300200	3450200100	3320100500	3620300500	1836718629	3320100700	3320100100			
JUL	3620300300	3620301400	3450200100	3620300400	3320100500	3620300500	1836718629	3620300200	3312800100	3320100700	3320100100	3320100900		
AUG	3450200100	3620301400	1836718629	3320100500	3620300400	3620300200	3312800100	3620300500	3320100900					
SEP	3620300300	3620301400	3313200200	3320100500	1836718629	3620300400	3620300200	3370200100	3320100900					
OCT	3313200200	3620300300	3620301400	3620300200	3620300400	3000000000	3320100500	3320100100	3312800100	1836718629	3320100600	3000000001		
NOV	3313200200	3620300300	3620301400	3620300400	3620300200	3320100500	3320100100	1836718629	3000000000	3390100500	3370200100	3312800100	3000000001	3320100400
DEC	3313200200	3620300300	3620300400	1836718629	3320100500	3620301400	3620300200	3320100100	3370200100					

Among them, serial numbers of water meter with water leakage amount of more than 100 cubic meters for more than 10 months include: 3620300200, 3620300300, 3320100500, 3620301400, 1836718629, 3620300400, for which more attention should be paid, with equipment to detect and verify, and conduct repair, so as to reduce economic losses from waste of water supply.

Table 4. Serial numbers of water meters with water leakage amount of more than 20 cubic meters and less than 100 cubic meters in each month

JAN	3320100900	3320100300	3390100500	1836718633	3320100200	3320100100	3520300100	3320100600	3421900100	3320100700	3000000000	3480200100	3312800100	3620300100	3320100800	3180700100	3370200100	183671860	3390100300			
FEB	3390100500	3620300200	3320100200	3320100900	3320100400	3320100100	3620300500	3312800100	3320100300	1836718633	3370200100	3320100700	3320100800	1836718625								
MAR	3000000000	3620300600	3320100400	3320100500	3320100300	3421200300	3030100100	3422200100	3620300200	3390100500	3180700100	3360300100	1836718625	1836718633	3390100200	3000000001	3480400100	3280100100				
APR	3320100900	3320100200	3320100300	3421900100	3000000000	3620300500	3390100500	3320100400	3370200100	3320100800	3620300100	3620302800	3480200100	3000000001	3210100100							
MAY	3320100200	3030100100	3421900100	3000000000	3370200100	3390100500	3312800100	3000000001	3320100800	3210100100	3620302800	3280100100	3320100300	1836718625	3480200100							
JUN	3320100900	3320100200	3312800100	3421900100	3320100600	3000000000	3390100500	3620300100	3000000001	3370200100	3320100800	3370100100	3210100100	3620302800								
JUL	3320100200	3320100600	3000000001	3030100100	3000000000	3421900100	3390100500	3620300100	3370200100	3620302800	3320100800	3520300100	3620301300	3210100100	3290100300	3210100200						
AUG	3320100200	3320100700	3320100100	3000000000	3390100500	3620301300	3421900100	3370200100	3520300100	3210100100	3320100800	3620300300	3290100300	3000000001	3620300100	3620302800	3161100100					
SEP	3000000000	3320100100	3390100500	3312800100	3620300500	3620301300	3320100200	3320100700	3421900100	3000000001	3320100800	3450200100	3210100100	3620300100	3320100300	3320100400	3520300100					
OCT	3320100900	3390100500	3370200100	3620301300	3400500100	3421900100	3620300500	3320100800	3320100400	3620300100	3210100100	3320100300	3520300100	3290100300	3320100700	3421400100						
NOV	3210100100	3320100600	3320100900	3320100300	3520300100	3320100200	3421900100	3421300300	3620300500	3320100800	3170100600	3320100700	3620300100	3160200300	3400500100	3480200100	3390100300	3620301300	3290100300	1836718625	1836718633	3421400100
DEC	3320100900	3620300500	3421900100	3320100600	3390100500	3312800100	3620300100	3000000000	3520300100	3400500100	3320100200	3280100100	3210100100	3320100800	3000000001	3320100300						

Through statistical findings, serial numbers of water meters with more water leakage amount of than 20 cubic meters and less than 100 cubic meters for more than 8 months include: 30000000001, 3370200100, 3000000000, 3210100100, 3320100300, 3620300100, 3320100200, 3421900100, 3320100800, 3390100500. The school should regularly inspect the pipes of these water meters, so as to found in time the intensified leakages to avoid more losses.

3. 4 Question IV

In order to guarantee the normal operation of the water supply network, it is necessary to carry out certain maintenance and management operations. To this end, by using the conclusion of Question III, 6 major leakage positions is needed to carry out maintenance and replace the corresponding water pipes. Through investigation, it is found that the diameter of each section is determined by both the flow rate and the flow velocity. When the flow rate is constant, if the applied flow rate is larger, then the pipe diameter is smaller and the pipeline cost is lower. However, a larger flow rate will lead to an increased loss of the falling head, which will also increase the height of the water tower and the frequent cost of pump operation. On the contrary, if the applied flow rate is small, then the pipe diameter will be larger. Although it can reduce the loss of the falling head and frequent operating expenses, the costs for pipelines would be increased [4]. Therefore, when determining the diameter of water pipes to be replaced, the diameter of the water pipes used in the accessory water meters should be taken into account to obtain the corresponding material cost. On the other hand, labor cost can be determined according to the general number of people, duration and single day labor cost of the work force in use, thereby determined the minimum maintenance cost model (7) of the school's annual expenditure: minimum maintenance cost = labor cost + material cost, that is:

$$Q = g \cdot t \cdot l \cdot d + \sum_{i=1}^{\infty} c_i \cdot e \qquad (7)$$

Then it is assumed that each meter maintenance point requires 5 people, with the maintenance cycle set to 7 days and 150 yuan as the daily labor costs; as for water pipes used at the 6 maintenance points, if the caliber value is 50 or less, PPR pipes will be used; if the caliber value is 50 or more, steel pipes will be used, with 5 meters of each type of pipe to be used, and obtained that the minimum maintenance costs of the school is about: 33, 593. 75 yuan. If the water price of this school is calculated at 4. 3 yuan/cubic meter as the third-grade price of residential water, the total flow of water meters at night from 2: 00 am to 5: 00 am in the whole year is 54, 932. 45 cubic meters, and the water cost of leakage in the whole year is calculated to be about 236, 209. 535 yuan.

Through the above calculation and analysis, it can be found that for the Q value, it has been only taken into account the maintenance of the hidden leak points; if there are water pipes on the ground that need to be repaired, then the relevant maintenance labor costs and material costs should also be added, meanwhile, it is also necessary to take account of the specific situation of the leakage water meter points to arrange the number of work force and unit price and length of the materials used for the replacement of the water pipes. For the above reason, the currently listed maintenance costs for water pipe network of this year only serve as a reference for the following year's budget; if due consideration is given to the labor inspection costs, and the purchase of related inspection equipment [5], then the school's leakage issues will be more effectively improved. On the other hand, the school should further increase its publicity efforts to conserve water resources and reduce water waste, so as to continuously enhance students' awareness of conserving and saving water resources.

each client can send requests for reservations to use a common resource, the server can grant or deny a client's request, and the model must satisfy the mutual exclusion property (i.e., conflict in using resources between clients) with certain minimum probability. Through the SYM rule, we make the server as a component M1 and the composition of N clients as the other component M2. The verified property is ⟨P⟩≥0.9.We use the method of Feng et al. [23] to inject (nonprobabilistic and probabilistic) failures into the server respectively. Table 2 shows experimental results for the client–server.We first present a sound SYM for compositional stochastic model checking. Then, we propose a learning framework for compositional stochastic model checking PAs with rule SYM, based on the optimization of LAGR techniques. Our optimization can terminate the learning process in advance, if a counterexample appears in any membership and equivalence query. We also extend the framework to support the assume-guarantee rule SYM-N which can be used for reasoning about a stochastic system composed of $n \geq 2$ components: $M1 \| M2 \| \cdots \| Mn$. Experimental results show that our method can improve the efficiency of the original learning framework [23]. Similar to Feng et al. [22] and Kwiatkowska et al. [33], it can return the tightest bounds for the safety property as a reference as well.

In the future, we intend to develop our learning framework to produce richer classes of probabilistic assumption (for example weighted automata as assumptions [39]) and extend it to deal with more expressive types of probabilistic models.

4. CONCLUSION

In this study, the model obtained in the research of the campus water leakage issue are simple and easy to understand, and are convenient for practical tasting and application. When considering the relationship between superior and subordinate tiers of water meters, the superior water meters without corresponding subordinate water meters are eliminated at first, then the tiered relationship model is established, so that the model error would be relatively smaller. Meanwhile, the total night flow of water meters at 2: 00 to 5: 00 is regarded as the leakage amount of the water pipe network, and the obtained leakage result is basically in line with the actual situation, and would have reference significance for similar issues.

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