

DEVELOPING A WATER PIPE MANAGEMENT SYSTEM IN SEOUL USING THE GIS

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ABSTRACT:

The water mains burst in Seoul, Korea is one of the most frequently raised water management problems and the major reason can be found in the inefficiency in design and management of the network. The study developed a prototype system that allows the user to evaluate the level of deterioration and to design alternative water mains for simulation. The study suggests an evaluation scheme that models mains failure based on different variables such as pipe age, diameter, ground elevation, and pipe materials. Also, the user can interact with the system to create virtual pipelines that link the user-provided origin and destination points considering the efficiency in regional supply, distance, road network and construction cost. A shortest path algorithm called Dijkstra's algorithm was used for the pipeline simulation. The data was constructed using the GIS based on the residential blocks which are defined by supply region, water demand and street network. The system was applied to a test region in Seoul, Korea.

1. INTRODUCTION

Compared to the level of water supply as high as 99.9%, the rate of running water of Seoul does not reach that of most developed countries. Major reason is found in the bursts in water mains from water reservoirs to distributing reservoirs and in feed pipes to households. The problems lie in inefficiency in design and maintenance of the network. The only fundamental measure is to replace old pipes, which leads to the failure of water supply for a long period. In order to minimize the effects of water cut-off or to maintain stable supply, alternative mains are necessary.

According to the master plan of Seoul in 2000, most efficient network unit for management of water leaking is viewed to be based on the distribution blocks centred on the distributing reservoirs. The study suggests a framework to develop a GIS-based management system to monitor superannuated pipes and design alternative network. The analysis of old pipes was done based on the distribution block units. A shortest path algorithm called Dijkstra's algorithm was used for the pipeline simulation. The data was constructed using the GIS based on the residential blocks which are defined by supply region, water demand and street network. The system was applied to a test region in Seoul, Korea.

2. PIPE BURSTS MONITORING SYSTEM

The block system originally means the block-based management system designed to maintain the distributing pipes in Shizuku City after the earthquake in 1964. Although it was primarily devised for construction of water network which is resistant to disasters, the block-based system had dispersed in Japan as the system was proven to be efficient in water management in general. Seoul City employed the Shinzuku's

block system and divided the whole city into 39 reservoir-based blocks and again into 1st, 2nd and 3rd blocks summed to 2,037 small blocks. Organizing the block system made it easy not only to maintain the distribution but to control the water supply based on the blocks' demands. Again, based on the water use in each parcel, smallest blocks were created where the total water use becomes 1000~2000 tons per a day.

2.1 Block design

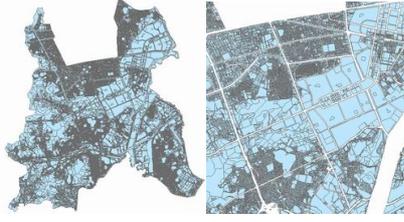
In creating the distribution blocks, the study used a different scheme from the one suggested in Seoul's master plan (Office of Waterworks of Seoul City 2000). After deciding the study area to Guro and Yangchun Wards, the study used the street network which is created hierarchically based on the road levels such as small roads(level 1), main roads(level 2), inter-districts(level 3) and highways(level 4). Level 2 road networks was first used in creating major blocks and then level 1 was used in dividing the major blocks into mid-sized blocks. The reason for using road networks to create blocks was to use existing digital GIS maps and to automate the process by using them. The processes are described in Figure 1.

2.2 Calculating superannuation of the block

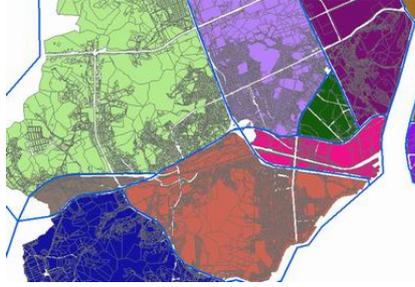
Although there are many different models around used for estimating pipe superannuation, the study simplified the modelling processes by using some representative values since the study was focused on a framework for developing a system rather than suggesting detailed models. The data used are the year of pipe installation, material, length, diameter, the elevation of distribution reservoir and the average elevation of the block. The superannuation of a pipe is calculated as the equation (1).

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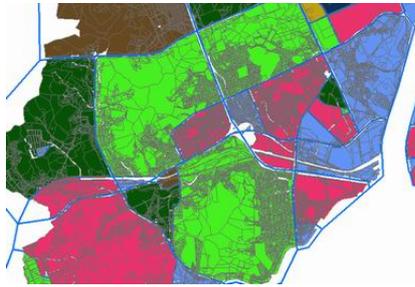
(a) Removing roads from the parcel map



(b) Creating large-size distribution blocks



(c) Creating mid-size distribution blocks



(d) Completing distribution blocks based on water consumptions

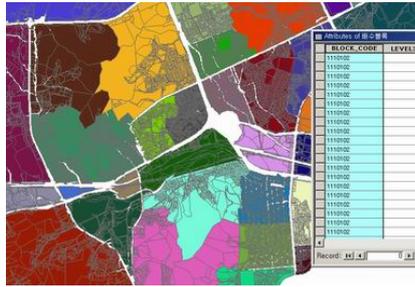


Figure 1. The processes for designing distribution blocks

$$S_i = \frac{YP - YI_i}{D_i} \quad (1)$$

where S_i : superannuation of pipe i
 YP : present year
 YI_i : the year installed of pipe i
 D_i : the durability of pipe i

If we take into account the length portion of the pipe compared to the aggregate length in a block and the weight value, the equation (1) can be rewritten as equation (2).

$$S_i = \frac{YP - YI_i}{D_i} \times \frac{L_i}{TL} \times P_i \quad (2)$$

where L_i = the length of pipe
 TL = the aggregate length of all pipes in a block
 P_i = the weight value assigned to pipe i

Table 1 shows the duration of pipe materials and table 2 shows the weight values assigned from 1 to 5 based on diameters of pipes.

Table 1. Duration of materials of pipes

Code No	Material	Duration(years)
001	Cast iron	30
003	Zinc	10
004	Softened vinyl	15
005	Polyethylene	15
006	Stainless	30
007	Copper	25
010	Plastered cast iron	20
019	Fabric-covered steel	40
028	Fabric-lined polyethylene	30
040	Impact-resisting	30
999	Others	

Table 2. Weight values according to the diameters of pipes

Diameter(millimetres)	Weight value
< 30	1
30-100	2
100-200	3
200-300	4
> 300	5

The study used equation 4 in calculating pipe ages when the water pressure between a distribution reservoir and a block is taken into account.

$$ER - EB - MHL \quad (3)$$

where ER : Elevation of the reservoir
 EB : Average elevation of the block
 MHL : Mean head loss

Here, the head loss is calculated using Darcy-Weisbach's equation as follows.

$$H_l = \lambda \times \frac{l}{D} \times \frac{v^2}{2g} \quad (4)$$

where H_l : the head loss
 λ : the coefficient of friction
 l : the length of the pipe
 D : the diameter of the pipe
 v : the velocity of current
 g : acceleration of gravity

3. OPTIMAL PATH BETWEEN RESERVOIRS

Optimal path problem is the problem of finding the minimum-cost path from a node to the other in a network. This study finds an optimal path between two points or distribution reservoirs using Dijkstra's algorithm and calculates the construction cost based on the found optimal route.

3.1 Applying Dijkstra's algorithm

Dijkstra's algorithm is one of the popular shortest path algorithms that explore minimum-cost path in a network. It has been frequently applied in transportation field that searches a shortest path from the origin to the destination. In Dijkstra's algorithm, the process starts from an origin and gradually explores the neighbour of nodes to determine the minimum-cost path until it reaches the destination. The process finds the shortest paths from a given source to all nodes in a network; therefore this problem is sometimes called the single source shortest problem (Morris 1998, Skiena 1998). Dijkstra's algorithm is introduced in numerous books about computer algorithms, so it is not described here further.

The study finds optimal paths using two types of cost; first the length of links as traditional Dijkstra's algorithm would use and second, the aggregate distance between a link and all small blocks included in a large-sized reservoir block. To use the second method, each segment of the street is first assigned the aggregate length from the all small blocks in a reservoir block to the link segment. Then, the same Dijkstra's algorithm is applied, this time, using the aggregate block length as the cost, resulting in a path of optimal distance to the small blocks. It turns out that the second method prevents a path from being located inclined to one side in a reservoir block.

3.2 Calculating the construction cost

Along with the process for generating the optimal paths, the study also calculated the construction cost along the path using the equations in Table 3. (Ha 2000)

Table 3. Cost of buried unit pipe

Diameter (mm)	Cost of buried unit pipe (Won/m)	R ²	MAE (%)
Φ75 – 350	$e = 19904 + 19.659 \times d^{1.40}$	0.9995	0.9
> Φ400	$e = 41685 + 1.3302 \times d^{1.80}$	0.9973	0.3

4. SYSTEM DEVELOPMENT

Two management systems — the pipe monitoring system and the optimal path system — were integrated in a user interface. The study used Visual Basic and ESRI's MapObject component to develop the interface. Along with such basic functions as zooming and panning, the system included two major modules, each with many sub functions. Figure 2 shows an example of pipe superannuation management. One of the key aspects of this module is the block designing function. Instead of using the traditional blocks which have been used so far, the system allows the user to create different blocks based on the current street network and water consumption of each parcel. This way, the system made it possible to design blocks dynamically according to varying attributes such as continuously changing street network or water use. Figure 3 illustrates a process for creating an optimal path between two user-provided points. When entering the points, the user is guided by the system that shows location of distribution reservoirs.

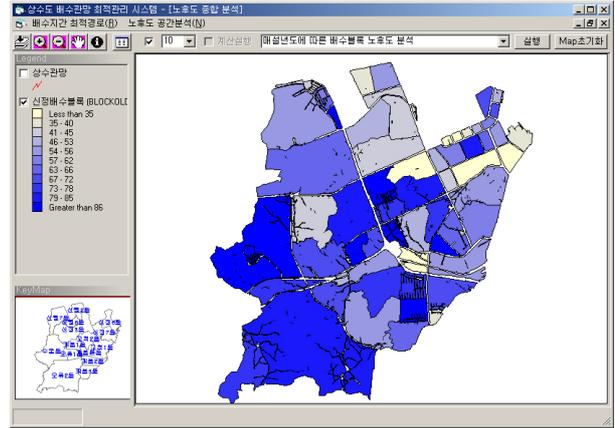


Figure 2. Pipe superannuation monitoring system

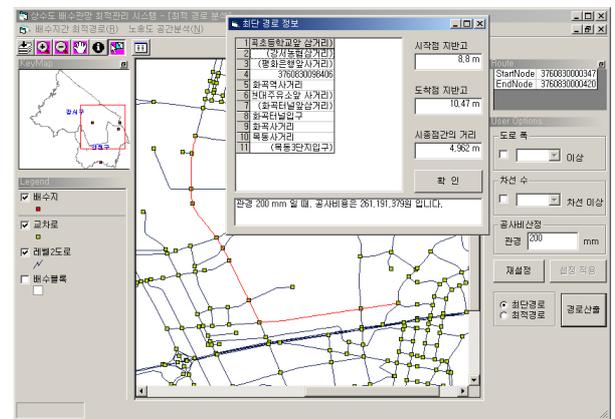


Figure 3. Optimal path creation system

5. CONCLUDING REMARKS

Since construction for water pipes usually requires time and money on a large scale, the decision should be made based on proper estimation and analysis. The study, with the aim to support such decision making, developed a prototype system that can help in two areas; firstly, block designing and pipe monitoring and second, optimal path simulation between major reservoirs. With further refinement, the system is expected to help in following aspects:

- Block-designing can be made more reasonable by incorporating up-to-date street network and water consumption.
- The pipe management module also helps the decision makers by allowing them to use various factors affecting the superannuation.
- Alternative pipe routes can be created by simple user operations on the screen showing existing reservoirs and pipe network.

To make the system more practical, it should be equipped with such functionality as elevation-extraction from DEM maps to calculate the superannuation and the pipe route considering the elevation differences. Also, other separate systems such as water-leak monitoring can be integrated into the system to help comparison of logical superannuation with field values.

ACKNOWLEDGEMENTS

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