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OPTIMAL BUDGET ALLOCATION MODEL FOR REHABILITATION OF SEWER SYSTEM CONSIDERING SOCIAL AND ENVIRONMENTAL CHANGES

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Municipalities face to challenges related to urban infrastructure, mainly related to aging infrastructure. The metropolitan area of Seoul, Korea, reported that more than half of the entire sewer systems are over 30 years old. The deteriorated sewer systems caused serious safety disaster such as sink hole and other social problems. Furthermore, these phenomena continue to accelerate because the sewer systems are seriously affected by variability of rainfall which results from the climate change and human migration from the social change. Therefore, it is necessary to do proactive rehabilitation instead of overdue maintenance considering the social and environmental change. This research presents the conceptual framework for deciding the priority for investment in the borough of Seoul which is based on the extensive evaluation for identifying the sewer pipelines which need rehabilitation work. To address the comprehensive evaluation of priority for investment, Genetic Algorithm (GA), is adopted to find optimal budget allocation for each borough which is derived from considering the technical, economic, environmental, and social aspects. The result can be used as reference to budget allocation to improve the sustainability of the sewer systems.

Keywords: Genetic algorithm, Climate change adaptation, Sustainability.

1 INTRODUCTION

Municipalities face to challenges related to urban infrastructure, mainly related to aging infrastructure. Among the urban infrastructure, Wirahadikusumah *et al*. (2001) discussed that the conditions of sewer systems are most often overlooked because the infrastructure facilities are underground and not visible to users. Accordingly, the deteriorated sewer systems caused serious safety disaster such as sink hole. The sink hole occurred in the metropolitan area of Seoul increased 30% every year along with accelerated aging process of the sewer pipelines.

The infrastructure failure happens unexpectedly if the degree of deterioration exceeds a certain point. In this study, we call such a point the critical point. Once the state of deterioration reaches the critical point, the cost for rehabilitation increases rapidly in comparison with the state before the critical point. Beyond the certain point, the condition of infrastructure goes badly rapidly and much more money need to rehabilitate. However, the current rehabilitation work is based on the grade of deterioration. The assessment of deterioration degree has been accomplished after the progress of the deterioration based on the current state of sewer systems. Because the rehabilitation work for entire deteriorated sewer systems is difficult due to budget limitation (Park *et al*. 2015) and the rehabilitation cost before the critical point is more inexpensive than after the critical point. Therefore, the examination of condition of the infrastructure considering the future demand from social change such as human migration or environmental change because of climate change need to be considered to predict the future deterioration state of sewer systems. This research suggests a conceptual decision-making framework that decides the optimal allocation of rehabilitation budget for sewer systems. The framework has focused on future changes such as human migration and climate change.

2 DESCRIPTION OF THE FRAMEWORK

The aim of this research is to address decision-making framework to find the optimal rehabilitation budget allocation. The research objective involves reflecting the future demand of sewer systems as well as technical deterioration condition. To achieve the objective, the decision-making framework is proposed as Figure 1.

(i) Divide the entire sewage treatment area per sewage treatment plant. One sewage treatment plant deals with disposal of several districts. In this research, the districts from on sewage treatment plant is one section.

(ii) Identify the technical condition of sewer systems. This technical condition is determined by the GIS data which rate the degree of deterioration of sewer pipelines. If the deterioration rate is severe (which is 'A' grade), the sewer systems are priority of investment for rehabilitation.

(iii) If not (degree of deterioration is lower than 'A' grade), the evaluation results of the environmental and social LOS are added to allocate the rehabilitation budget for each district area. (the weights of technical, environmental, and social LOS are derived from the survey from experts.)

(iv) Through genetic algorithm, the optimal budget allocation to minimize the effect from environmental and social changes for each district area is derived.

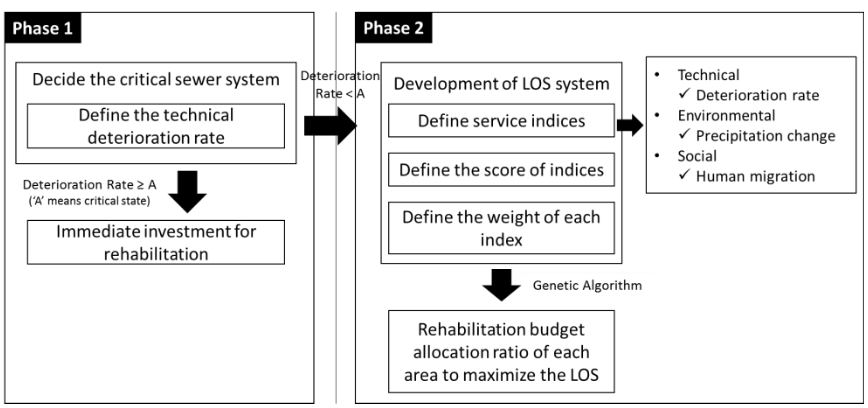

Figure 1. Decision-making framework to find the optimal rehabilitation budget allocation.

To develop the rehabilitation budget allocation system, this study introduces the level of service (LOS), which is a quantitative classification of the quality of traffic service into six letter grades. The LOS has a comprehensive objective, which includes the condition of the infrastructure, maintenance, service offerings, economic evaluation, and quantization of social demand. To evaluate the LOS, we must first define the target to evaluate, the performance index, and the performance measures.

In this research, the targets for evaluating the LOS comprise four areas, as shown in Table 1: economic, environmental, social, and technical LOS. The performance index is considered for each target area.

Table 1. Description of LOS for sewer management.

Target Area	Performance Index	Measurement
Economic	How to minimize the cost for maintenance sewer systems	• Maintenance Cost (*e.g.*, rehabilitation) • Inspection Cost
Environmental	Reflection of climatic variability	• Climate Change (*e.g.*, precipitation)
Social	Improved user satisfaction	• Complaints • Human Migration
Technical	Direct effects on the deterioration of sewer systems	• Age • Material

3 APPLICATION

3.1 Dataset

To apply the developed framework for budget allocation, the authors use GIS data on sewer systems from the Seoul metropolitan area. The data show technical information for the sewers, including the deterioration rate of the sewers in their current state and the sewage treatment centers to which each sewer is connected. The 25 districts of the Seoul metropolitan area are arbitrarily divided into four centers: W, X, Y, and Z.

3.2 Genetic Algorithms

Genetic algorithms (GA) are adaptive optimization algorithms that are based on natural systems necessary for evolution, particularly Charles Darwin's "survival of the fittest." The fittest individuals model genetic changes in a population of individuals. The main advantage of GAs is that they can find the optimal solution for various problems such as non-linear and multi-objective ones.

In this research, we consider three aspects to find the optimum budget allocation ratio which minimize budget allocation cost, the social and environmental effects to accelerate deterioration of sewer systems. To apply GA, the fitness function is set as in Eq. (1) which minimizes the negative value of the summation of S_i, E_i, and T_i.

$$Min\ F(x) = \sum_{i=1}^{4} -(w_S S_i + w_E E_i + w_T T_i) \quad (1)$$

where, w_S, w_E, w_T are the weight of social, environmental, and technical LOS, $S_i = s_i x_i$,, social LOS, $E_i = e_i x_i$, the environmental LOS, $T_i = t_i x_i$, the technical LOS, x_i is the budget allocation ratio of i center for the entire budget for i = 1, 2, 3, 4, where i is the number of the center. In this study, the weights of each LOS are same as 1 arbitrarily.

The constraint equation is only one for simplicity of problem that the total amount for the budget allocation rate is 100% as in Eq. (2). To make more realistic problem, further research considers the complicate constraints which reflect real conditions of sewage treatment centers.

$$\sum_{i=1}^{4} x_i = 100\ (\%). \quad (2)$$

3.3 Results

The computational experiment for the GA was implemented using the MATLAB 2013 optimization toolbox.

Table 2. Investment ratio for the sewer budget.

	Center W	Center X	Target Area	Target Area
Current Investment Ratio	37.51%	26.24%	17.65%	18.57%
Optimized Investment Ratio	10.05%	25.79%	54.1%	10.06%
Variation	-27.46%	-0.45%	36.45%	-8.51%

Table 2 provides the results for the introduced budget allocation system using the GA. The first row shows the ratio of sewer rehabilitation considering only the technical LOS for each center. The second row shows the ratio derived from the developed budget allocation framework considering the environmental and social LOS as well as the technical LOS. The third row shows the variation in the two ratios. The existing budget allocation system suggests that that the budget should be allocated mostly to center W at 37.51% and least to center Y at 17.65% of the entire sewer renovation budget. This is because current system regards technical deterioration state as important for rehabilitation of sewer systems. However, the optimized budget allocation ratio derived from the proposed budget allocation model using the GA is different from that of existing budget allocation system. Optimized budget allocation ratio implies that although the current technical deterioration rate is large in center A, there are more social and environmental problems around center Y in the future as well as a higher possibility of surcharges due to heavy rain. Therefore, not in center X but in cent Y, the more budget need to be allocated. The consideration of social and environmental effects can make the proactive prevention for deterioration of sewer treatment systems. The research can be applied to reflect the climate change and social issues.

4 CONCLUSION

This paper suggested a basic framework for a budget allocation system for sewer rehabilitation. To provide for proactive rehabilitation, this research suggested a framework that considers the environmental and social LOS in addition to the technical LOS. However, this research has some limitations. This model does not consider the economic LOS, which is crucial in making budget allocation decisions. In addition, when considering the environmental and social LOS, some performance indexes, such as population emigration, were omitted. Given these limitations, further research will concentrate on developing the system, and to make the system more realistic, the inclusion of additional factors and verification of the system will be the main areas of focus.

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