A Study on the decision method of investment priorities to improve by the results in the technical diagnosis of Water Supply Network Facilities

By

KIM, Jeongpil

CAPSTONE PROJECT

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF PUBLIC MANAGEMENT

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Committee in charge:

Professor Lee, Junesoo, Supervisor ____________________

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ABSTRACT

A Study on the decision method of investment priorities to improve by the results in the technical diagnosis of Water Supply Network Facilities

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This research paper aims to come up with a methodology for rational decision of investment priority for facility improvement according to the result of technical diagnosis of water supply network facilities. Of course, this study was also imposingly designed to derive and present major improvements that are needed to make the more rational and efficient use of the current technical diagnosis performance.

For this research, relevant papers or data related to technical diagnosis were collected a nd analyzed, and the needs were identified by conducting in-depth interviews with K-water ex perts in related work. Based on this, a methodology for resetting key factors and selecting inv estment priorities by combining AHP and PROMETHEE techniques (MCDM) was presented.

Finally, I think the findings are meaningful in laying the foundation for further research and development in a more improved direction, rather than a methodology for dramatically improving technical diagnosis. The results of this research will be of interest to budget officer and facility manager in K-water and workers of water supply facilities across the country.

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1. Introduction

With the recent rise in the level of consciousness and welfare benefits of the Korean people, the level of demand for stable and safe drinking water supply has become increasingly stringent. The importance of K-water is also getting stronger as it has the national water supply as its main mission. According to the K-water Crisis Response Report (K-water, 2019), 45% of the crisis response[1] in K-water managed facilities are about water supply network facilities. In addition, as shown in Table 2, the crises with drinking water supply facilities, such as the Incheon Red Water Accident, can develop into a national crisis that can cause long-term and extensive damage. Therefore, investment for proper facility improvement is needed to prevent the crisis of the water supply network facilities in advance. But the budget for facility improvement has not been able to keep up with actual costs.

Table 1. The status of K-water Crisis Response as of 2019

<table>
<tr><th rowspan="2"></th><th rowspan="2">Sum</th><th colspan="3">Water Supply Network</th><th colspan="3">Water Resources</th><th rowspan="2">Damage from Storm and flood</th><th rowspan="2">General accident</th><th rowspan="2">Drought</th><th rowspan="2">Others</th></tr>
<tr><th>Pipe Network</th><th>Equip.</th><th>Water Quality</th><th>Facility</th><th>Equip.</th><th>Water Quality</th></tr>
<tr><td>Number of Crisis (2019)</td><td>386</td><td>175 (45%)</td><td>10 (3%)</td><td>65 (17%)</td><td>1 (-%)</td><td>9 (3%)</td><td>27 (7%)</td><td>59 (15%)</td><td>9 (2%)</td><td>11 (3%)</td><td>20 (5%)</td></tr>
</table>

Table 2. The recent crisis cases of the water supply network facilities in Korea

Region of crisis case	Year	Type of Crisis	Status of impact (Scale of damage)
Gumi City	2011	Stop of Water supply	· Period : 4-5 days · District : 3 cities & countries · Population : about 0.5 million
Cheongju City	2015	Stop of Water supply	· Period : 3-4 days · District : 2 district of cities · Population : about 0.04 million
Incheon Metropolitan City	**2019**	**Red water supply**	· **Period : 30-60 days** · **District : 2 districts of city** · **Population : about 0.67 million**

[1] **.Crisis response**: Response to hazardous situations occurring in K-water managed facilities (Dams, water supply and sewage, canal etc.)

The purpose of this study is to provide an optimal decision method of investment priorities to improve by the results in the technical diagnosis [2] of Water Supply Network/Distribution Systems (or facilities). The facility investment and improvement strategies in a timely manner are important because safe and stable drinking water need to be provided from water treatment facilities to faucets (or taps).

Through the five-year technical diagnosis, K-water has been developing and improving problems in the operation of facilities for the stable maintenance and investment of drinking water supply network facilities. Since K-water's budget for improving the various problems derived from the technical diagnosis of the facility is always limited, the methodology of prioritizing investment for a stable supply of drinking water is very important.

The technical diagnosis of the water supply network facilities is carried out in accordance with two main criteria. One is the Manual for Water Supply Network Diagnostics (Ministry of Environment, 2017) and the other is the Guidebook for Technical Diagnostics of Water Transfer Facilities (K-water, 2010). The manual (ME, 2017) provides the main items and evaluation criteria of the technical diagnosis of the water supply facilities, and the guidebook (K-water, 2010) presents detailed methods of technical diagnosis and criteria for determining aging of facilities in more detail than the manual.

K-water has been also researching and developing methodologies for evaluating pipe aging, such as Development of Determination System for Retrofitting of Water supply pipe (K-water, 1995) and Effective Evaluation of Deterioration through the Internal and External Examination in Water Mains (K-water, 2002). However, past researches quantitatively evaluates the degree of aging of the water supply network and suggests whether facility improvement is necessary, and there is a lack of methodology to prioritize facility improvement investment based on the diagnosis results.

2. **Technical diagnosis**: A diagnosis with legal obligation to derive improvements and investment plans for stable water supply per 5 years

As a result of further investigation into the methodology for prioritizing facility investment, Kim, Park, Lee and Jeon (2007) suggested the method of evaluation of risk factors and decision making for rehabilitation of Water Supply Network using AHP[3]. This study suggested how to utilize AHP technique by selecting the key factors in determining the priority of investment for replacement of old pipes. Their study is likely to be quite consistent with this study and approach. However, the limitation is that it is not an investment of overall facilities but a limited method to improve an aged facilities. Looking further at similar research cases in determining the priority and method of improvement of old facilities, Kong, Lee and Kwak (2018) argue that suitable construction methods should be selected to improve the performance of old water pipes, taking into account the priority of structural problems, joint leaks, hydraulic problems and water quality problems. To sum up the previous research results related to the subject, there are many technical studies related to the technical diagnosis of the water supply system, but using these results, there seems to be some lack of research on investment priorities or strategies for the maintenance and operation of sustainable facilities.

The problem is none of priority for mid to long-term facility investment based on technical diagnosis results. In other words, current facility investment is being implemented with a limited budget in an unsystematic, ineffective and subjective way without decision method of improvement priorities.

In addition, when the need for improvement through technical diagnosis is derived, there is no management level evaluation of the improvement efforts of the facility management department. Therefore, this study wants to approach with one main question and three sub-question. The main question is "How can water supply facilities be improved for prevention of crisis? ". The sub-question are 1) what are the key factors to improve water supply network

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3. **AHP** : Analytic Hierarchy Process

facilities? 2) What is the optical method for investment priority decisions? 3) Is it necessary to introduce a system that evaluates the level of facility management?

The scope of this study is to present a methodology to reasonably select investment priorities for facility improvement on an annual basis, taking into account additional external factors such as the importance, urgency, financial status, and operator opinions of the facility.

The findings of this study could solve problems that have been indiscriminately implemented without clear principles and review criteria in utilizing limited facility improvement budgets. This will ensure the safety and stability of the facilities and, consequently, the stable supply of drinking water will be sustainable. This will drastically reduce the crisis of water supply. Of course, the limitations of this study exist. The failure to establish a process for selecting a clear investment priority in the past has practical difficulties in applying generalized principles because water supply facilities have their own maintenance or operational characteristics. However, it is expected that this process of prioritizing investment will be applied more clearly and specifically if further research is carried out and developed in the future.

The results of this research will be of interest to budget officers and facility managers in K-water and workers of water supply facilities across the country. Previously, budget managers and facility managers had made claims based on their respective interests due to the lack of a clear process on priorities for facility investment, but if the criteria for selecting priorities become clear based on this study, quick and reasonable decision-making will be possible without disagreement.

2. Methodology of study

2.1. Procedure of study

An establishment of overall approach direction and propulsion procedures for research subjects. A total of 4 Stages were used to draw conclusions through the following research procedure (figure 1). If supplementation was required in the progress of each phase, the procedures of the previous phase might be repeated and the research will be conducted flexibly depending on the conditions.

Figure 1. Procedure of this study

[1st Stage] Understanding Problem of Technical Diagnosis

▶ Literature Review, 1st In-depth Interview (with Experts)

[2nd Stage] Development of Applicable New Analysis Model

▶ Deriving Key Variables, 2nd In-depth Interview(with Experts)

[3rd Stage] Case studies of Model on K-water Diagnostic Report

▶ Applicability of new model, Deriving & supplementing errors

[4th Stage] Conclusions and Proposing Additional Improvements

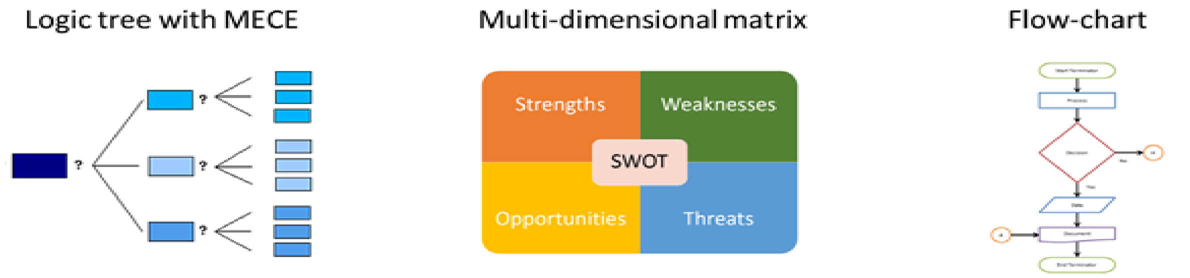
▶ Proposal for improvements such as Law, Institution and HRM, etc.

*** *(New Analysis Model)*** *Additional Survey or Analysis method (e. g. AHP) will be used if necessary*

2.2. Methodology of study

Three important methodologies was approached in the Capstone Project process. First, various logical thinking techniques such as Figure 2 was applied to collect and analyze existing literature research and related data more systematically and rationally, and secondly, in-depth interviews were conducted with K-water's group of experts in the field of technical diagnosis to collect information on the direction of improvement. Finally, it was to use AHP and PREMETHEE method, which were Multi-Criteria Decision Making (MCDM) techniques, as methodologies for selecting investment priorities.

Figure 2. Logical Thinking techniques to be used in research



3. Literature review

Manual for Water Supply Network Diagnostics (Ministry of Environment, 2017)

The manual (ME, 2017) suggests that the facility improvement plan to be implemented in the short and long term based on the results of the technical diagnosis conducted every five years should be established. In this case, an evaluation committee or advisory committee should be formed in addition to objective evaluation criteria to draw up the optimal plan considering the characteristics of each institution or facility. In particular, the following items should be fully reviewed in implementing decisions to prioritize facility improvement:

First, systems or individual facilities with great room for functional improvement are said to be subject to improvement.

Second, through the system-wide technical diagnosis of each system for the transmission and distribution system, a comprehensive review is made of whether the evaluation points of other indicators to supplement a particular indicator are high, and whether the system requirements function can be satisfied, even if the evaluation points of the particular indicator are low. Therefore, it is necessary to consider the characteristics and conditions of each system. Third, it is necessary not to think of room for improvement only by significantly degraded functions in individual systems or facilities, but to consider the future of the entire water supply project from a broad and high point of view to obtain a high facility effect. Finally, it is necessary to determine the level of water supply services according to local circumstance and to review them, including those intended to contribute to the financial scope and efficient management.

Through the emphasis of the preceding study, it was planned to recognize and promote the need for a detailed review of the factors that should be selected as the key factors for selecting investment priority in this study and to be newly established through the review of existing key factors.

Guidebook for Technical Diagnostics of Water Transfer Facilities (K-water, 2010)

The guidebook (K-water, 2010) provides detailed guidance on major tasks, diagnosis procedures, and detailed items of water supply network technical diagnosis, especially in the multi-regional water supply sector, to understand the overall details of the technical diagnosis.

However, the guidebook suggests that the facility improvement plan should be established according to the results of the technical diagnosis, as in the manual (ME, 2017), but the existing technical diagnosis report does not have a detailed description of this part and is simply listed in the facility improvement list. In this study, I would like to study and present the process of selecting investment priority for the facility improvement list as an improvement plan.

Effective Evaluation of Deterioration through the Internal and External Examination in Water Mains (K-water, 2002)

The improvement study (K-water, 2002) identified problems with various techniques related to aging assessment of pipelines developed domestically in the past improved and supplemented evaluation items and evaluation criteria to facilitate the evaluation of aging. Based on this, a model for the evaluation of aged was developed through detailed on-site inspections to help establish plans for the improvement of pipe facilities through more accurate evaluation. However, in this study, there is also a limit to derive practical facility improvement priorities by utilizing the results of the obsolescence as a methodology-oriented study for the evaluation of obsolescence.

Water Infrastructure Diagnostics Advanced Performance Report (K-water, 2020)

The Advanced Performance Report (K-water, 2020) is a report published to analyze and improve problems in the existing water infrastructure technical diagnosis field, and prior to this study, it presents a comprehensive review of various fields with similar problem awareness.

The main contents are analysis of institutional, performance and methodological problems of current technical diagnosis, analysis of problems of facility diagnosis system under various statutes, and institutional readjustment are required, and the introduction and introduction of various advanced diagnostic equipment actively carried out in the United States, Japan, and Australia are also proposed. In particular, regarding the selection of investment priority for facility improvement, which is a research subject, it is proposed as an essential and necessary part of efficient use of the limited budget, and two previous similar cases are introduced.

First, the 2025 Basic Plan for Water Supply and Maintenance (Ministry of Land, Infrastructure and Transport, 2015) presents the AHP weighted hierarchy for selecting priorities for Multi-Regional Waterworks and Industrial Water Pipelines. Second, the Strategic Plan for Improving the Reliability of Stabilization of Waterworks (K-water, 2020) presents a model on how to derive priority for water supply pipeline projects.

These two approaches are thought to set good precedent for selecting key factors for investment priority selection to be applied in this study and for eliciting AHP hierarchy.

Determination of Investment Priority for River Improvement Project at Downstream of Dams Using PROMETHEE (KSCE, 2012)

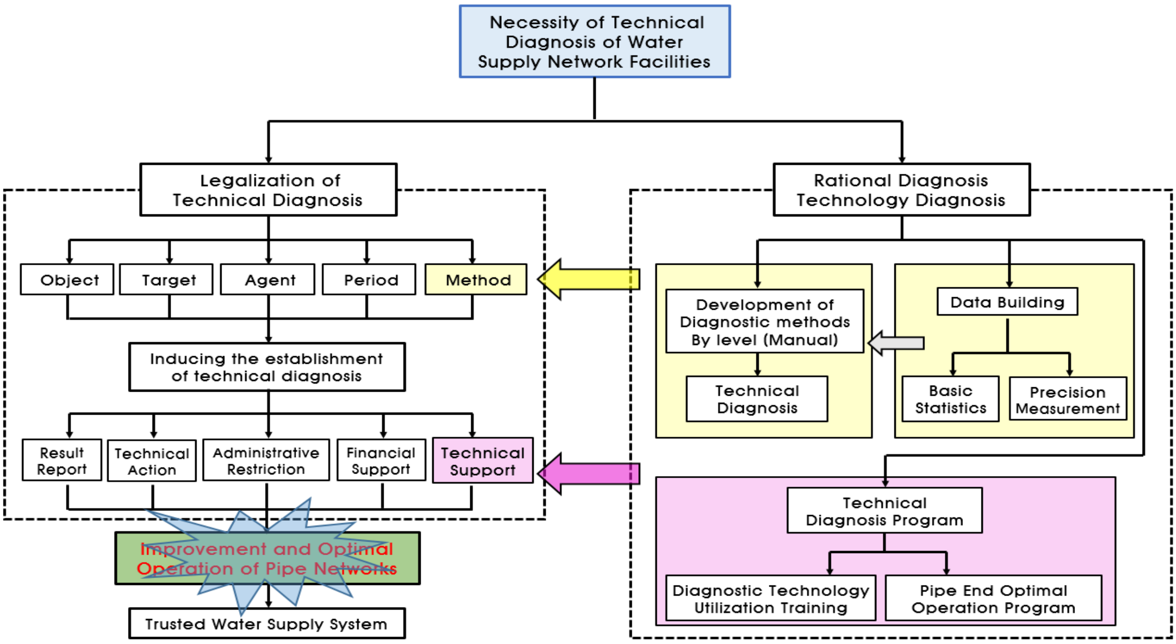
Based on the eigenvector method proposed by AHP, Kim Gil-ho (2012) presents a model that determines the criteria and attributes of evaluation and determines the priority of investment by performing PROMETHEE. PROMETHEE (Preference Ranking Organization Method for Environment Evaluation) is a technique for deriving ranking preferences for alternatives using the concept of preference runoff and preference inflow. This prior study is expected to serve as an important motif in researching new models that apply the process of selecting investment priorities for facility improvement based on the results of this technical diagnosis.

4. Overview of technical diagnosis of the water supply network facilities

4.1 Objective of technical diagnosis

The technical diagnosis of the water supply network facilities is aimed at contributing to solving problems discovered by the diagnosis and improving the current condition by scientifically and rationally diagnosing the current condition of the water supply pipe network and its operational and management entities so that the purpose of the water supply network facilities can be smoothly achieved. This diagnosis is a legal regulation that should be implemented every five years under the Waterworks Act, and the purpose and process as seen in Figure 3 are implemented as a basic concept.

Figure 3. Objective of technical diagnosis of the water supply network facilities

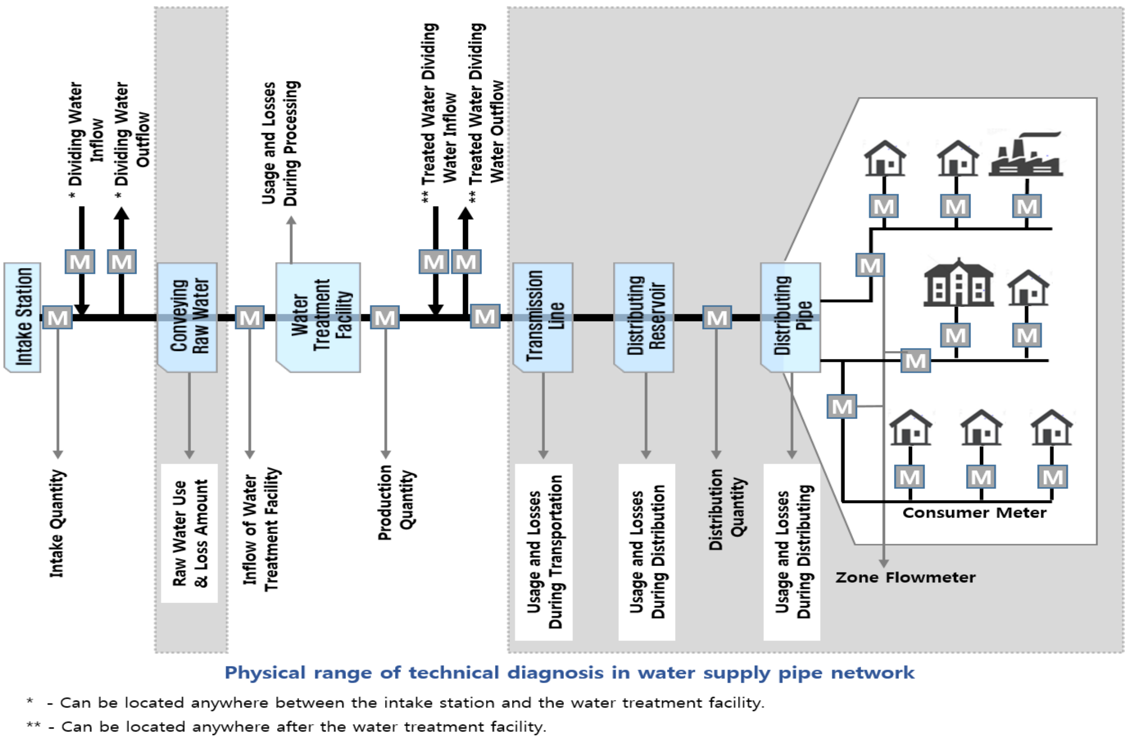


4.2 Scope of technical diagnosis

The technical diagnosis scope of the water supply network facilities is for pipes and accessories that diverge from the water supply facilities, transport facilities, distribution facilities, and drains on the water supply design basis. In other words, the target facilities for technical diagnosis are as follows.

1) Waterways and their accessories from the water supply station to the water purification plant.
2) Water pipes, distributions, and valves attached to them after the water purification plant.
3) Water supply facilities from the water supply branch point to the meter of the distribution pipe.
4) Distribution, pressurization, etc.

Figure 4. Conceptual Scope of technical diagnosis in water supply network facilities



The **technical diagnosis** in water supply network facilities under the Waterworks Act is an evaluation of the comprehensive performance of the repair water facilities in a pipe network, and the most significant difference is that **the precision safety diagnosis** of the special law assesses the structural safety of the facilities.

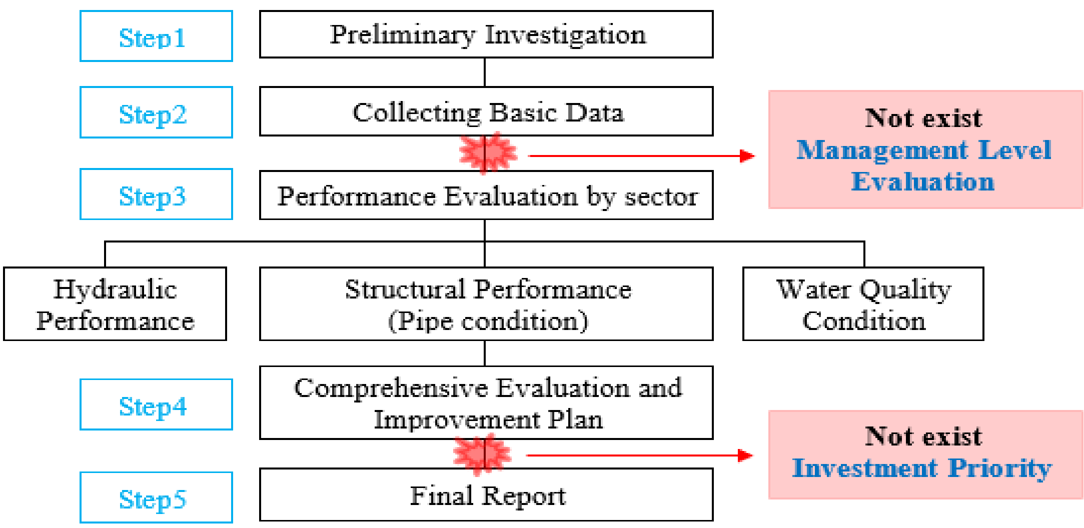
Table 3. Comparison of technical diagnosis and precision safety diagnosis

	Technical Diagnosis in water supply network facilities	Precision Safety Diagnosis
Relevant Basis	· Article 74 of the Waterworks Act · Notice on the scope and implementation method of technical diagnosis of water supply pipe network	· Article 7 of the Special Act in the Safety of Facilities · Detailed guidelines for safety inspection and precision safety diagnosis
Diagnostic Cycle	· Every 5 years	· Within one year from 10 years after completion, and at least once in four to six years thereafter.
Diagnostic Task	· **Comprehensive performance assessment of hydraulic / structure / water quality**	· **Proposing grades and repair and reinforcement plans through structural performance evaluation**
Overlapping Task	-	· Structural Performance Evaluation Task
Solution Plan	· Data sharing of diagnosis results	· Data sharing of diagnosis results

4.3 Procedure of technical diagnosis implementation

The technical diagnosis is carried out in advance by surveying each sector (hydraulic, structure, and water quality) performance assessment and collecting basic data, and the procedures for establishing the results and improvement measures accordingly. Technical diagnosis procedures such as Figure 5 show that management level evaluation and investment priority are necessary, and these are the main topics of this study.

Figure 5. Flow-chart of technical diagnosis in the water supply network facilities



5. Key issues and improvement of study

5.1 Key issues

(Key-1) Not exist Management Level Evaluation *: Between Step2 and Step3*

1) The Technical diagnosis of water supply pipe network, which is mandatory every five years under the Waterworks Act. but there were lacks systematic management.
2) Lack of systematic management were including diagnostic results/improvement history
3) **Lack of level evaluation for facility management department's efforts to improve based on technical diagnosis**

(Key-2) Not exist Investment Priority *: Between Step4 and Step5*

1) **Lack of priority for mid to long-term facility investment based on technical diagnosis results**

5.2 Key improvements from this study

Through this study, I would like to present improvement directions and systematic management measures for several key issues found in the analysis stage of the current problem of technology diagnosis in water supply network facilities.

Table 4. Comparison of As-Is and To-Be in technical diagnosis with result of this study

	As - Is	**To - Be**
Management Level Evaluation	· Not exist improvement level evaluation method (Facility department's effort?)	· Provision of management level (Including improved details over the past 5 years)
Investment Priority	· Not exist investment plan to improve facility (Including improvement cost)	· Proposal of investment priority (Including approximate cost provision)
Systematic management	· Not exist history of diagnosis results and improvement	· Operation of the integrated facility diagnosis/history management system (e.g. Precision safety diagnosis)

6. In-depth interview with expert group

6.1 Objective

The purpose of In-depth Interview is to identify problems in the current technical diagnosis system through interviews with K-water internal experts and business managers related to research topics, and to secure feasibility for the research direction at this time. In addition, in developing the investment priority decision-making process, the key factors and analysis models were developed as a prior process for achieving the best results through sharing ideas with experts.

6.2 When & Who to interview

Initially, the first in-depth interview for overall direction setting and the second in-depth interview for opinion inquiry on the model were planned to be conducted before the research materialization, but only one in-depth interview (written) was conducted based on the results specified in the research process according to the COVID-19 situation.

In-depth interviewees such as table 5 were selected and conducted by four experts inside K-water. First, opinions on the future rational direction of technical diagnosis in the overall position of the organization were collected from the senior manager and manager in charge of technical diagnosis belonging to the water comprehensive diagnosis office of the head office, which oversees the technical diagnosis of the water supply network facilities. Next, the senior manager and manager of the basin headquarters in charge of actual facility management received opinions on the direction of improvement in establishing and implementing an investment plan for facility improvement by utilizing actual technical diagnosis results.

Table 5. In-depth interviewee list

4 Experts of General Dept. & Facility Management Dept. in K-water	
Comprehensive Water Diagnostics Dept. (2)	**Geum River Basin Water Supply Service Dept. (2)**
Senior Manager (1), Manager (1)	Senior Manager (1), Manager (1)

6.3 Summary of interview results

I would like to summarize the results of in-depth interviews with technical diagnosis experts inside K-water. First, the overall consensus is on the need for methodologies to select investment priorities based on the results of the technical diagnosis. Second, it is necessary to readjust the overlapping parts of the various facility diagnosis systems, along with legal and institutional improvements to technical diagnosis. Finally, it raises the need to strengthen the diagnosis and improvement measures of water quality problems within the recently emerging water supply network facilities. Reflecting the results of these interviews, I would like to summarize this study's conclusions as suggestions for improving technical diagnosis. The main contents of each interview question are as shown in Table 6.

Table 6. Main contents of in-depth interview results

Question Items	Main Opinions
■ **Add or exclude technical diagnosis items**	✓ Water quality areas such as red water and larvae, which have recently become an issue, are conducting water safety and volatility assessments in technical diagnosis, but reliability and utility are low due to the use of existing data and small number of samples. Therefore, it is necessary to examine the problem improvement plan for discoloration through long-term data acquisition and analysis using the RPM (Resuspension Potential Method) technique, etc. to identify the risk point of accumulation of low velocity sediment and the risk point of turbidity by switching water systems. ✓ Need to expand the direct evaluation of pipelines. ✓ Adjustment is required as there are many overlapping contents with the 'performance evaluation' service implemented in accordance with the Special Act on Safety and Maintenance of Facilities.
■ **Problem or improvement of the technical diagnosis evaluation method**	✓ Currently, technical diagnosis is limited to assessment-oriented diagnosis of the condition, which makes it less useful on-site, so diagnosis that can help improve on-site operations is needed through further investigation of improvements as well as assessment. ✓ A comprehensive review with connected facilities is required.

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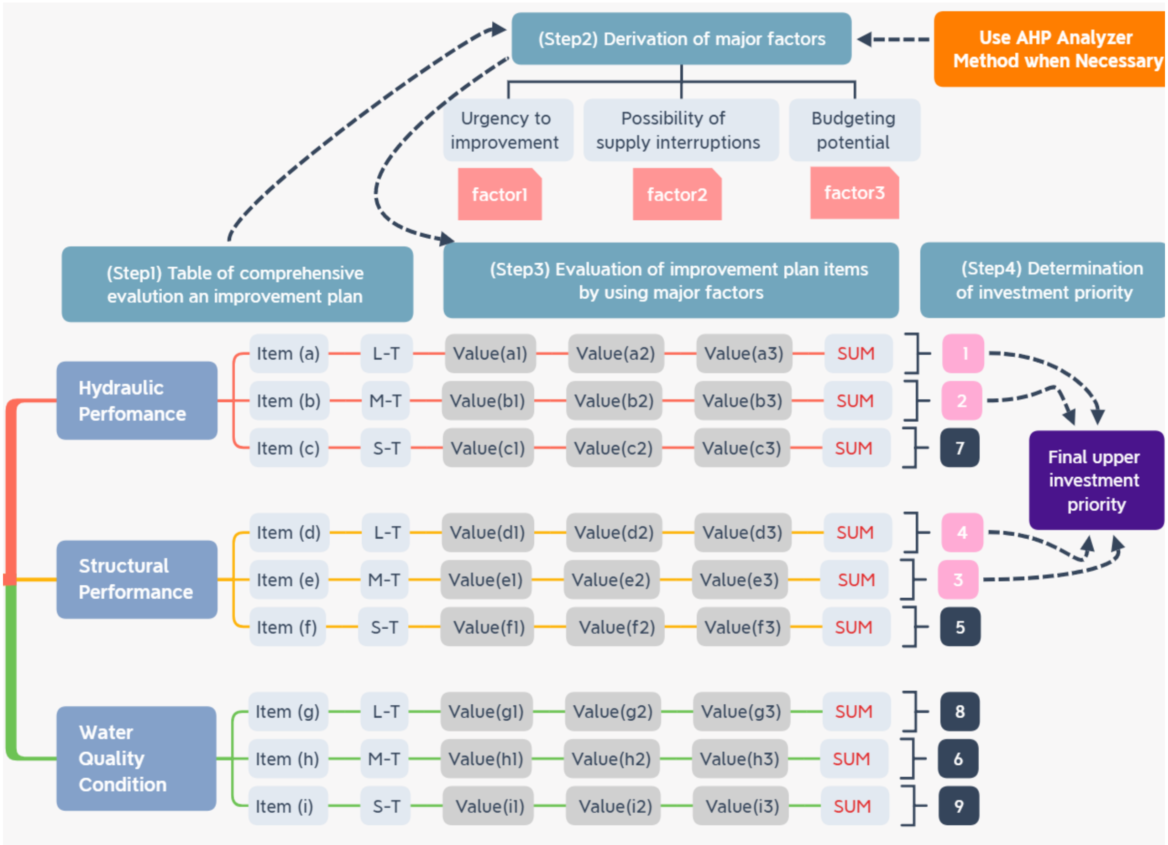
Question Items	Main Opinions
■ **Needs for improvement in terms of regulation or process**	✓ It is necessary to revise a number of regulations, notices, items, etc., such as ambiguous scope of tasks of the current network technical diagnosis and the technical diagnosis of the water purification plant, exclusion of network diagnosis in areas where the block system is not established, and discrepancies in relevant regulations.
■ **Experts/executive's opinion on capstone project**	✓ As the current technical diagnosis performance alone lacks the collection of basic data for investment priority selection, it is necessary to improve the results of technical diagnosis in order to secure basic data for priority evaluation. ✓ Need to give priority to the urgency of the project for facility safety management. ✓ It is necessary to present investment priority by compiling opinions of the management department on the results of technical diagnosis.
■ **Opinion about Management Level Evaluation system**	✓ It is judged that a level of management will be possible if the existing diagnosis focused on simple facility assessment is preceded by a technical diagnosis focused on deriving improvements. ✓ Improvements efforts and improvements should be evaluated at the same time.
■ **Opinion on the direction of the analysis model development**	✓ The methodology is necessary to maximize the effectiveness of the technical diagnosis and should be applied through continuous development in the future.
■ **Needs for further improvement in order to improve the performance of technical diagnosis and enhance the availability of the business**	✓ It is necessary to diagnose and derive improvements from the overall system perspective to ensure pipeline stability by improving operation of departments such as water purification plant and pumping station, rather than simply diagnosing facilities based on pipe network. ✓ Need to present investment priorities and annual investment plans and establish an annual report. ✓ The same results need to be obtained as diagnosis and inspection conducted under other laws and the establishment of a system for data management.

7. Decision method of investment priorities

7.1 A Conceptual map of new model

In order to develop an investment priority selection model, the facility improvement list based on the results of the technical diagnosis was first defined as Figure 6.

Figure 6. Conceptual map of Model in Investment Priorities



(Step1) Comprehensive evaluation

- Approximate project cost by improvement item and confirm the required time.
- Need to have sufficient coordination of management departments before finalizing the required timing

(Step2) Derivation of major factors

- AHP Analyzer method is used to calculate weights between different factors.

(Step3) Evaluation importance of improvement

- The scores calculated by considering the various weight factors are added together.

(Step4) Determination Investment Priority

- Ranked and listed according to the aggregated evaluation scores, the top priority will be given to future budget investments. Based on these results, the facility management department shall utilize the results for future budget planning and execution.

7.2 Case study of existing evaluation methods

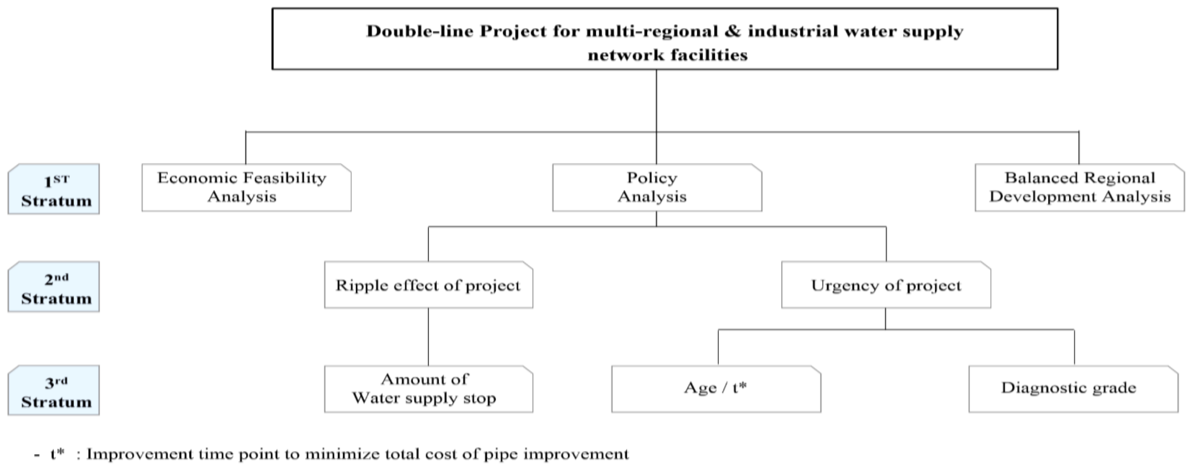
7.2.1 (Case1) 2025 Master Plan for Development of Water Supply

The first case study is a case study in Figure 7 for selecting priorities for double-line projects for multi-regional and industrial water supply network facilities used to determine investment priorities in the 2025 Basic Plan for Water Supply and Transportation (Ministry of Land, Infrastructure and Transport, 2015).

As a result of the analysis of this case, the three-layer classification for AHP analysis was implemented for the purpose of prioritizing large-scale project units for national financial projects (Master Plan for Development of Water Supply). Therefore, there is a problem with a number of items that are not applicable to the Factor and the criteria for selecting investment priorities after the technical diagnosis of one unit facility. For example, items such as "Balanced regional development analysis" or "Policy analysis," which are the factors of the 1st Stratum, and "the Age," which is a factor of the 3rd Stratum, are difficult to apply to this study.

In addition, large-scale facility investment (more than 30 billion won for national finance projects, reflecting the Master Plan for Development of Water Supply) among the list of improvement needs as a result of technical diagnosis will be reflected in the higher plan, and the selection of investment priority within a single facility based on the results of the technical diagnosis will be deemed meaningless.

Figure 7. AHP Structure for double-line projects for multi-regional & industrial water supply network facilities



7.2.2 (Case2) Strategic Plan for Improving Reliability of Stabilization of Waterworks

The second case study is an example of a review of the method of calculating project priorities for each water supply network project priority assessment item(Table 7) in the Strategic Plan for Improving Reliability of stabilization of Waterworks(K-water, 2020).

As a result of the analysis of this case, the "equity of project" items in investment priority within a single facility, as in Case1, is deemed unnecessary for this study. It is also believed that by oversimplifying the priorities of each detailed assessment item, it will be used to derive new key factors by referring to each item, although situations are insufficient for a reasonable analysis model.

Table 7. A study on the priority of the water supply network projects

Evaluation standard	Evaluation items	Evaluation method
Urgency	· Amount of water supply stop	· Actual amount of water supply stop during standard recovery time by facilities(thousand ㎥/day).
	· Accident history	· Number of accidents by facility x Length(km) x Operating period(10 years)
	· Age	· Standard years (2020) – Installation years + 1
Equity	· Balanced regional development	· Regional backwardness ranking(2019)
Efficiency	· Efficiency ranking	· Efficiency of project(Amount of water supply stop / Cost)

7.3 Reassessment of key factors for determining investment priorities

Reorganization of the AHP hierarchy is required through a reassessment and addition of items for the Key Factor to determine investment priorities presented in existing studies and reports through the Case Study.

7.3.1 Prerequisites

1) Simplification to as little as three levels as possible for the construction of a lower-level AHP hierarchy, independent structures between factors in the same layer, and dependent relationships between higher-to-lower layers.

2) The existing case study is a high-scale priority methodology for selecting priorities among individual facility units (multi-regional waterworks, etc.). On the other hand, this study eliminates unnecessary factors considering that it is a priority selection for improvements within a unit facility.

3) In addition to quantitative factors, opinions of facility managers with abundant knowledge-how on facility conditions are reflected in the factors.

7.3.2 Reassessment of key factors

Key Factors for selecting investment priorities previously presented through Case Study was re-evaluated, including application, elimination and addition, considering the characteristics of the technical diagnosis. The results were as shown in Table 8 and were finally re-evaluated as 13 key factors in the three-layer structure.

Table 8. The result of key factor reassessment

Factor	Sortation	Stratum	Adoption	Reassessment detail
Economic Feasibility Analysis	Existing	1st Stratum	x	· No B/C analysis required for single facility scope prioritization. → Investment costs of more than 30 billion won are designed to be excluded by sorting before prioritizing the process(replacement to "Efficiency of project")
Policy Analysis (Necessity)	Existing	1st Stratum	○	· Preserve as a basic requirement for maintaining stable supply capacity of facilities. → The terms are embodied and redefined (policy analysis → necessity analysis)
Balanced Regional Development Analysis	Existing	1st Stratum	x	· Since a single facility exists in the same area, there is no need for "balanced regional development".
Efficiency Analysis	New	1st Stratum	○	· Rename the economic analysis to apply the adoptable calculation method. → (Existing facility) Water Stop / Cost → (New facility) Supply expansion / Existing
Recognition Analysis	New	1st Stratum	○	· Recognition of the importance of the project by the supervising/management department of facilities

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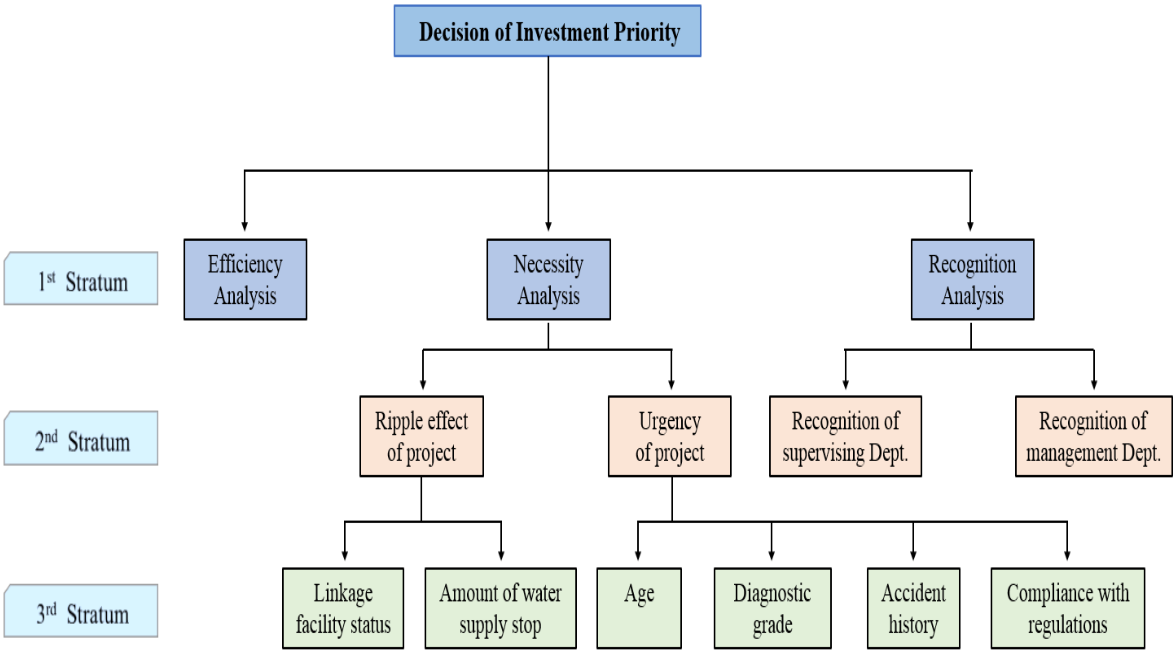
Factor	Sortation	Stratum	Adoption	Reassessment detail
Ripple effect of project	Existing	2nd Stratum	○	· Evaluation factor depending on the amount of water supply stop or the presence of linkage facilities in the event of an accident, such as pipeline failure.
Urgency of project	Existing	2nd Stratum	○	· Urgency of projects considering Age, diagnostic grade, accident history, compliance with regulations, etc.
Linkage facilities status	New	3rd Stratum	○	· Dependent factor of "Ripple effect", Items according to the existence of emergency linkage facilities in the event of an accident.
Amount of water supply stop	Existing	3rd Stratum	○	· Dependent factor of "Ripple effect", Granting evaluation points according to the amount of damage caused by water supply stop.
Age	Existing	3rd Stratum	○	· Dependent factor of "Urgency of project", Grading by age according to the criteria for judging old pipes.
Diagnostic grade	Existing	3rd Stratum	○	· Dependent factor of "Urgency of project", Grading according to the diagnostic grade given by the results of the technical diagnosis.
Accident history	Existing	3rd Stratum	○	· Dependent factor of "Urgency of project", Grading based on the number of accidents that occurred within the last 10 years.
Compliance with regulations	New	3rd Stratum	○	· Dependent factor of "Urgency of project", Grading based on compliance with relevant laws and regulations.
Recognition of supervising dept.	New	2nd Stratum	○	· Dependent factor of "Recognition analysis", Grading based on the judgment of the importance of the project by supervising department of facility.
Recognition of management dept.	New	2nd Stratum	○	· Dependent factor of "Recognition analysis", Grading based on the judgment of the importance of the project by management department of facility.

7.4 Hierarchy and evaluation criteria for deriving Weight of key factors

7.4.1 Design of AHP hierarchy

The AHP hierarchy for the investment priority ranking process based on the Key Factors reassessment results is as shown in Figure 8. The AHP survey will be conducted by a group of experts, taking into account the independent structure among the three classes and the dependency structure between the upper and lower layers. In addition, based on the results of the survey, the study plans to structure the Weight of Factor through double contrast between two factors in the same layer. (According to the unique characteristics of each facility, the diagnosis department can re-assess and adjust the key factor for each individual technical diagnosis result.)

Figure 8. AHP Structure Design for Evaluation Model



7.4.2 Setting of detailed evaluation criteria for each key factors

In order to redefine the AHP hierarchy and determine investment priorities, the acquisition scores for each key factor must be calculated. To achieve this, the method of calculating scores should be studied through the collection and verification of data for a considerable amount of time, and in this study, I would like to present detailed evaluation criteria (proposals) for each key factor as Table 9 through 17 as a basic concept from the perspective of prior research. Specific evaluation criteria in the future need to be quantified and specified through further research by experts in each field.

Table 9. Efficiency Analysis

<table>
<tr><td>Stratum</td><td>· 1st Stratum</td></tr>
<tr><td>Definition</td><td>· Prevention of water supply stop and evaluation of stable supply through retrofitting of existing facilities or new construction</td></tr>
<tr><td>Evaluation Standard</td><td>· Calculation
- (Existing facility) Amount of water supply stop(1,000 ㎥/day) / Cost(billion won)
- (New facility) Supply expansion(1,000 ㎥/day) / Cost(billion won)
· Score (5 point scale)
<table>
<tr><td>Result</td><td>X ≥ 0.1</td><td>0.1 > X ≥ 0.08</td><td>0.08 > X ≥ 0.06</td><td>0.06 > X ≥ 0.04</td><td>X < 0.04</td></tr>
<tr><td>Score</td><td>5 point</td><td>4 point</td><td>3 point</td><td>2 point</td><td>1 point</td></tr>
</table></td></tr>
</table>

Table 10. Recognition of supervising dept.

<table>
<tr><td>Stratum</td><td>· 2nd Stratum</td></tr>
<tr><td>Definition</td><td>· Recognition of the importance of the project by the supervising department of facilities</td></tr>
<tr><td>Evaluation Standard</td><td>· Calculation
- Scoring based on level of recognition of necessity through survey of the supervising dept.
· Score (5 point scale)
<table>
<tr><td>Result</td><td>Absolutely important</td><td>Important</td><td>Ordinary</td><td>Unnecessary</td><td>Absolutely unnecessary</td></tr>
<tr><td>Score</td><td>5 point</td><td>4 point</td><td>3 point</td><td>2 point</td><td>1 point</td></tr>
</table></td></tr>
</table>

Table 11. Recognition of management dept.

<table>
<tr><td>Stratum</td><td>· 2nd Stratum</td></tr>
<tr><td>Definition</td><td>· Recognition of the importance of the project by the management department of facilities</td></tr>
<tr><td>Evaluation Standard</td><td>· Calculation
- Scoring based on level of recognition of necessity through survey of the management dept.
· Score (5 point scale)
<table>
<tr><td>Result</td><td>Absolutely important</td><td>Important</td><td>Ordinary</td><td>Unnecessary</td><td>Absolutely unnecessary</td></tr>
<tr><td>Score</td><td>5 point</td><td>4 point</td><td>3 point</td><td>2 point</td><td>1 point</td></tr>
</table></td></tr>
</table>

Table 12. Linkage facility status

Stratum	· 3rd Stratum
Definition	· Items according to the existence of emergency linkage facilities in the event of an accident.
Evaluation Standard	· **Calculation** - Scoring based on the presence or absence of linkage facility. · **Score** - (Existing linkage facility) 1 point, (No existing linkage facility) 5 point

Table 13. Amount of water supply stop

Stratum	· 3^{rd} Stratum
Definition	· Granting evaluation points according to the amount of damage caused by water supply stop.
Evaluation Standard	· **Calculation** - Amount of water supply stop(1,000 ㎥/day) / Usual amount of water supply(1,000 ㎥/day) · **Score** (5 point scale)

Result	X ≥ 0.5	0.5 > X ≥ 0.4	0.4 > X ≥ 0.3	0.3 > X ≥ 0.2	X < 0.2
Score	5 point	4 point	3 point	2 point	1 point

Table 14. Age

Stratum	· 3^{rd} Stratum
Definition	· Grading by age according to the criteria for judging old pipes.
Evaluation Standard	· **Calculation** - Base year (0000 year) - Installation year + 1 · **Score** (5 point scale)

Result	X ≥ 45	45 > X ≥ 35	35 > X ≥ 25	25 > X ≥ 15	X < 15
Score	5 point	4 point	3 point	2 point	1 point

Table 15. Diagnostic grade

Stratum	· 3^{rd} Stratum
Definition	· Grading according to the diagnostic grade given by the results of the technical diagnosis.
Evaluation Standard	· **Calculation** - Base year (0000 year) - Installation year + 1 · **Score** (Application to the higher score among the two evaluation results)

1. Evaluation of pipe condition

Result	Grade Ⅲ	Grade Ⅱ	Grade Ⅰ
Score	5 point	3 point	1 point

2. Evaluation of safety about water quality

Result	Grade Ⅳ	Grade Ⅲ	Grade Ⅱ	Grade Ⅰ
Score	5 point	3 point	2 point	1 point

Table 16. Accident history

Stratum	· 3^{rd} Stratum
Definition	· Grading based on the number of accidents that occurred within the last 10 years.
Evaluation Standard	· **Score** (5 point scale)

Result	X ≥ 5	5 > X ≥ 4	4 > X ≥ 3	3 > X ≥ 2	X < 2
Score	5 point	4 point	3 point	2 point	1 point

Table 17. Compliance with regulations

Stratum	· 3^{rd} Stratum
Definition	· Grading based on compliance with relevant laws and regulations.
Evaluation Standard	· **Calculation** - Scoring based on the presence or absence of non-compliance with regulations. · **Score** - (Existing non-compliance) 5 point, (No existing non-compliance) 1 point

7.5 Design of investment priority decision-making procedures

7.5.1 Basic concept

In designing the investment priority decision process, I would like to proceed with the following basic concepts:

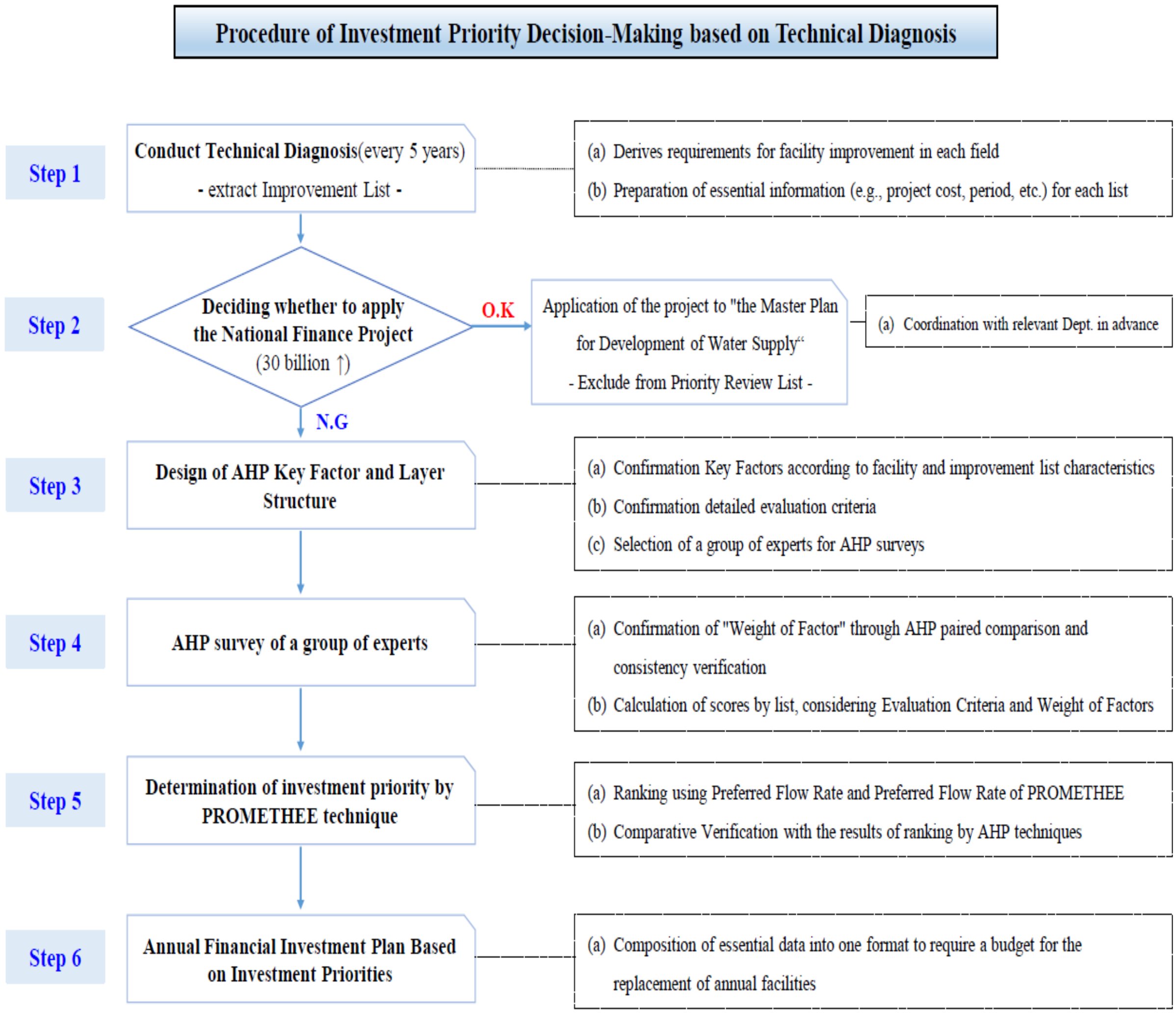
1) In the case of technical diagnosis of water supply network facilities, accumulating such basic data should be preceded because there is no clear data, including project period, required investment costs, etc., on improvements resulting from the diagnosis, and the process for prioritizing decisions cannot be progressed.
2) Among the list of improvements, projects that require the implementation of more than 30 billion won in national finance projects should be excluded from the priority selection list in advance and divided into separate national financial projects (Master Plan for Development of Water Supply).
3) The survey is conducted on a group of experts to determine the weight of factors by layer through AHP hierarchy, paired comparison, and consistency verification.
4) Investment priority decisions can be analyzed through the comparison of alternative preferences through the evaluation criteria for each factor in the AHP analysis procedure. However, I would like to present a methodology that utilizes PROMETHEE (Preference Ranking Organization METHOD for Environment Evaluation) techniques to provide a more reasonable priority for a number of alternatives (improvement lists).

This technique is one of the multi-criteria decision making techniques used in one of the preceding studies, the" Determination of Investment Priority for River Improvement Project at Downstream of Dams Using PROMETHEE (KSCE, 2012)".

7.5.2 New Model of Investment Priority Decision-Making Procedure

Based on the AHP hierarchy and Key Factors defined earlier, the results of the survey by a group of experts (the department in charge of diagnosis and management of facilities, etc.) and the multi-criteria decision-making (MCDM) technique can finally select the investment priority for the facility improvement list, as shown in Figure 9 when looking at the new procedure model.

Figure 9. The New Model of Investment Priority Decision-Making Procedure



7.6 Setting the weight of key factors through AHP Survey

7.6.1 Overview of AHP survey

In order to present weights for each Key Factor in the AHP hierarchy (1-3 stratums) for investment priority decision making, 14 experts were selected from K-water headquarter technical diagnosis department, basin headquarters staff, and staff with extensive experience in waterworks management. Experts have an average working period of 12.6 years, and have worked in the water sector for more than 8.6 years. (As a result of consistency verification, the three experts exceeded the allowable range and were excluded from analysis.)

Table 18. Survey Group Expertise Level *Unit: years*

Sortation		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	Average
1. Total working period		7	16	16	5	14	14	14	14	15	13	11	**12.6**
2. Department	Head office	1	2	8	-	3	4	4	8	3	8	3	**4.0**
	Basin headquarters	-	2	-	4	6	4	6	-	-	-	5	**2.5**
	Branch	6	12	8	-	5	6	4	6	12	6	11	**6.1**
3. Job field	Water Supply Network	6	11	14	4	7	6	7	10	12	6	11	**8.6**
	Water Resources	-	3	1	1	7	3	7	3	-	-	-	**2.3**
	Others	1	2	1	-	-	5	-	1	3	7	-	**1.8**

7.6.2 Introduction to AHP analysis procedure

There are various MCDM (Multi-Criteria Decision Making) techniques and among AHP techniques, various subdivided methods are used in the detailed analysis. In this study, Weight of factors was derived according to the following analysis procedure among these:

1) A group of experts in the relevant field conducted an AHP survey.
2) Obtain a paired comparison matrix for each hierarchical factor.
3) The square of the paired comparison matrix is obtained and normalized to obtain the Eigen Vector.
4) Verification of Consistency of the paired comparison matrix (CI and CR)
   (a) Consistency Index (CI): Calculated as (λ max – n) / (n –1), complete consistency results in λ max = n and CI = 0.

(b) Consistency Ratio (CR): CI divided by Random Index(RI)

(c) Criteria for Consistency Assessment: CI or CR < 0.15 (Criteria can vary based on the subjective judgment of AHP analysts)

5) Determination of weights by collective evaluation of the survey results of a group of experts with consistency

(a) Types of collective evaluation: Eigen Vector Geometric Mean method or Eigen Vector Arithmetic Mean method

(b) Application: Eigen Vector Geometric Mean method

- The Geometric Mean method is used to obtain averages of data that significantly reduce the influence of anomaly, which is likely to affect anomaly.

Ex) The weights assessed by each expert $X_1, X_2, \cdots X_n$, the Geometric Mean is $(X_1 \times X_2 \times X_3 \cdots$ Can be calculated as $\times X_n)^{1/n}$. If the sum is less than one, regularize it and use it.

6) Repeat steps 1 through 6 to derive the weights for each factor at each Stratum.

7.6.3 Setting the weight of key factors by AHP analysis

The weight of each of the 1st to 3rd Stratum was calculated using the geometric mean technique for the weight evaluation results of 11 out of 14 experts surveyed, excluding 3 who exceeded the tolerance range of the Consistency Index.

1st Stratum

As a result of analyzing the weight of factor of the 1st Stratum, The weights of " **Efficiency Analysis: Necessity Analysis: Recognition Analysis**" were analyzed **27.2%: 51.2%: 21.6%.**

Table 19. Efficiency: Necessity: Recognition *Unit: %*

Sortation	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	Average	Normalization
Efficiency	20	30	30	25	30	25	30	30	30	30	30	**26.96**	**27.20**
Necessity	55	50	50	45	55	50	50	45	55	50	55	**50.78**	**51.24**
Recognition	25	20	20	30	15	25	20	25	25	20	15	**21.36**	**21.56**
Sum	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**99.10**	**100.00**

2nd Stratum

As a result of analyzing the weight of factors of the 2nd Stratum, The weights of " **Ripple effect of project: Urgency of project**" were analyzed **0.49: 0.51** and the weights of "**Recognition of supervising dept.: Recognition of management Dept.**" were analyzed **0.30: 0.70.**

Table 20. Ripple effect of project: Urgency of project

Sortation	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	Average	Normalization
Ripple effect of project	0.8333	0.3333	0.1667	0.8333	0.8889	0.7500	0.1250	0.2500	0.8333	0.2500	0.1250	**0.3755**	**0.4912**
Urgency of project	0.1667	0.6667	0.8333	0.1667	0.1111	0.2500	0.8750	0.7500	0.1667	0.7500	0.8750	**0.3889**	**0.5088**
Sum	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**0.7644**	**1.0000**

Table 21. Recognition of supervising Dept.: Recognition of management Dept.

Sortation	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	Average	Normalization
Recognition of supervising Dept.	0.2000	0.3333	0.8333	0.1111	0.2500	0.1667	0.1667	0.2500	0.8333	0.2500	0.1667	**0.2603**	**0.3049**
Recognition of management Dept.	0.8000	0.6667	0.1667	0.8889	0.7500	0.8333	0.8333	0.7500	0.1667	0.7500	0.8333	**0.5935**	**0.6951**
Sum	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**0.8538**	**1.0000**

3rd Stratum

As a result of analyzing the weight of factors of the 3rd Stratum, the weights of " **Linkage facility status: Amount of water supply stop**" were analyzed **0.41: 0.59** and the weights of "**Age: Diagnostic grade: Accident history: Compliance with regulations**" were analyzed **0.06: 0.29: 0.42: 0.23.**

Table 22. Linkage facility status: Amount of water supply stop

Sortation	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	Average	Normalization
Linkage facility status	0.8000	0.8000	0.1667	0.2500	0.8750	0.7500	0.2000	0.2500	0.1667	0.2500	0.1250	**0.3269**	**0.4094**
Amount of water supply stop	0.2000	0.2000	0.8333	0.7500	0.1250	0.1250	0.8000	0.7500	0.8333	0.7500	0.8750	**0.4715**	**0.5906**
Sum	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**0.7985**	**1.0000**

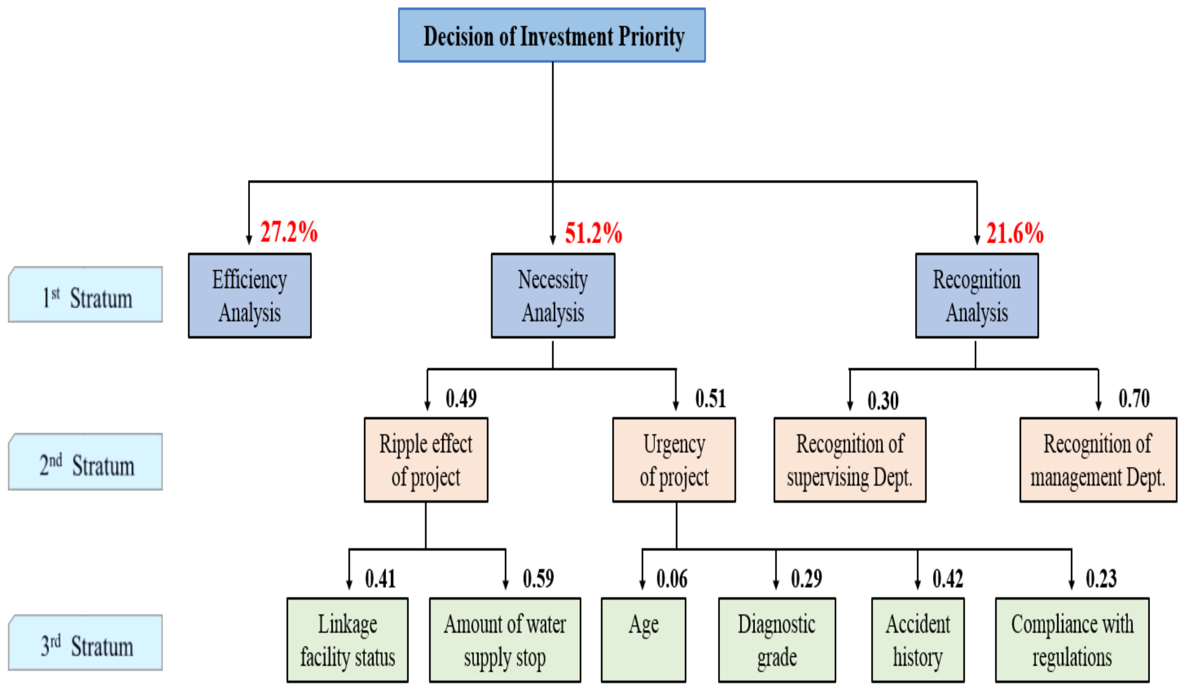
Table 23. Age: Diagnostic grade: Accident history: Compliance with regulations

Sortation	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	Average	Normalization
Age	0.0414	0.0909	0.0628	0.0579	0.0368	0.0531	0.0459	0.0531	0.0531	0.0531	0.0932	**0.0535**	**0.0647**
Diagnostic grade	0.1244	0.1818	0.2273	0.2509	0.1197	0.2651	0.4157	0.2651	0.2651	0.2651	0.5721	**0.2386**	**0.2886**
Accident history	0.5280	0.5485	0.4952	0.6274	0.6011	0.5670	0.1333	0.5670	0.5670	0.1148	0.3014	**0.3437**	**0.4157**
Compliance with regulations	0.3062	0.1818	0.2147	0.0638	0.2424	0.1148	0.4051	0.1148	0.1148	0.5670	0.0334	**0.1910**	**0.2310**
Sum	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	**0.8268**	**1.0000**

7.6.4 Final AHP Hierarchy Model after applying weight of factors

The final AHP Hierarchy model, which analyzed and confirmed the weight of the key factors by stratum 1 to 3 through AHP survey conducted on experts at K-water, is as shown in Figure 10. Of course, this model makes sense for each facility to be reviewed, adjusted and utilized in consideration of the unique characteristics of the corresponding facility when conducting the technical diagnosis.

Figure 10. AHP Hierarchy Model after applying weight of factors



7.6.5 Investment Priority Decision Making based on AHP analysis

AHP, one of the MCDM (Multi-Criteria Decision Making) techniques, can be prioritized by using a survey and the paired comparison for multiple alternatives (so-called, relative AHP method). In this case, an absolute aggregate score can be calculated using the weights selected and the values of each factor as previously presented, and the investment priority can be determined using the following procedures:

1) Establish detailed evaluation criteria for each factor. (Expert survey if necessary)
2) AHP techniques are used to determine weight of factors of each hierarchy.
3) The absolute value is calculated by the "Acquisition Score by Evaluation Criteria × Weight of factors" in each improvement list.
4) Deriving investment priority in order of high scores in acquisition scores.

However, the relative AHP method is limited because the list of facility improvement based on the results of the technical diagnosis, which is a research subject, requires a comparison between 10 or more, not 3 or 4 small numbers.

7.7 Introduction of investment priorities by PROMETHEE method

7.7.1 PROMETHEE method

The PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) specifically presented by Brans and Vincke (1985) is a technique for deriving the rank preference of alternatives using the concepts of Positive Outlining Flow and Negative Outlining Flow. Rather than introducing detailed techniques, this study would suggest that an introduction to the PROMETHEE technique and an optimal methodology using two techniques, AHP (the calculation of weights by key factors through the paired comparison) and PROMETHEE (the selection of investment priorities), are needed for future follow-up studies. In Korea, MCDM (Multi-Criteria Decision Making) techniques are utilized in various fields, and AHP techniques are most actively applied in the field of water resources. Although non-

AHP techniques, including PROMETHEE, are being used in practice, most of them are used at the research level. In the using case, Ko (1992) evaluated the operation rate of multi-purpose reservoirs using AHP and weighting methods, while Choi (2009) performed a flood risk analysis using PROMETHEE. In addition, Nam (2007) proposed a plan to increase the capacity of multi-purpose dams, while Min (2009) was used to determine the priority of management of non-point pollutants in the upper reaches of So-yang Lake. There are several examples of prioritization using PROMETHEE in various fields as well as water resources.

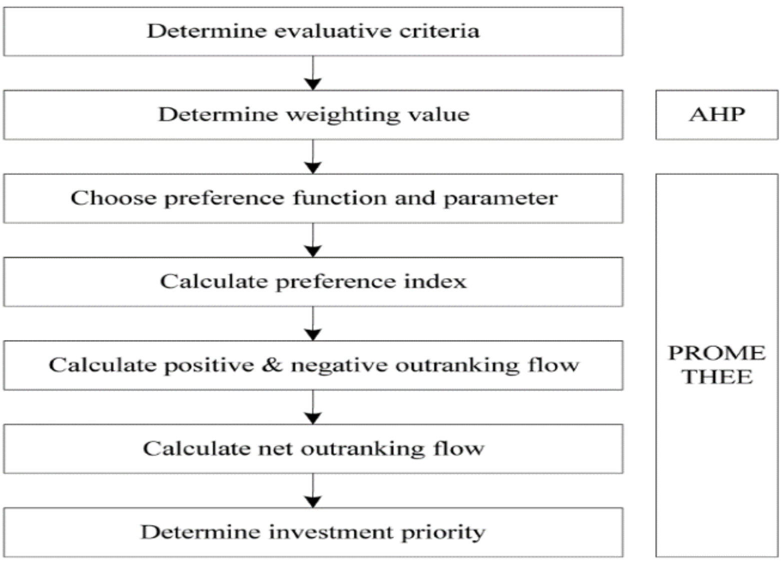
7.7.2 Application of PROMETHEE method

The PROMETHEEII technique uses positive outranking flow [φ^{+}(a)] & negative outranking flow [φ^{-}(a)] calculated by each evaluation criteria and weight of factors without the paired comparison between alternatives of investment list. Also derive the investment priorities from net outranking flow [φ (a) = φ^{+} (a) - φ^{-} (a)]. If detailed basic data such as investment costs are provided later as a result of technical diagnosis, it is believed that investment priority selection using this technique can be applied.

7.7.3 Ranking analysis procedure combining AHP and PROMETHEE

Finally, it would be optimal to use procedures that combine the advantages of AHP and PROMETHEE techniques, such as Figure 11, for investment priority decision making.

Figure 11. Ranking analysis procedure by combining of AHP and PROMETHEE



8. Proposal of Management Level Evaluation (MLE)

8.1 Purpose of proposal

Currently, there is a problem with the lack of level evaluation of the performance, effort and management level of the management department for five years on the need for improvement according to the results of the previous technical diagnosis in the waterworks technical diagnosis manual. It is necessary to provide alertness for stable water supply network management by providing feedback to the management department on improvement efforts based on the list of improvement needs presented in the previous diagnosis results.

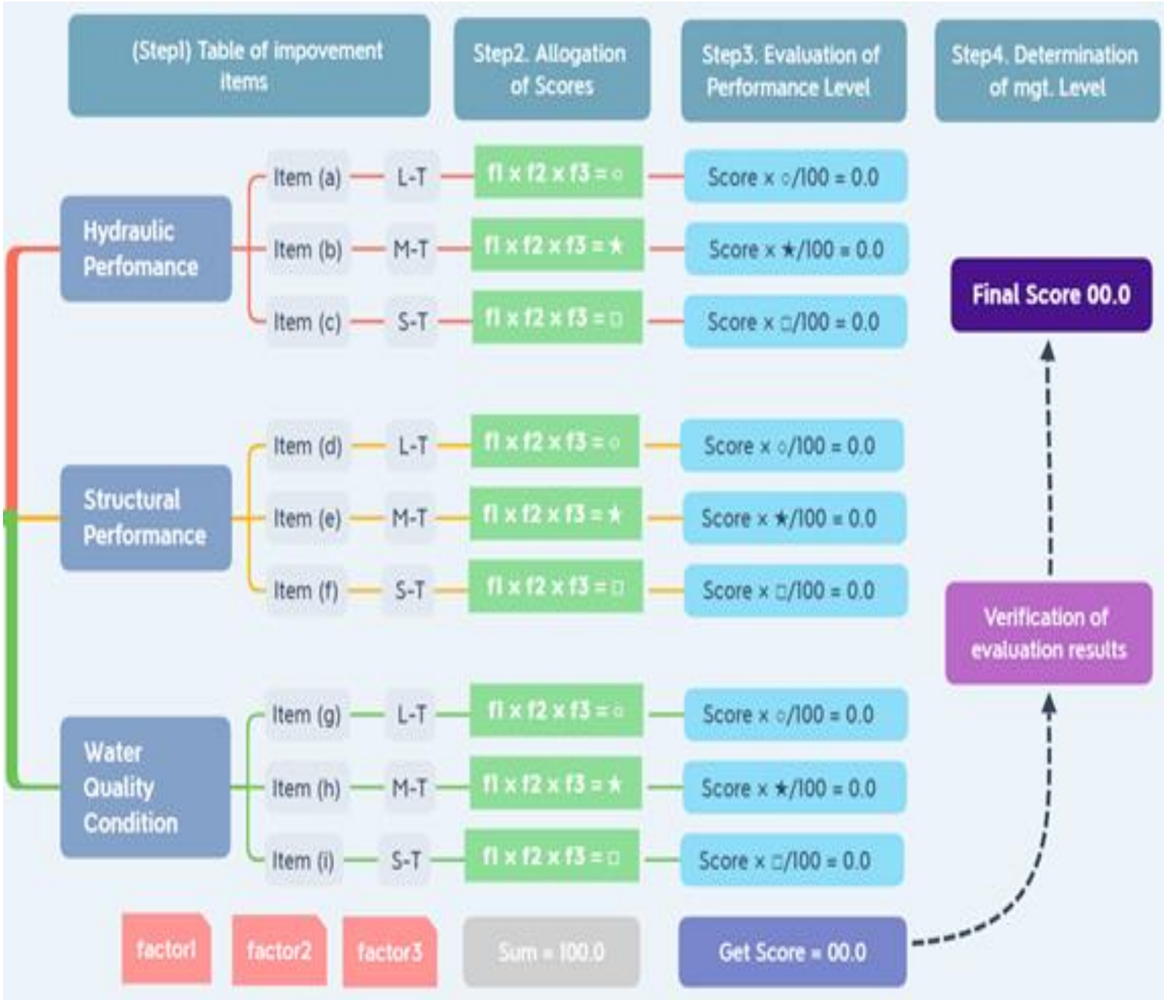
8.2 Prerequisites

In order to evaluate the level of management, systematic performance management should be preceded by detailed data for the specification of assessment indicators and the calculation of points of those indicators so that performance comparison can be made. Therefore, the organization should add and implement provisions to systematically stack the data in the company regulations or manuals.

8.3 Concept of procedure for Management Level Evaluation (MLE)

Evaluating the management level is a matter that can never be taken favorably by the department concerned. However, prevention efforts are needed more than anything else because the impact of water supply network facilities is far beyond imagination when an accident occurs. Considering the recent Incheon red water accident, systematic management is essential, and it is deemed essential to maximize performance by linking it with performance evaluation. The basic concept of MLE (Management Level Development) procedure is to be presented in 4 steps. The basic procedure of MLE is proposed by expressing it in Conceptual Map as shown in Figure 12. This merely presents its necessity and basic orientation, and the detailed procedure will have to be embodied through follow-up research.

Figure 12. Conceptual Map of model in Management Level Evaluation



(Step1) Characteristics of factor

- **(factor1)** the weight factor of hydraulic/structure/water quality according to the scale of characteristics of the facility.
- **(factor2)** the weight factor according to the importance of improvement items.
- **(factor3)** the weight factor according to the time (short, medium and long term) required for important

(Step2) Scorecard

- Distribute the total score of the investment plan for the entire facility to be 100 points, taking into account the weight factors.

(Step3) Evaluation Criteria

- Score acquisition is given on the basis of 100 points, varying by level of execution, such as improvement completion, budget security, planning, and basic survey by item.

(Step4) Determination Mgt. Level

- According to the final score of the acquisition, it is determined by class of "Very poor ~ very good"

9. Conclusion

9.1 Main conclusion of study

9.1.1 Decision method of investment priorities

Previously, the facility management department was making unplanned and entertaining facility investments because the technical diagnosis report did not provide efficient budget investment measures for the management department, and the systematic and accident prevention facility management was insufficient.

In this study, the Key Factors were determined by reassessing the key factors to determine the reasonable weight of the Key Factors, which is the most important of the assessment for investment priority decisions, and the detailed evaluation criteria for each factor were presented. In addition, I derive and present Weight of Factors that reflects the opinions of K-water experts through AHP techniques. Finally, I propose to introduce a PREMETHEE technique, one of the MCDM (Multi-Criteria Decision Making) techniques, by reviewing past similar research cases as a method for selecting investment priorities.

Through this study, I believe that by presenting efficient investment priority methodologies and procedures for water supply network facilities that need to be improved, this study will maximize the utilization of water supply technical diagnosis conducted every five years and contribute to the stable supply of multi-regional water and crisis prevention.

9.1.2 Proposal of Management Level Evaluation (MLE)

It was also the limitation of government organizations such as public institutions and public enterprises in the past that did not easily detect internal organization's performance and errors. However, considering the ever-growing scale of physical and mental damage in the event of a crisis such as the recent Incheon Red Water, it is also necessary to actively accept the concept of Internal Control.

From this perspective, it was proposed to introduce a Management Level Evaluation (MLE) to ensure that members of the organization can be more transparent and actively implement public administration by conducting a fair management level evaluation of the facility management department and disclosing it internally and externally.

9.1.3 Additional proposals on improvement of technical diagnosis

The water quality sector, such as red water and larvae, which have recently become issues, is conducting water safety and volatility evaluations in technical diagnosis, but the reliability and utility are low due to the use of existing data and a small number of sampling. Therefore, it is necessary to review red water risk areas, filter test equipment, and long-term data acquisition and analysis using Resuspension Potential Method (RPM) techniques to examine the risk of accumulating low velocity sediment and the risk of turbidity.

In the long run, the water supply system needs to be expanded to a comprehensive diagnostic concept to derive and improve overall facility management and operational problems of the water supply system, such as water intake, water treatment, and pumping stations.

9.2 Suggestions for follow-up research

9.2.1 Limitations of study

In order to verify the validity of the investment priority decision-making procedure in this study, it is most appropriate to verify the entire process based on the completed technical diagnosis report of water supply network facilities, but the current technical diagnosis report does not contain detailed data on the key factors required for the new model. In order to verify this, it is deemed that the overall enactment and revision of laws, standards, regulations, and manuals related to technical diagnosis of water supply network facilities should be preceded.

In addition, the proposal to introduce a Management Level Evaluation (MLE) for a facility management department may be opposed by the department because it contains the concept of performance assessment for the management department, which is likely to be a mere formality, even if applied in the future. It is also believed that institutional supplementation should be preceded.

9.2.2 Suggestions of follow-up research tasks

First, a follow-up research is needed to verify the entire procedure using a combined technique of AHP and PREMETHEE after completing a technical diagnosis report with data accumulated to apply a new model of investment priority evaluation.

Second, it is needed to design and verify detailed model for Management Level Evaluation (MLE) about the facility management department.

Third, in order to determine the conditions of aged pipes and improve accuracy, management of ordinary maintenance activities, such as failure pipe data, can be used to determine the amount of irrigation that reflects them. However, due to the lack of a framework to collect and manage these data effectively and extensively, follow-up research is also considered necessary.

Finally, it is needed on how to establish a computerized system for technical diagnosis performance management to enable historical management of the entire process, including systematic technical diagnosis results, improvement, and re-evaluation.

References

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Appendix

Appendix 1. Scope and main contents of Technical Diagnosis of Water Supply Network Systems

Sortation	Scope of task	Main content
Basics and Status Data	Design of pipe network MAP	Check the status and maintenance status of the pipe network chart
	Block System Establishment	Check compliance and maintenance status of block system construction
	Pipe Network Related Civil Petitions	Inspection of causes and solutions for pipe network-related complaints
	Network-based organization and staff management	Management of network-only organizations and inspection of operation status
Facilities	Distribution Reservoir Facilities	Inspection of management status and maintenance status of distribution reservoir facilities
	Pipe Body	Determining maintenance status and obsolescence
	Pump Facility	Check pump facility management status and maintenance status
	Valves	Check the status of valves and maintenance of facilities
	Fire hydrant	Inspection of the status of fire hydrant facility management and maintenance status
	Decompression facility	Check the status of management and maintenance of the pressure relief facility
	Other Required Facilities	Inspection of additional necessary facilities based on the judgment of other water service operators
Maintenance	Rate of accounted water	Inspection on current rate of accounted water and maintenance method
	Water pressure management	Inspection of current status and maintenance methods of water pressure management
	Leakage management	Inspection of current status and maintenance methods of water leakage management
	Service connection Facilities management	Inspection of water quality management status
	Rehabilitation of old facilities	Maintenance and rehabilitation of old facilities
	Measuring Instrument Management	Inspection of measuring instruments and maintenance status
	Water cut-off	Check the status of water cut-off and actions taken in case of water cut-off
Emergency Response Capability	-	Inspection of operation and planning status of facilities in case of emergency
System diagnostics	Transportation and Distribution facilities	State Diagnosis of the Whole Transportation and Distribution System
	Facilities	Diagnosis of the status of each facility (by block) system

Appendix 2. . In-depth interview questionnaire

Index	Contents
General Information	**Q1. Personal Information of Interviewee** · Name, Current assigned task, Career and participation period
In-depth Interview	**Q2. What are your opinions on the problems/improvements of the water supply technical diagnosis implementation system?** Q2-1. What is required to add or exclude technical diagnosis items? (e.g. Excluding duplicate items from precision safety diagnosis, Adding SWG(Smart Water Grid)) Q2-2. What are the problems or improvements of the technical diagnosis evaluation method? Q2-3. What is the need for improvement in terms of regulation or process?
	Q3. What is the experts/executive's opinion on my capstone project? Q3-1. What is your opinion on giving priority to investment in the technical diagnosis conclusion? Q3-2. What is your opinion on the addition of an effort level assessment to the management department based on past diagnosis results in the technical diagnosis report?
	Q4. What is your opinion on the direction of the analysis model development? Q4-1. What are the opinions or improvements to the approach of the analysis methodology? Q4-2. Can you suggest the best methodology you think of? Q4-3. What do you think should be the most important part of the analysis model?
	Q5. What is the need for further improvement in order to improve the performance of technical diagnosis and enhance the availability of the business?

Appendix 3. Paper of AHP Survey

Survey on AHP Evaluation of Weight of Key factors for making decision Investment Priorities for Improvement of Facilities based on the Results of Water Supply Network Facilities

This survey is to comprehensively evaluate Weight of Key factors for making decision investment priorities for improvement of facilities based on the results of water supply network facilities by using AHP (Analytic Hierarchy Process) method. Please answer each question from the perspective of a specialist. Careful response is requested as inconsistent response may cause the survey to be conducted again.

Department: ____________________
Name: ___________________________

AHP (Analytic Hierarchy Process) is

The decision-making method that comprehensively evaluate the feasibility of the project by stratifying considered evaluation items and estimate their relative level of importance.

◉ How to Answer Survey Questions ◉

1. This questionnaire is intended to determine the proper weight of the Key Factor selected by the researcher.
2. The comparison of evaluation items is to evaluate the relative importance (or aptness) of evaluation criteria A compared to B.
3. Please read the evaluation guidelines, structure, and details, and summary of the study given each page before answering the questions.

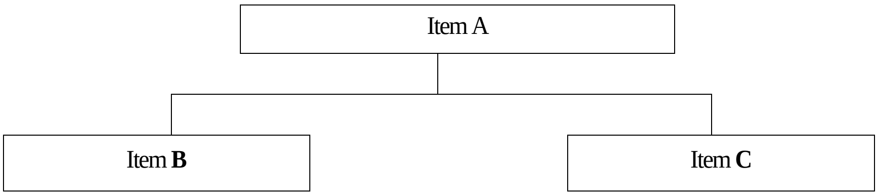
1. Note for Survey Questions

1. Answering example

Ex) If you think an item B is <u>very important</u> than item C based on criteria of item A, then mark as below example.

evaluation item	absolutely important		very important		important		moderately important		Equal		moderately important		important		very important		absolutely important	evaluation item
item B	⑨	⑧	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	⑧	⑨	item C

[Figure 1] Evaluation example



2. Degree of consistency in answers

□ In AHP analysis, the degree of consistency in answers is represented as an ‘inconsistency ratio.’ If an inconsistency ratio is **0.15 or higher**, consistency is lacking and suggesting the need for re-study. There are two causes of higher inconsistency ratio.

> Ex) 1. A > B: A is 2 times more important than B
>
> 2. A ≫ C: A is 4 times more important than C
>
> → should respond B > C

[Cause 1] Lack of ordinal consistency: change of order A > B > C in response

[Cause 2] Lack of cardinal consistency: in case B is 9 times more important than C in response of example above

2. Background of survey (Summary)

The following points summarize the main purpose and direction of this research. Please refer to this and respond to the survey.

1. Background

The importance of managing the water supply network system is significant, as the proportion of accidents in various management facilities accounts for 45% (2019). The need for systematic management of the water supply network has emerged as a result of the Incheon Red Water Crisis (2019), and national projects such as the local water supply modernization project have been actively carried out. **Therefore, systematic investment decision making is essential**.

2. Problems

1) Technical diagnosis of water supply network system, which is mandatory every five years under the Waterworks Law, lacks systematic management.
   - Just the fulfillment of legal obligations.
   - Lack of systematic management, including diagnostic results/improvement history.
2) **Lack of priority for mid to long-term facility investment based on technical diagnosis results.**
3) Lack of level evaluation for facility management department's efforts to improve based on technical diagnosis.

3. Project objectives

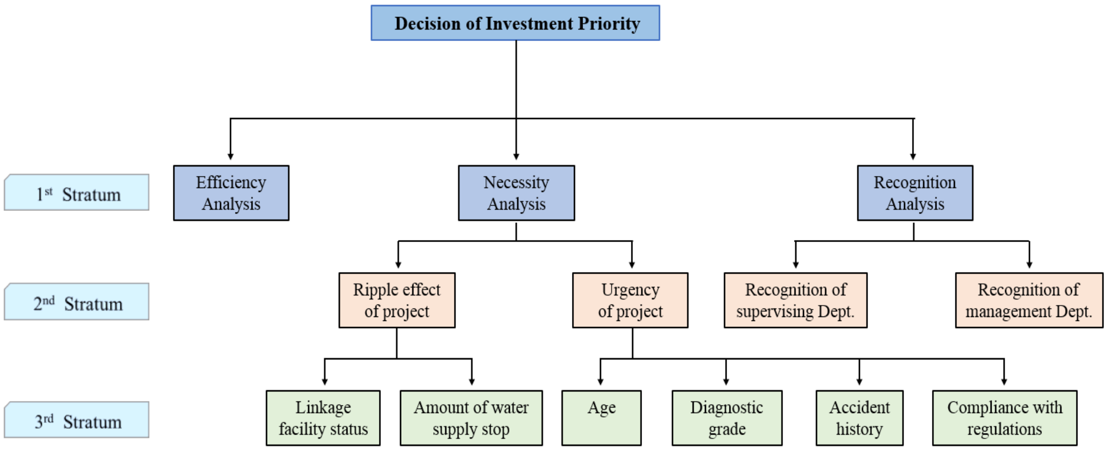
1) **Development and case verification of methodologies to select mid- to long-term facility investment priorities based on technical diagnosis results.**
   - Current diagnosis results suggest problems and only investment priorities according to water pipes deterioration.
2) Development and case verification of methodologies of level evaluation for facility management department's efforts to improve based on technical diagnosis.
3) Suggestion: Finding and Proposing the Improvement of current system and standards for the Technical Diagnosis of Water Supply Network Systems.

4. Key improvements

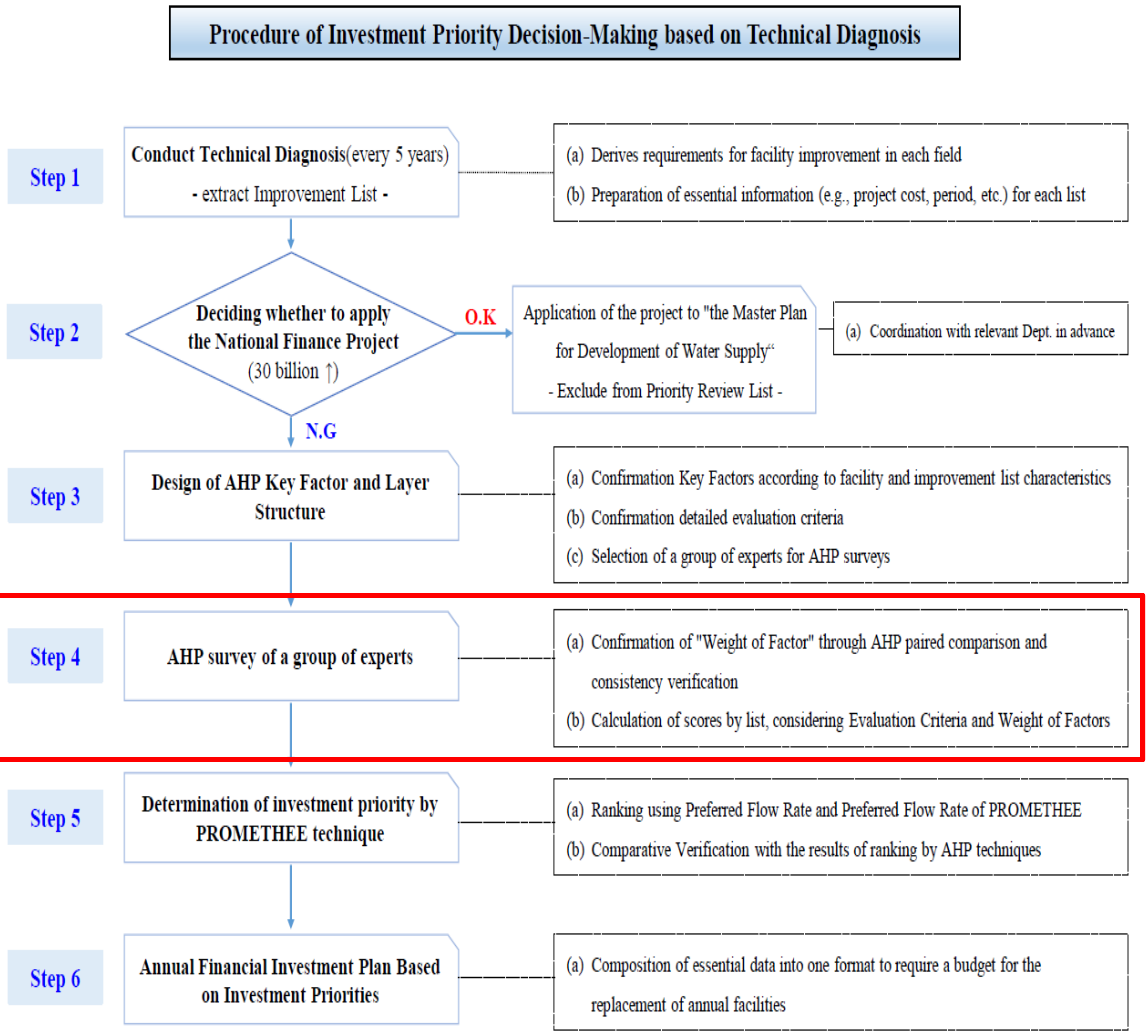
	As - Is	To - Be
Management Level Evaluation	· Not exist improvement level evaluation method (Facility department's effort?)	· Provision of management level (Including improved details over the past 5 years)
Investment Priority	· Not exist investment plan to improve facility (Including improvement cost)	· Proposal of investment priority (Including approximate cost provision)
Management by System	· Not exist history of diagnosis results and improvement	· Operation of the integrated facility diagnosis/history management system (e.g. Precision safety diagnosis)

5. Overview of this AHP Survey

1) In determining the priority of investment in the list of facility improvements based on the results of the technical diagnosis of the water supply network facilities, the following key factors are defined in accordance with the AHP hierarchy and reasonable weights are determined for each key factor.



2) **The New Model of Investment Priority Decision-Making Procedure**



3) **Detailed evaluation criteria for each key factors**

- It's separate from this AHP survey, so just keep that in mind.
- Once the Key Factor of each layer is determined as a result of the survey, the investment priority is determined based on the evaluation criteria below by each factor, and the final score of the investment is applied.

(a) Efficiency Analysis

Stratum	· 1st Stratum
Definition	· Prevention of water supply stop and evaluation of stable supply through retrofitting of existing facilities or new construction
Evaluation Standard	· **Calculation** - (Existing facility) Amount of water supply stop(1,000 ㎥/day) / Cost(billion won) - (New facility) Supply expansion(1,000 ㎥/day) / Cost(billion won) · **Score** (5 point scale)

Result	$X \geq 0.1$	$0.1 > X \geq 0.08$	$0.08 > X \geq 0.06$	$0.06 > X \geq 0.04$	$X < 0.04$
Score	5 point	4 point	3 point	2 point	1 point

(b) Recognition of supervising dept.

Stratum	· 2nd Stratum
Definition	· Recognition of the importance of the project by the supervising department of facilities
Evaluation Standard	· **Calculation** - Scoring based on level of recognition of necessity through survey of the supervising dept. · **Score** (5 point scale)

Result	Absolutely important	Important	Ordinary	Unnecessary	Absolutely unnecessary
Score	5 point	4 point	3 point	2 point	1 point

(c) Recognition of management dept.

Stratum	· 2nd Stratum
Definition	· Recognition of the importance of the project by the management department of facilities
Evaluation Standard	· **Calculation** - Scoring based on level of recognition of necessity through survey of the management dept. · **Score** (5 point scale)

Result	Absolutely important	Important	Ordinary	Unnecessary	Absolutely unnecessary
Score	5 point	4 point	3 point	2 point	1 point

(d) Linkage facility status

Stratum	· 3rd Stratum
Definition	· Items according to the existence of emergency linkage facilities in the event of an accident.
Evaluation Standard	· **Calculation** - Scoring based on the presence or absence of linkage facility. · **Score** - (Existing linkage facility) 1 point, (No existing linkage facility) 5 point

(e) Amount of water supply stop

Stratum	· 3rd Stratum
Definition	· Granting evaluation points according to the amount of damage caused by water supply stop.
Evaluation Standard	· **Calculation** - Amount of water supply stop(1,000 ㎥/day) / Usual amount of water supply(1,000 ㎥/day) · **Score** (5 point scale)

Result	X ≥ 0.5	0.5 > X ≥ 0.4	0.4 > X ≥ 0.3	0.3 > X ≥ 0.2	X < 0.2
Score	5 point	4 point	3 point	2 point	1 point

(f) Age

Stratum	· 3rd Stratum
Definition	· Grading by age according to the criteria for judging old pipes.
Evaluation Standard	· **Calculation** - Base year (0000 year) - Installation year + 1 · **Score** (5 point scale)

Result	X ≥ 45	45 > X ≥ 35	35 > X ≥ 25	25 > X ≥ 15	X < 15
Score	5 point	4 point	3 point	2 point	1 point

(g) Diagnostic grade

Stratum	· 3rd Stratum
Definition	· Grading according to the diagnostic grade given by the results of the technical diagnosis.
Evaluation Standard	· **Calculation** - Base year (0000 year) - Installation year + 1 · **Score** (Application to the higher score among the two evaluation results)

1. Evaluation of pipe condition

Result	Grade Ⅲ	Grade Ⅱ	Grade Ⅰ
Score	5 point	3 point	1 point

2. Evaluation of safety about water quality

Result	Grade Ⅳ	Grade Ⅲ	Grade Ⅱ	Grade Ⅰ
Score	5 point	3 point	2 point	1 point

(h) Accident history

Stratum	· 3rd Stratum
Definition	· Grading based on the number of accidents that occurred within the last 10 years.
Evaluation Standard	· **Score** (5 point scale)

Result	X ≥ 5	5 > X ≥ 4	4 > X ≥ 3	3 > X ≥ 2	X < 2
Score	5 point	4 point	3 point	2 point	1 point

(i) Compliance with regulations

Stratum	· 3rd Stratum
Definition	· Grading based on compliance with relevant laws and regulations.
Evaluation Standard	· **Calculation** - Scoring based on the presence or absence of non-compliance with regulations. · **Score** - (Existing non-compliance) 5 point, (No existing non-compliance) 1 point

3. Survey for AHP Evaluation (Weighting)

■ **[Survey I]** AHP hierarchy structure to determine the relative importance between the first layer of the AHP hierarchy, efficiency analysis, necessity analysis, and recognition analysis. Please consider carefully which factors are relatively more important in making this investment priority decision.

I. Please determine the relative importance among Efficiency Analysis, Necessity Analysis, Recognition Analysis. (The total score must be 100. ex) 25: 50: 25)

- Please answer within **Scope of Preliminary Weight** Calculation in <Table 1>

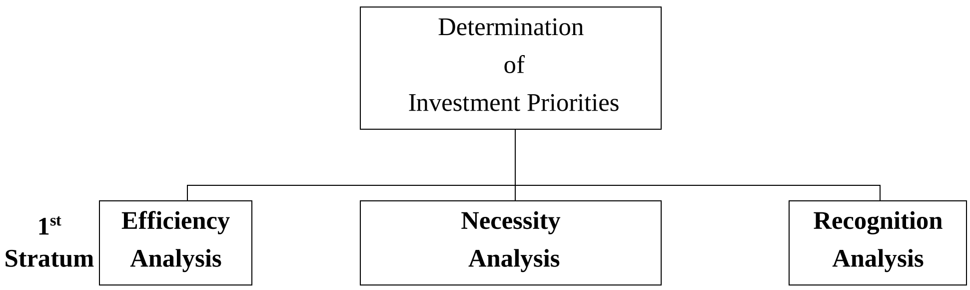
Efficiency Analysis: Necessity Analysis: Recognition Analysis = ______ : ______ : _____

<Table 1> Scope of Preliminary Weight Calculation

(Unit: %)

Efficiency Analysis	Necessity Analysis	Recognition Analysis
20 ~ 30	35 ~ 55	15 ~ 30

[Figure 1] Relative Importance of First-stratum

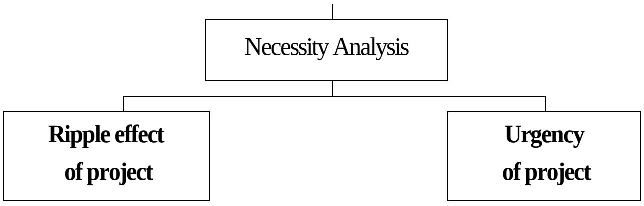


■ **[Survey Ⅱ]** the following questions II is intended to determine the level of relative importance of second-stratum evaluation items. Please answer each question carefully from the perspective of a specialist.

Ⅱ-1. Relative Importance in Second-stratum (based on Necessity Analysis)

Evaluation Item	absolutely important		very important		important		moderately important		Equal		moderately important		important		very important		absolutely important	Evaluation Item
Ripple effect of project	⑨	⑧	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	⑧	⑨	Urgency of project

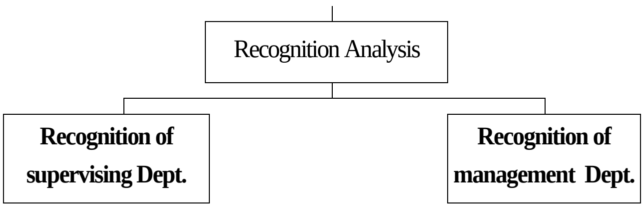
[Figure 2] Relative Importance of Second-stratum (Necessity Analysis)



Ⅱ-2. Relative Importance in Second-stratum (based on Recognition Analysis)

Evaluation Item	absolutely important		very important		important		moderately important		Equal		moderately important		important		very important		absolutely important	Evaluation Item
Recognition of supervising Dept.	⑨	⑧	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	⑧	⑨	Recognition of management Dept.

[Figure 3] Relative Importance of Second-stratum (Recognition Analysis)

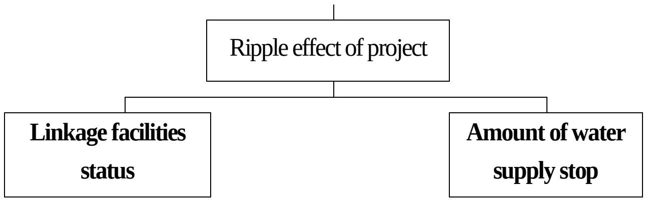


■ **[Survey Ⅲ]** the following questions Ⅲ is intended to determine the level of relative importance of third-stratum evaluation items. Please answer each question carefully from the perspective of a specialist.

Ⅲ-1. Relative Importance in Third-stratum (based on Ripple effect of project)

Evaluation Item	absolutely important		very important		important		moderately important		Equal		moderately important		important		very important		absolutely important	Evaluation Item
Linkage facilities status	⑨	⑧	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	⑧	⑨	Amount of water supply stop

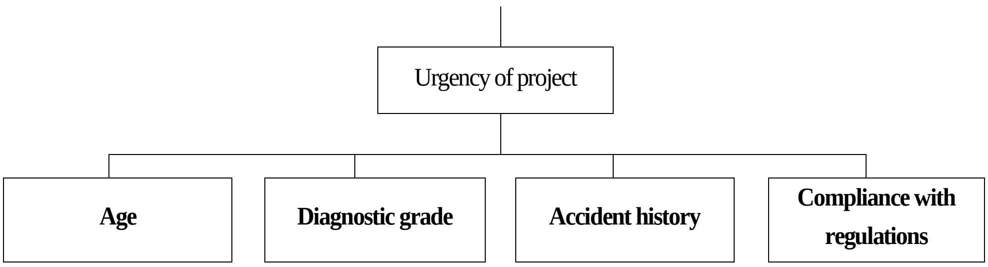
[Figure 4] Relative Importance of Third-stratum (Ripple effect of project)



Ⅲ-2. Relative Importance in Third-stratum (based on Urgency of project)

Evaluation Item	absolutely important		very important		important		moderately important		Equal		moderately important		important		very important		absolutely important	Evaluation Item
Age	⑨	⑧	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	⑧	⑨	Diagnostic grade
Age	⑨	⑧	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	⑧	⑨	Accident history
Age	⑨	⑧	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	⑧	⑨	Compliance with regulations
Diagnostic grade	⑨	⑧	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	⑧	⑨	Accident history
Diagnostic grade	⑨	⑧	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	⑧	⑨	Compliance with regulations
Accident history	⑨	⑧	⑦	⑥	⑤	④	③	②	①	②	③	④	⑤	⑥	⑦	⑧	⑨	Compliance with regulations

[Figure 5] Relative Importance of Third-stratum (Urgency of project)



◈ Thank you for participation!! ◈