A Study on the Establishment of Autonomous Operation System for Data-Based Water Purification Facilities

By

PARK, Daewon

CAPSTONE PROJECT

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

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Committee in charge:

Professor Lee, Junesoo, Supervisor Junesoo Lee

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ABSTRACT

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This research paper aims to lay the foundation for the establishment of a data-driven water purification plant autonomous operation system by presenting how to generate and transmit the underlying measurements of the data and manage the acquired data. It also identified the role required for operators who work 24 hours a day at the water purification plant to settle down stably when introducing an autonomous operation system for water purification plants.

For this study, papers and data related to automatic operation of water purification plant s and smart factories were collected and analyzed, and in-depth interviews with K-water's rela ted business experts were conducted to identify problems and needs. Based on this, the directi on that should be preceded to establish an autonomous operation system in the water purificat ion plant was presented.

Finally, I think this study is meaningful in laying the foundation stone so that it can be studied and developed in a more improved way rather than a methodology that enables the establishment of a water purification plant autonomous operation system.

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1. Introduction

With the global trend of Corona 19, interest in digital transformation and non-face-to-face technology is increasing. In K-water, which operates national infrastructure, technology for normal operation of water purification facilities and stable supply of tap water has emerged as a hot topic in the event of infection of operators operating water purification plants such as Corona 19. In addition, as information and communication technologies, artificial intelligence, big data, and hyper connection technologies are rapidly developed, information and communication technologies and fourth industrial revolution technologies are used in the public service sector to solve various social issues. K-water also strives to introduce an autonomous operation system of water purification facilities by combining information and communication technology and artificial intelligence.

K-water has installed and operated facilities, and equipment in its water purification plant in accordance with various operating environments across the country. Operators are conducting regular remote monitoring and control of facilities and equipment installed in the entire process of producing and supplying tap water through the standard water operation system (iWater).

The monitoring and control of the water purification plant is carried out based on the decision of the operators, resulting in operational deviation depending on the capacity of the operator. Experienced operators with various experiences and many know-hows respond quickly to accidents both large and small, but new operators sometimes develop them into big accidents because they cannot cope with even a little problem. According to an analysis of multi-regional water supply accidents, Lee (2020) believes that automation and intelligence on crisis response are urgently needed as 43 accidents occur on average in multi-regional water supply, and inundation accidents, power outages, and chemical leakages.

Table 1. Analysis of multi-regional water supply system accidents

	Sum	Pipe accident	Water quality	Waterworks accident								a human accident
				Sum	Electricity	Flooding	Fire	Communication	Chemical leakage	Flooding Disorder	Facility accident	
Number of Crisis	342	181 (52.9%)	125 (36.5%)	30 (8.8%)	11 (3.2%)	8 (2.3%)	1 (0.3%)	2 (0.6%)	1 (0.3%)	5 (1.5%)	2 (0.6%)	6 (1.8%)

The problem is that K-water has continued to invest in automation and intelligence of water purification plants. For the automation of water purification plants, improvements were derived by defining and evaluating automation levels for each process, and system development was also implemented, such as intelligent alarm systems for abnormal situations to diagnose alarms and suggest ways to action.

However, the expected results have not been achieved. Therefore, this study seeks to approach one main question and three sub-questions. The main question is, "What should be preceded by the establishment of a waterworks autonomous system?" First, "Why is it difficult to complete automatically operate the entire process of the tap water production and supply?" and secondly, "How should data be collected and managed?" and finally, “What is the role of future operators following the introduction of an autonomous water purification plant operation system?”

The scope of this study is to analyze why it is difficult to fully automate the operation of water purification facilities and to establish an autonomous operation system, and to provide directions for improvement.

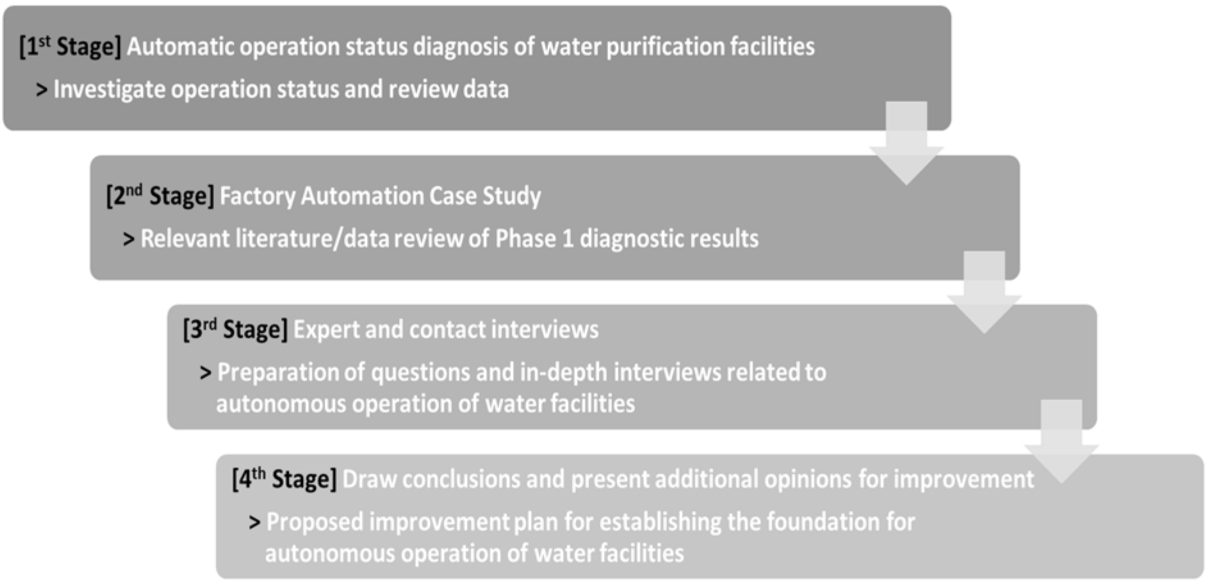
The results of this study are likely to be able to present areas that should be carried out preferentially for the establishment of an autonomous operating system for water purification facilities. This will support the establishment of a stable autonomous operating system, and this will resolve the operational deviation of operators in the future and enable rapid accident response.

2. Methodology of study

2.1. Procedure of study

In establishing the overall direction of access to research topics and procedures for implementation, the following research procedures were carried out in four stages (figure 1). Various logical thinking techniques were applied to the progress of each step to conduct existing literature research and related data collection and analysis more systematically and rationally, and the previous step's procedures were repeatedly reviewed if supplemented. In addition, in-depth interviews with experts in the relevant field of K-water were conducted to derive problems through classification and analysis and present improvement measures.

Figure 1. Procedure of this study



2.2. Data collection

2.2.1. Interview

The purpose of the In-depth Interview was to identify the requirements for establishing a waterworks autonomous operation system through interviews with K-water internal experts and personnel related to the research topic, present the overall direction and methodology of the study.

2.2.2. When to interview

Originally, it was planned for the first interview on the direction before the study materialization and the second in-depth interview after the design of the model, but it was replaced by an in-depth interview (written) based on the specifics of the research process depending on the COVID-19 situation.

2.2.3. Who (target) to interview

In-depth interviewees were selected and conducted by six K-water internal experts. The K-water Institute selected two experts in charge of the development of artificial intelligence technology and four people in charge of the automation of water purification facilities at the water purification plant to collect opinions on the problems and improvement direction of the autonomous operation system.

Table 2. In-depth interviewee list

Experts of the AI research Dept. & Facility Operation Dept. in K-water	
AI research Dept. (2)	Facility Operation Dept. (4)
Senior Manager (2)	Senior Manager (3), Manager (1)

2.2.4. Key questionnaire

Through this study, I would like to identify various key issues for the introduction of an autonomous operation system for water purification facilities and suggest ways to improve them.

(Key) Establishing a Foundation for Autonomous Operation System

1) Why is it difficult to carry out fully automatic operation of the entire tap water production and supply process?
2) What is necessary for a water purification plant autonomous operation system to settle reliably?

3) What is the role of future operators following the introduction of an autonomous water purification plant operation system?

2.3. Data analysis

2.3.1. Content analysis

Through classification and analysis of this interview, we would like to discuss key issues discovered by experts and personnel related to the autonomous operation system of water purification facilities.

3. Literature review

Future smart water purification plant building strategy based on 4th industrial technology (K-water, 2020)

Shin Dong-ki (2020) specifies that smart water purification plants are needed to solve difficulties in responding to various types of water accidents and minimize efficient facility management and management costs and suggests four tasks to realize smart water purification plants.

First, the Factory Energy Management System (FEMS) should generate demand forecasting models through monitoring and analysis of real-time power consumption using various sensors and artificial intelligence technologies and facility operation patterns. This resulted in a 4% power cost reduction by applying it to the K-water Boryeong Water Purification Plant in 2017 and contributed to securing stability by equalizing different operating patterns for each operator.

Second, smart safety management. The latest information and communication technology is used to identify operators' risk situations in real time and enable rapid rescue of operators in danger. Safety rules shall be guided to operators at high-risk locations, and golden time shall be secured for prompt initial action by automatically sending an alert to safety management personnel when an accident occurs when they stay in a dangerous area for more than a certain time or when no movement is detected.

Thirdly, it is the preservation of facilities. The prediction conservation platform uses sensors (IoT) and artificial intelligence technologies for important facilities such as pump motors and wanted boards to monitor and analyze facility conditions in real time and self-diagnose anomalies to determine the timing of maintenance in a timely manner. It has been introduced to K-water Gwacheon booster pumping stations on a trial basis to monitor the status of pump operation efficiency, flow rate, pressure fluctuation, vibration, and bearing temperature, and to improve operational efficiency and stability by facilitating pre-detection of facility performance and failure signs.

Fourth is autonomous operation of water purification plants. The water purification plant autonomous operation system automatically determines major operating factors such as water purification finished water quantity and chemical injection rate based on big data and artificial intelligence platforms to increase response to human error and rapid water quality fluctuations. The autonomous operation of the artificial intelligence water purification plant, which is currently under a pilot project at the Hwaseong Water Purification Plant of K-water, is being promoted to operate by choosing whether to use autonomous operation to strengthen the stability of the facility. Each process is also being built to optionally enable artificial intelligence.

In Shin Dong-ki (2020), the task for building a smart water purification plant can be learn about the functional effects of smart water purification plants, and the role of private and government can be detailed to learn about cooperation by institution. However, the process automation level of water purification plants has been stagnant for a long time at a lower automation level than autonomous operation. In this study, I intend to present directions for establishing an autonomous operating system for water purification facilities through a review of the causes.

Korean version of New Deal, Data Network AI-based Data Dam for National Digital Transformation (NIA, 2010)

Park Moon-woo (2020) presents the concept and business details of Data Dam, a key task of the digital New Deal announced by the government, to overcome the global economic crisis triggered by the Corona 19 crisis and secure momentum for innovative growth.

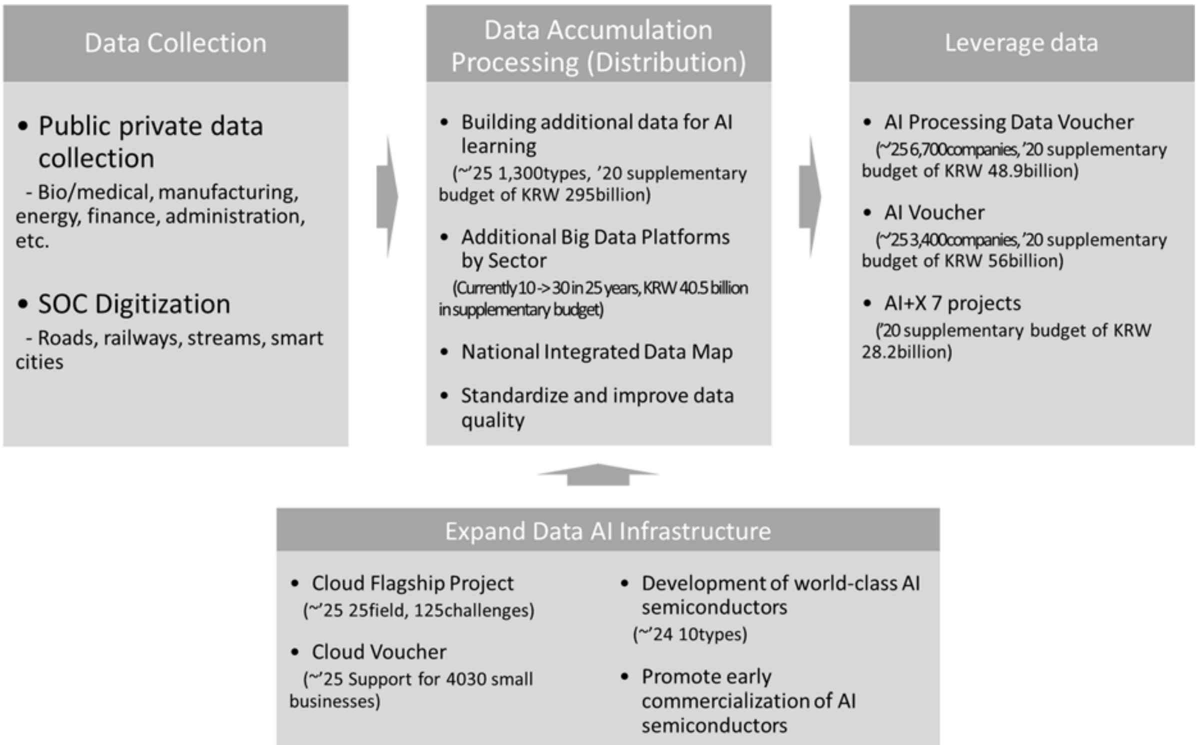
The purpose of the data dam is to accelerate the data economy by collecting, processing, combining, trading, and utilizing data, and to spread services that combine 5G mobile communication and artificial intelligence (AI) technologies. It is used in factories, homes and cities by making dams with water collected from various streams and producing electricity. Like this, it accumulates and analyzes data collected from various places to learn artificial intelligence. The learned artificial intelligence aims to create a digital infrastructure that will trigger innovation across industries and societies by utilizing it in factories (smart factories), homes (smart homes), cities (smart cities), education (smart education), and medical care (smart healthcare).

Data dams are intended to create a periodic value chain from data collection to distribution to utilization. Through this, the government intends to grow the data market from 16.8 trillion won as of 2019 to 30 trillion won in 22 years and 43 trillion won in 25 years. It is also planning to increase 5G penetration rate from 14.3% to 45% in 22 years and 70% in 25 years. It also announced that it will train 150 AI companies by 25 years and plans to invest 8.5 trillion won (7.1 trillion won) by 22 years, and 18.1 trillion won (15.5 trillion won) by 25 years.

Korean economy as well as society a whole is accelerating the transition from analog to digital. The importance and value of artificial intelligence (AI) are emphasized in solving various social problems and social innovation in the age of intelligence information, and data (Big Data) is emphasized as an important means of economic development.

Through this information, we need to think about how to collect, process, and utilize data. It is believed that it will be a motif to inform the importance of collecting, accumulating and appropriately utilizing high-quality data.

Figure 2. Activation of the data value chain



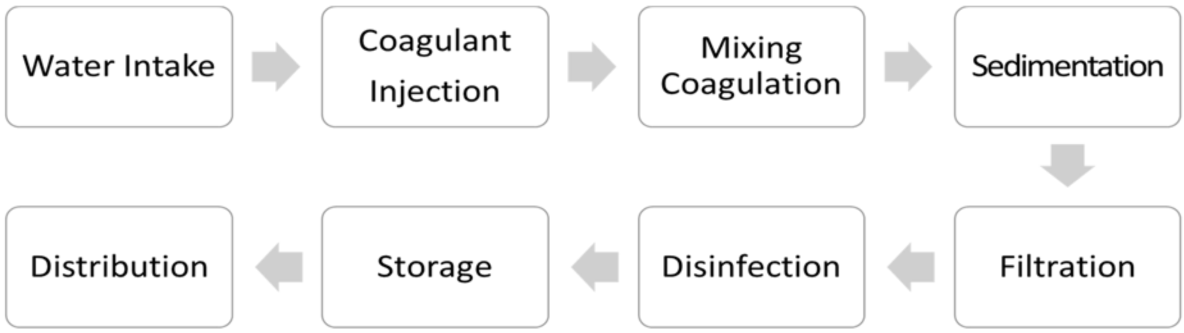
4. Overview

4.1 Process of tap water production and supply

Tap water is produced through each process of water intake, coagulants injection, mixing coagulation, sedimentation, filtration, disinfection and supplied to each consumer through pipes.

Water Intake station send water from rivers or dams to water purification plants through pumps or intake structures. Coagulant Injection is the stage of injecting coagulants to cause very fine particles to clump together into large particles. Mixing / Coagulation is a mixture of particles and coagulants to form flocs into large clump. Sedimentation settles out larger suspended particles and sends clear top water to the next process. Filtration collects pollutants floating in the water and removes the remaining fine particles and microorganisms. Backwash is implemented to clean the sand filter. Disinfection is to ensure the water free from disease-causing organisms. In this stage, chlorine is added into water to kill germs and microorganisms and ensure that the water is safe to drink and to protect public health after the water departs from the plant. After this process, the water will pump to the community (distribution) and the end of the water treatment process.

Figure 3. Water Treatment Process



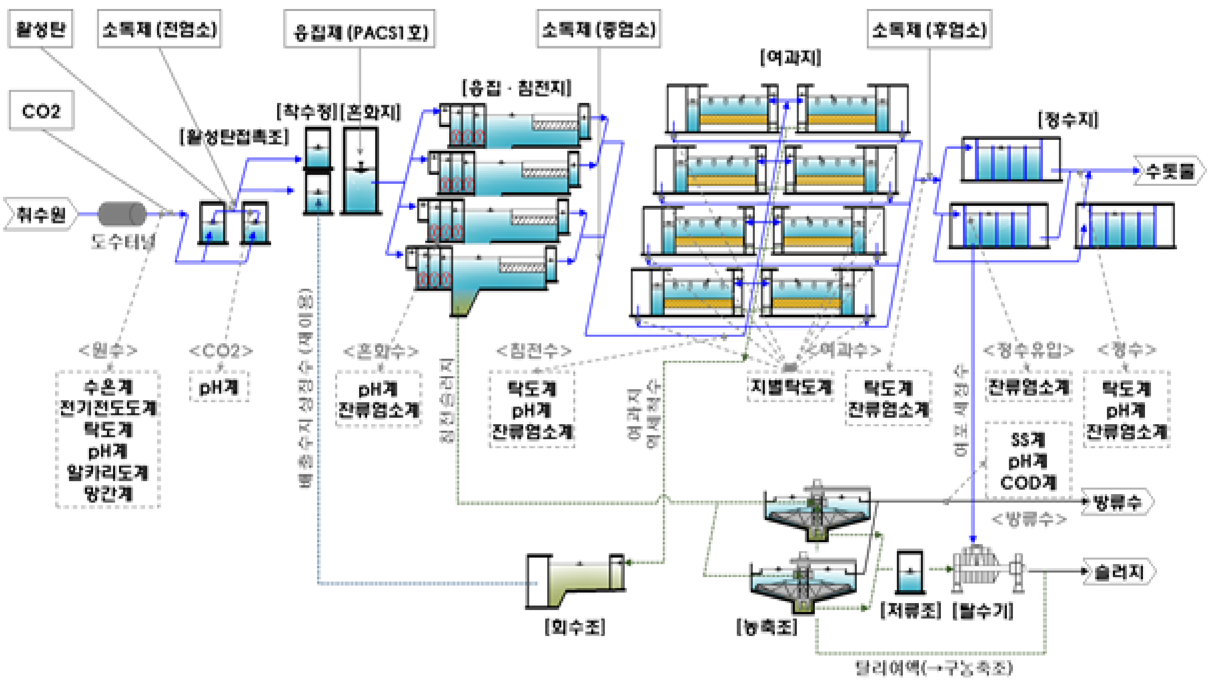
4.2 Status and targets of operation by process

The water intake process is manually operating facilities such as pumps and valves to determine the amount of water that is consumed and supply the amount that is determined. At this time, the desired water quality is obtained through manual selection of water intake depth or water intake point depending on the water quality of the raw water. Operation and shutdown of water intake pumps, selection of water intake gates, and control of valve are carried out manually for target water intake and water quality.

The gauging well manually adjusts the flow rate of raw water by considering the level of clear well and the amount of water purification production. It is going to manually select incoming valves and adjust valve for target raw water flow rate.

The coagulant injection process determines the appropriate coagulant input rate according to the raw water quality and flow quantity and injects the coagulant. Manual methods for determining coagulant input rates include "jar-test" that directly checks the input rate for the water quality of the raw water and "survey table" prepared by operating hours based on experience accumulated experiments. As an automatic method, the input rate is calculated according to the raw water quality through polynomials obtained by regression of raw water quality (turbidity, temperature, pH, alkalinity, etc.) and input rate. In addition, K-water has introduced and operated a pilot method of determining the input rate through artificial intelligence for autonomous operation of water purification plants.

Figure 4. Detailed operation status of unit process



The Mixing / Coagulation process manually determines the rotational speed by season or water quality, and manually operates the stirring speed at the site facility or remotely. The coagulator rotation speed is set to be slower from the mixed area to the sediment area, and in winter when it is not cohesive, the rotation speed is reduced than in summer.

During the sedimentation process, sludge, which is a mass of foreign substances, is discharged regularly. The discharge cycle is manually determined considering the amount of sludge by season and water quality, and the sludge collector operation and drawing valve operation by deposition are automatically carried out according to the determined cycle. At this time, the amount of sludge discharged is manually set and operated so that it can be adjusted to an acceptable amount in the discharge water treatment process.

The filtration process shall be operated by manually determining the quantity of filter operation and operation site in consideration of the level of clear well and the amount of water purification production. The filtration in operation is stopped according to the time set by experience or the filter head, and the filtration is automatically operation and various valve adjustments are performed when determining the backwashing (cleaning filter media). The filtration process is automatically carried out in a set order and time to ensure that run, stop and backwashing are determined and determined by operator's experience.

The disinfection process is chlorine-injected by feedback control or flow rate control according to the manual determination of residual chlorine concentration, which is the target of clear well inflow. The chlorine tanks and chlorine injectors used are manually determined by the operators, and in the case of feedback control, the system automatically adjusts the chlorine volume by comparing the target residual chlorine with the residual chlorine inflow.

The clear well is installed for the purpose of controlling the imbalance between the filtration volume and the amount of water transferred due to power failure or rapid change in demand when water is supplied by pumps or gravity and mixing chlorine.

In the distribution process, operators manually determine the supply amount according to the usage of the capacity and manually operate facilities such as pumps and valves to supply the determined volume. If the water from the water purification plant does not reach its final acceptance level, a booster pump is installed at the middle point to add strength. Facilities such as booster pumps and valves are operated manually. In order to supply targeted supplies, pump operation quantity and valve control are carried out manually.

4.3 Level of automation by process

In K-water, the level of control for each process is divided into four stages (completely automatic, automatic, manual, and field manual) and the level of automation is defined and operated.

Table 3. Comparison of technical diagnosis and precision safety diagnosis

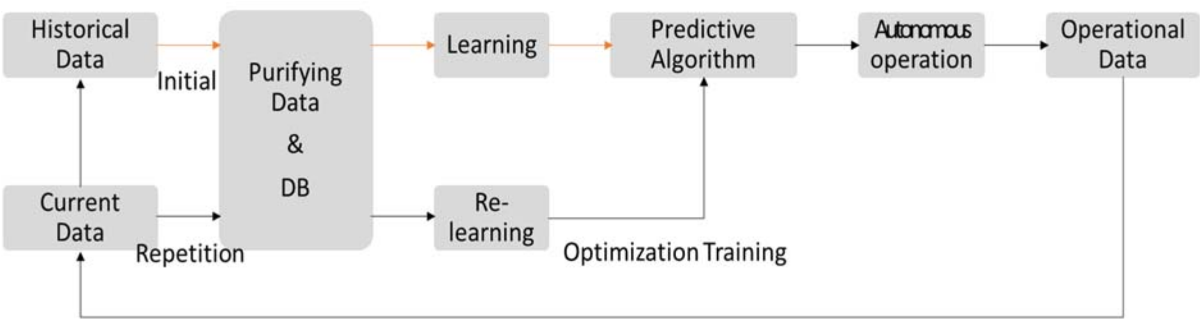
Process	Water Intake	Coagulant Injection	Mixing	Coagulation	Sedimentation	Filtration	Disinfection	Distribution
Current Automation Level	Manual	Manual	Auto	Manual	Manual	Auto	Auto	Manual
		View table Regression	Rotational speed control		Sequential operation	Operational Index	Feedback Control	
Standard control logic		Apply					Apply	

4.4 Status of introduction of autonomous operation of water purification plants

K-water is conducting a pilot project for the coagulant injection process of Hwaseong Waterworks to establish an AI-based autonomous driving system through big data analysis and prediction of waterworks.

In order to cope with rapid water quality changes and overcome the limitations of the injection rate of operators considering the survey table and operation experience, the chemical injection rate can be determined in real time by making decisions with artificial intelligence.

Figure 5. AI Machine Learning Type Diagram



It operated for 21 consecutive days for effect analysis under high turbidity (average 60NTU, maximum 303NTU) conditions and was able to verify fast water treatment stability. Compared to the sedimentation process turbidity in the past period, the operation stability was very good, with up to 1.08 NTU lower compared to the sedimentation process turbidity, and the AI coagulant injection rate was very good, given that the average value of sedimentation process turbidity fell 0.06 NTU even in high turbidity situations.

Figure 6. Data Analysis and Algorithm Processes

			Machine learning (supervised learning)		Machine Learning (Unsupervised Learning)	
	1. Pre-processing	2. Selecting Variables	3.Clustering/ Classification	4. Prediction	5. High turbidity response	6. Post-correction
Goal	Filter Data Extreme Value Processing	Select input variables, Analyze relationships between variables	Clustering/classification by similar properties	Clustering/ Classification Data-Driven Prediction	High turbidity data Make up for lack of learning	Unique Reflect Properties
Major content	Refine Data (1.3 million)	Final Four Selection	K-means 10 clustering	GBR Algorithm	Machine Learning+ Regression Prediction Model	Flow Link Target Calibration

When autonomous operation of coagulant was conducted, the amount of coagulant dosage could be reduced by 4.17% in general, and the amount of coagulant dosage has increased by 1.03% in high turbidity. However, as the goal is to treat high turbidity quickly, coagulant has increased, but water quality has been able to operate reliably.

It is expected that more stable autonomous driving will be possible by optimizing data pre-processing standardization and post-processing, improving reliability of water quality continuous automatic measuring devices, expanding remote monitoring control targets and supplementing measurement environments, and upgrading artificial intelligence algorithms.

Table 4. Operation status of artificial intelligence at Hwaseong Water Purification Plant

	Daytime Operations	*Day-Night Continuous Operations*
Operating Method	*Real-time chemical injection rate artificial intelligence control*	
Operating Period	*'20.8.6 ~ 8.12(7d) 09:00~18:00(9h)*	*'20.8.13 ~ 8.27(14d) 09:00~Next Day(9h)*
Operator	*Operation and daily inspection of other processes*	*Monitoring of emergency situations, operation of cuts, and daily inspection*

5. In-depth interview

Table 5. Main contents of in-depth interview results

Question Items	Main Opinions
■ **Understanding the measured value and operating the instrument**	✓ Measure items can be classified as **quantity and water quality** and have **different characteristics**. ✓ Measuring instruments **suitable for the installation environment** shall be installed and operated. ✓ The more measuring instruments, **the more accurate recognition** is possible. ✓ Secure stability by operating instruments **in duplicate**. ✓ Measured values shall be **digitized and transmitted**.
■ **Improvements in data production and management**	✓ In the case of data generated by sensors or instruments, the deviation or noise of the value is so large that it is used after various pretreatment processes. ✓ We cannot help but go through the pre-processing process, but we need **to make efforts to improve the quality of the raw data itself.** ✓ **Critical sensors or instruments need to be operated redundant**.
■ **Data Management Direction**	✓ Since the data generated by the waterworks is the value after the production and supply process of tap water, the utilization of the data is insufficient except for the limited process. ✓ In situations where data utilization is insufficient, data quality management has been performed in a later order than tasks that directly affect the production and supply of tap water. ✓ **It is necessary to manage data quality at all time through an organization and human resources dedicated to data management.**

- *Continued on the previous page* -

Question Items	Main Opinions
■ **Opinion on the role of operators in the introduction of an autonomous operation system**	✓ Needs the ability to combine autonomous operation system with existing standard water operation system (iWater). ✓ Continued initial response in the event of an emergency at night and on holidays. ✓ Initial correspondence to false and missing values.
■ **Matters to present and improve directions for the establishment of an autonomous operation system for water purification facilities**	✓ Since autonomous operation is based on data, it is important how well the **digital transformation** of the water supply facility is carried out. ✓ **Measures** are needed to **data the experience and know-how of operators.** ✓ **Need to train experts for data preprocessing and utilization**.

6. Establishing a foundation for autonomous operation system

6.1 Water Purification Plants Automation Level Analysis

6.1.1 Automation level status by water purification process

K-water defines the automation levels of water purification plants as shown in the table 6.

Table 6. Define Automation Level

Automation level	*Definition*
Fully automatic operation	*The accumulated operation information-based control logic program automatically determines the set value of the target factor and operates the facility interlocking operation.*
Automatic operation	*Operation linked to facilities by determining the set value of the target factor by the operator*
Manual operation	*Individual control of the facility in the central control room and in the field*
Manual operation on site	*Individual facility control in the field*

The level of automation by process of water purification plants operated by K-water is as shown in the table 7.

Table 7. Automation level status by water purification process

Process	Automation level	Automation content
Water Intake	*Manual operation*	Water intake control considering the level of the clear well and the production flow rate shall be operated manually by the operator according to the operation of the clear well level and the prediction of the water demand
Coagulant Injection	*Automatic operation*	Automatic operation in which the operator determines the target injection rate and sets it in the system for the stable operation of the chemical process, and the chemical injection facility is operated in conjunction with the operation thereof
Mixing	*Manual operation*	Manual operation in which the operator individually controls the mixer in the central control room or on-site due to low frequency of operation of the mixer
Coagulation	*Manual operation*	Manual operation in which the operator individually controls the coagulator in the central control room or on-site due to low frequency of operation of the flocculator
Sedimentation	*Automatic operation*	Automatic operation of the sludge collector and the drawing valve in conjunction with the operation time determined by the operator and the limit switch for the proper discharge of sediment sludge
Filtration	*Automatic operation*	The operator determines the filter index and the time of station influence, and the station influence process automatically operates the pump and valve facilities in conjunction with the control logic
Disinfection	*Fully automatic operation*	Feedback control is provided to optimize the operation of different disinfection processes according to the operator's work proficiency. The target injection rate is automatically corrected by feedbacking residual chlorine at the rear end through control logic. Fully automatic operation with chlorine injection facility interlocking.

6.1.2 Efforts to increase the Automation Level

In order to increase level of automation of water purification plants, K-water has been strengthening functions and stability of water purification systems. The standard water operation system (iWater) program for facility remote monitoring and control was redundant and synchronized at the water purification plant, supplemented communication interface program settings, improved alarm management programs, and standard control logic program development and application.

The standard control logic program has been applied to chemical and disinfection processes and has improved the accuracy of the program by updating operating factors, correcting the location of chlorine injectors, and optimizing the sampling location.

6.2 Why is it difficult to perform fully automatic driving?

6.2.1 Problems with water purification data from a big data perspective

The characteristics of big data can be defined as Value, Variety, Velocity, and Volume. From the perspective of each characteristic, we want to find out the problem of water purification plant data.

First, it is the view of Value. Measuring instruments operated by water purification plants are generating meaningless data through inaccurate measurements by realistic conditions, not ideal installation conditions and ideal measurement environments. Even if the best instruments are brought in, the longer the operation period increases, the worse the measurement value will be, and most of them violate the trust of the operators with inaccurate data. Although it is important how accurate and useful the myriad data will be when collected and how much it can be associated with the necessary processes, the overall reliability of the data is compromised due to the lack of accuracy.

Secondly, it is the perspective of Variety. It is impossible to collect various data unless the price of the instrument becomes low. In addition, there are many instruments with only one manufacturer, and it is impossible to respond quickly in the event of a failure, and the program cannot be modified or improved if the manufacturer goes bankrupt.

Thirdly, it is Velocity's view. There is a significant lack of data generation speed and processing speed, and in the case of SCADA systems in operation, current data is also being handled excessively.

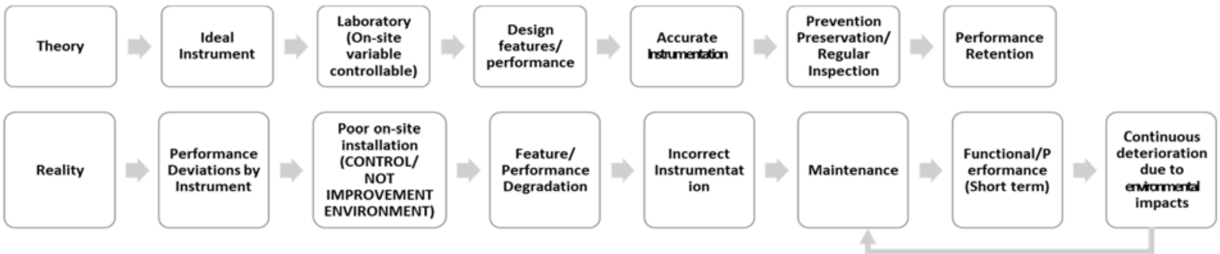
Finally, it is the perspective of Volume. Although huge amounts of data are needed to organize big data, current instrument installation status and quantity are significantly insufficient to accurately understand the operational situation. Each site has different environments and different facilities, so unless the entire water purification plant of K-water is unified, a lot of different data are needed, and even if it is unified, there is a limit to data collection by various variables.

6.2.2 Problems with water purification data from an instrumentation perspective

Accurate measurement is theoretically measuring the value of the measurement target within tolerance, which is difficult to define as "accurate" by measuring it once with one instrument. The resulting value, which differs only by the degree of tolerance, is an accurate measurement, when repeatedly experimenting with the same experiment or measuring multiple instruments at the same point on the same target.

In reality, it stores and utilizes the values that come from measuring the sampled target with an instrument that is assumed to have been tested and calibrated at a particular point.

Figure 7. Differences between Theory and Reality of Instrumentation



Instruments assumed to be tested and calibrated have numerous variations depending on the manufacturer's design capabilities, and are often underperformed by variables (raw water, sewage, moisture, air) in the field, even though they have accurate performance in a laboratory with perfect conditions.

Although the minimum required distance is not secured, in the case of flowmeters installed so that the cost-saving method does not change the pipe and results in a minimal error, inaccurate data is eventually produced and degenerated into useless data.

Residual chlorine measuring instruments and turbidity measuring instruments, which are the most important parts of the water treatment process, often occur inaccurate measurements by living organisms or humidity living in water. Although some spaces are equipped with anti-temperature humidifiers, all humidity and temperature cannot be controlled, leading to frequent measurement errors.

In addition, measured values require representation. Because the instrument cannot be installed indefinitely, it should be installed in a location where the situation or condition can be accurately recognized. However, instruments are often installed in locations where representation cannot be achieved due to many limitations in reality or due to misjudgment.

Instruments installed on pipelines are often not installed and operated in the best position due to construction conditions or legal licensing issues.

Instruments are installed and operated in the wrong location because they cannot find a representative location for water quality by process, and instruments are not installed in important locations because they do not know the location necessary to use control logic.

6.2.3 Problems with water purification data from a data quality perspective

Various problems in the acquisition, transmission, storage, and linkage of measurements have led to incorrect or missing data.

In K-water, there is no organization dedicated to the quality control of measurement values and data in which misjudgment or omission occurs. Many things are replaced or automated by machines, but there are still many things that humans do directly. Data quality control can also be automatically activated in the future, but it is still too early. So far, the focus has been on generating, collecting, and storing data, and thus the quality control level is not high. In addition, most institutions lack quality management personnel or organizations.

Currently, facility operation management and data quality management are carried out in parallel. Therefore, data quality management that is pushed back from priorities is not the concern of the person in charge.

Table 8. Causes of incorrect measurement and missing by Data Acquisition Path

Path	*Cause of disability*
Create	*Instrument failure, acquisition facility (PLC, RTU, etc.) failure*
Transmission	*Communication line failure, communication equipment failure*
Storage	*Server failure, DB system failure*
Linking	*DB system failure, Network failure*

6.3 Establishing the Foundation for introducing Autonomous Operation System

6.3.1 Understanding Instrumentation Topics

There are various types of measurement items, but they can be classified as quantity and water quality. Quantities include flow rates indicating volume to water, water levels indicating height, and pressure indicating the force or weight of water acting on an area. Water quality includes turbidity, which indicates the degree of cleanliness of water, residual chlorine, which is present in certain forms when water is disinfected with chlorine, and pH, which indicates the degree of acidity or alkaline in water.

The quantity item is immediately measured with no delay in the quantity of water, and the measured value can be defined as the representative value in the same pipe.

Figure 8. Understanding quantity items

The water quality category should take-into account the detention period. In other words, even within the same pipeline, the values vary depending on the location of the instrument.

Therefore, the measured value can be defined as the sample value within the same pipe. This is the reason installation quantity and location of instruments are important factors.

Figure 9. Understanding water quality items

Failure to understand the characteristics of quantity and water quality will result in unnecessary data being acquired, rather than situational awareness or data required for decision making and will not have sufficient data to make quick and accurate decisions.

6.3.2 Accurate Instrumentation

Basically, it is necessary to understand the characteristics of the measurement item and obtain the measurement value. This applies not only when the instrument is installed, but also when utilizing the acquired instrument. Above all, failure to take-into account the duration of water quality items often leads to incorrect decisions or failure to make decisions at an appropriate time.

Accurate measurements require installation of instruments suitable for the environment, the number of instruments, the location of instruments, stable data transmission, and preventive preservation and maintenance of instruments.

(Installation Environment and Instrument Specification) In order for the instrument to perform reliably in the field, it is necessary to install instruments with specifications suitable for the field situation. For example, a flow meter has the minimum required distance to be installed at a certain distance depending on the condition of the pipe at the front and rear ends. The minimum distance required for each type of flowmeter is shown in Table 9. If a flow meter is installed in an environment that does not meet the minimum required distance, the variation of the measured value will be severe and inaccurate values will be measured. In other words, it is essential to accurately investigate and diagnose the on-site installation situation and install the appropriate instrument at the installation point.

Table 9. Minimum Required Distance by Flow Meter Type

(Minimum Required Distance: Multiple of pipe diameter (D))

Installation Conditions		Electronic Flow Meter	Ultrasonic Flow Meter		Impeller meter
			Dry	Wet, Multi	
Upstream side	VALVE	3	20	5	5
	Curved pipe	5	10	5	5
	Magnifying pipe	3	20	3	5
	Condensed pipe	3	10	7	5
	Tee pipe	3	20	5	5
Downstream side	VALVE	2	10	2	3
	Magnifying pipe	2	5	3	3
	Curved pipe	2	3	3	2
	Tee pipe	2	3	2	2

(Understanding Instruments) The minimum required distance of a flowmeter, as an example of an instrument specification, is applied with a uniform intuitive distance criterion depending on the method of measurement. However, there is a difference in the actual specifications of each instrument product. Depending on the technology possessed by the manufacturer there are instruments that have shorter minimum requirements even with the same measurement method. Therefore, it is necessary to install instruments suitable for the installation environment, but also to understand the characteristics of the instruments installed accurately.

(Instrument Quantity) If you install the instrument at all points, you can check the exact situation. However, it is practically impossible due to the constraints and costs of the installation environment. Nevertheless, it is desirable to install instruments at as many points as possible, as statistics show that the more sampling, the more accurate values can be estimated. In some cases, data is analyzed and predicted instead of increasing the quantity of instruments. Each water purification plant in the Seoul metropolitan area, which uses Paldang's raw water, calculates the time when Paldang's water quality is reflected and uses it for chemical injection. The time required for the arrival of the Paldang's raw water to arrive is five hours for the Wabu Water Purification Plant, seven hours for the Seongnam Water Purification Plant, and nine hours for the Suji Water Purification Plant, respectively. Even with such data analysis and prediction, installing additional instruments at the midpoint of the pipeline where raw water is supplied will enable more accurate arrival times to be predicted.

(Instrument redundancy) For uninterrupted instruments, instruments must be installed redundant. During the operating period until the instrument is installed and replaced, the instrument cannot be operated without failure, and there is inevitable disruption time, such as inspection and calibration, to maintain performance. Instrument redundancy is a good way to obtain uninterrupted measurements. Since we cannot help but think about the problem of cost, we first recommend redundancy even the instruments inside the water purification plant.

(Instrument Measurement Location) Since instruments cannot be installed at all points, it is important where they are installed. This is because the location of the installation determines whether it is possible to overcome the limitations of quantity and acquire representative values. The measurement location is also relevant to the understanding of the afore-mentioned instrumentation items. Since the quantity field does not have a significant impact on location within the same facility, most of them can be representative when measured at the time and end of a facility. However, the measurement location is very important in the water quality sector. For example, when chlorine is injected from a water purification plant, the residual chlorine measured at the location where the chlorine is injected comes from a high level but does not match the residual chlorine level of the water being produced. This is because the injected chlorine reacts with water and stabilizes after a certain period of times and some chlorine is consumed while the water is in the water purification site and pipeline. For this reason, hydrostatic residual chlorine controls the level of hydrostatic effluent residual chlorine by considering the amount to be measured at the end of the supply pipeline.

(Measured value transmission) The measured values of the instrument are stored in the database (hereinafter referred to as DB) via collection devices (PLC, RTU, etc.) and servers.

There are two methods of transmitting measurements from instruments to collection devices: analog and digital transmission. Analog transmission is a method that utilizes current or voltage and is transmitted inaccurately depending on cable or distance. Digital transmission can be accurately transmitted by converting the measurements to '0' and '1'. There is also a way to convert analog signals generated by instruments into digital signals, but there is a possibility of inaccuracy as management points increase and analog transmission to transducers. Therefore, transmitting from the instrument to a digital signal is a method of accurately transmitting the measured value.

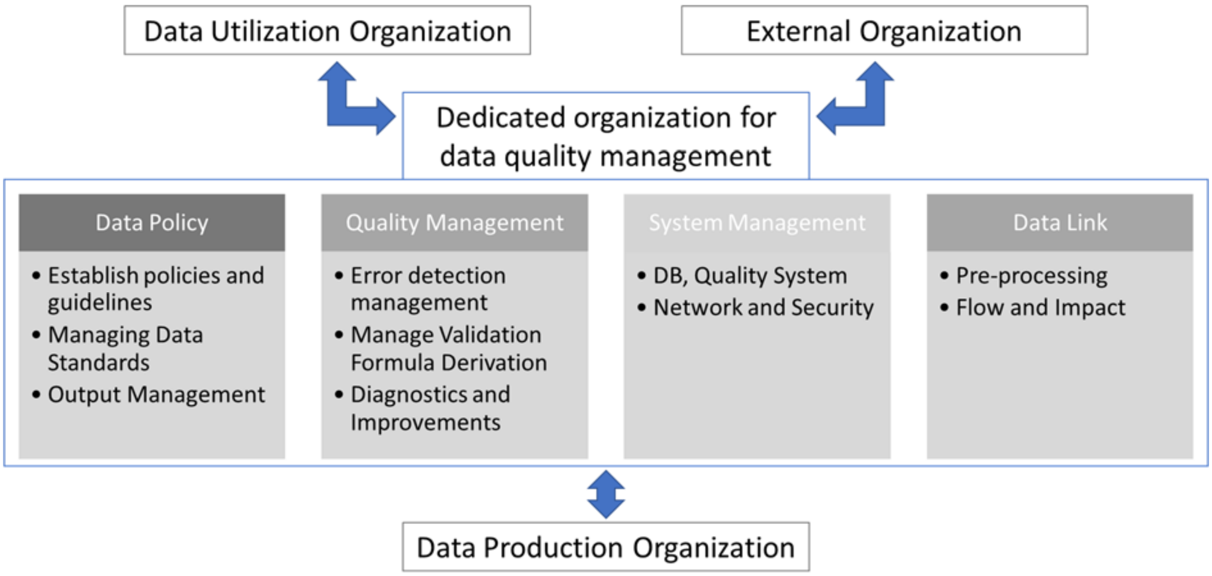
(Maintenance of measuring instruments) Even finely made instruments cannot perform if they are used for a long time or exposed to poor operating conditions. In addition, inaccurate measurements can be made if consumables used for measurement within the instrument are not replaced over a period of time. Maintenance is more important than anything else for the stable operation of measuring instruments. Much effort is needed, such as finding elements that could cause the instrument to fail, removing them in advance, periodically checking the operation status through regular inspections, and replacing consumables within a set deadline.

6.3.3 Manage Acquired Data

The acquired measurements are stored, managed, linked and utilized through DB. Values stored in DBs are commonly referred to as data. These generated data are utilized in various fields, and autonomous operating systems for water purification plants are also implemented by utilizing data. Therefore, if there is a problem with the representation or quality of the data, poor decision-making or accurate results are not produced. Furthermore, if essential data are not provided to the system, it becomes a situation in which decision-making or outcome-making cannot be made. As a result, the quality control and linkage part of the data is a very important part for the settlement of the water purification plant autonomous operating system.

(Data Management) It is necessary to establish an organization dedicated to data quality management and to recruit staff. Although many tasks are performed, such as establishing standards, establishing systems, testing and calibrating data for data quality management, paralleling other tasks does not help maintain high-quality data at all times. Since most measurements are acquired almost every real-time cycle, quality control must also be done in real-time. This is why organizations and personnel should be secured exclusively for data quality management roles (quality standards management, DB and quality system management, data monitoring, etc.).

Figure 10. Dedicated organizational role for Data Quality Management



(Data Link) In order to analyze and utilize data, data must be provided to systems that require data. In addition, additional external data as well as internal data are often needed. For example, when predicting demand for tap water, existing supplies, capacity, and contracted supplies are needed, but externally produced data such as weather are also needed. However, there are many restrictions on the linkage of external data. For externally produced data, it is not possible to control the type, cycle, quantity, etc. of data as much as is needed, and it may be difficult to accommodate the form or method of data being provided. Big data analysis requires a collection of data that can easily be utilized by converging internal and external data into a government-led format or standard.

Another obstacle that makes data connection difficult is security. Most public institutions are tied up in security issues. In some cases, it is expensive to comply with security and link data, and sometimes it is impossible to link. The government also needs to think about ways to solve security problems related to data connection rather than unconditionally stopping them for security reasons. For example, if the government aims to link and analyze data between public institutions, it is necessary to play a role in creating policies or channels to alleviate security problems.

6.4 Role of operators for the establishment of autonomous operation systems

6.4.1 Data management

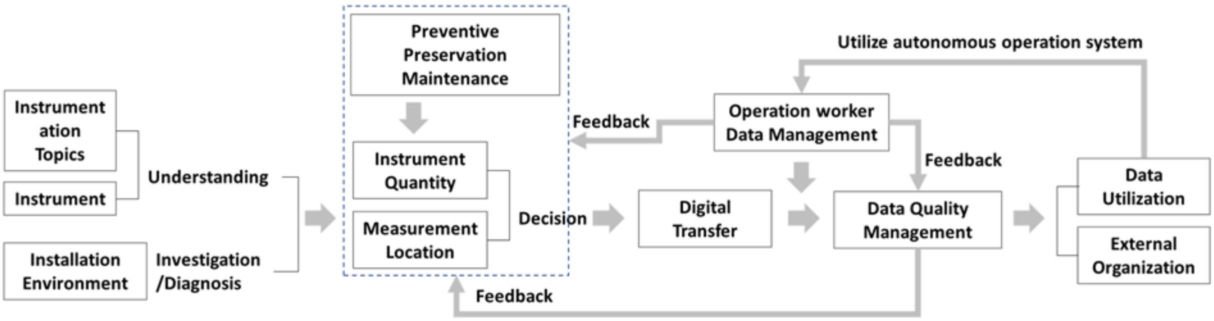
For data quality management, the most important part is to manage the entire process of data creation, storage, and utilization through a dedicated organization, but the attention and efforts of the people in charge at each stage are also essential. It is the first place where operators operating water purification plants can notice inaccurate measurements as they encounter measured measurements for the first time. There are many changes in the workload of data quality management according to the interest and efforts of the operators. If an operator actively responds to measurement values or higher in the event of a facility failure, he/she can prevent various accidents or minimize the impact of accidents, as well as improve the quality of raw data. In addition, operating a water purification plant with interest in data at a time when the operation method of the water purification plant is changed to data-based autonomous operation is also a way for operators to operate the water purification plant well. The role of monitoring and managing the measured values always in producing water that the people can drink with confidence is also essential for operators.

6.4.2 Utilize Autonomous Operation System

It would be most desirable if the system for autonomous operation of water purification plants could operate without any help from humans, but human help is needed because the reality is technically in a transitional stage. When producing water, some adjustments to water quality targets or quantities may be needed.

An operator shall be able to produce as much water as necessary by utilizing the autonomous operation system. In addition, if the water quality or volume of water produced through the autonomous driving system goes against the target, it should know how to utilize the system to correct it. Operators need to make efforts to understand the operating principles and utilization methods of the autonomous operation system and to include experience and know-how in the system.

Figure 11. Process for laying the foundation for introducing an autonomous operation system for Water Purification plants



7. Conclusion

7.1 Main conclusion of study

7.1.1 Why is it difficult to fully automatic operation of water purification plants?

(Big Data) Data from water purification plants do not have an appropriate analytical base with low reliability, insufficient diversity, slow throughput, and small quantities.

(Measurement) The difference between theory and reality has not accurately recognized and the representative value of the operational situation has not measured.

(Data Management) Data quality control is not properly achieved due to the absence of an organization to reliably data measurements and manage the quality of acquired data.

7.1.2 Proposals for laying the foundation for an autonomous operation system

Autonomous operation system of water purification plant is based on data. In order for the analysis or implemented logic to perform, instrumentation is stable and quality control of the data acquired through it is necessary.

The operation of the instrument is important to acquire accurate measurements. Measuring instruments appropriate for the installation environment shall be installed and measured at as many points as possible or at locations with representation of the installation environment through understanding of the instrument, and measured values shall be digitized and transmitted. Preventive preservation and maintenance are also needed to ensure that these systems remain stable.

Systematic data management is needed through the establishment of a dedicated organization to manage data quality, and state-level support, and systems that can be utilized without security problems by standardizing methods or forms of managed data.

7.1.3 Role of operators following the introduction of an autonomous operation system for water purification plants

The role of the operator, who is the closest to the measured value, is important for the establishment of the autonomous operating system. First of all the data quality deterioration should be minimized by determining whether the measurement value is abnormal, and the experience and know-how of operators can be realized and utilized through the autonomous driving system.

Table 10. Problems related to the establishment of an autonomous operation system and directions for the improvement.

Field	Problem	Improvement Direction
Big Data	Low reliability, lack of diversity, slow throughput, lack of quantity	Understanding Instrumentation Items and Instruments. Investigate and diagnose your installation environment.
Instrumentation	Inaccurate instrumentation persistence. (Instrument deviation, poor environment, incorrect instrument location, failure, etc.)	Instrument installation appropriate for the installation environment. Instrument redundancy, installation quantity maximization. Select the representative instrumentation location. Preventive Preservation and Maintenance.
Data Management	Absence of quality control organizations and personnel.	Establishing a quality control organization Government-led data linkages and security policies.
Operator		Instrument monitoring management (initial response). Applying systems of experience and know-how.

7.2 Suggestions for follow-up research

7.2.1 Limitations of study

In order to identify problems with the operation of the instrument and verify alternatives in the study, it is most reasonable to compare before and after cases of improvement in the operation method but based on interviews from people with experience in running water purification plants and experts in related fields. Comparative verification of postwar examples is required by applying the direction of improvement to the water purification plant.

The proposal for a new data quality management organization is likely to be difficult for a large-scale organization to be established at once because public institutions involve increasing manpower through government approval and require employees' consensus. It is believed that even small-scale organizations will be established, and that it will be necessary to gradually increase the number of employees and expand the organization in the future.

7.2.2 Suggestions of follow-up research tasks

First, research and standardization of measurement locations for each environment of a water purification plant in order to have representation of the operation situation.

Second, research and standardization of data pre-processing processes suitable for water purification plant autonomous operation systems.

Third, review of systems and measures that continuously reflect the experience and know-how of water purification plant operators in the autonomous operation systems.

Finally, conduct on-site testing and research by automation stage by redefining the level of automation for autonomous operation of water purification plants (referring to the autonomous driving stage of automobiles).

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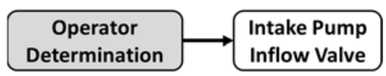
Appendix

Appendix 1. Define automation levels by unit process.

1) Water Intake

Automation level	*Definition*
Fully automatic operation	*Operation of the intake pump or the inflow valve of the water purification plant by the control logic based on the water purification level and the flow rate of the water purification discharge.*
Automatic operation	*The operator determines the target flow value and sets it in the system, and the intake pump or water purification valve is interlocked by the control logic based on the target flow value.*
Manual operation	*Operator moves/stop the intake pump individually in the central control room and on-site and controls the inflow valve of the water purification plant*
Manual operation on site	*Operator individually starts/stop the intake pump in the field and controls the inflow valve of the water purification plant*

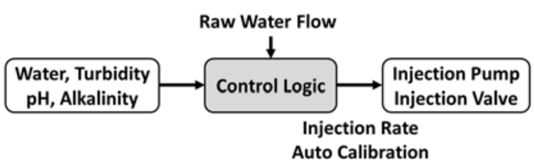
Fully automatic operation



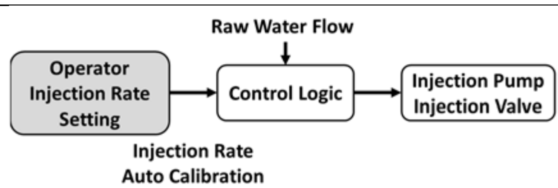
Manual operation

2) Coagulant Injection

Automation level	*Definition*
Fully automatic operation	*Automatically correct the injection rate by controlling logic based on water temperature, turbidity, pH, and alkaline, and operate the chemical injection facility in proportion to the flow rate of raw water.*
Automatic operation	*The operator determines the target injection rate and establishes it in the system and operates chemical injection facilities in proportion to the amount of raw water inflow according to the target injection rate.*
Manual operation	*Operator controls individual chemical pumps or valves in central control room and on site.*
Manual operation on site	*Operator controls individual chemical pumps or valves on site*



Fully automatic operation

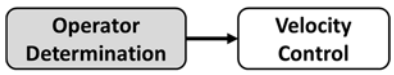


Automatic operation

3) Mixing

Automation level	*Definition*
Fully automatic operation	*Automatically start/stop/speed (Hz) control of the mixer by raw water flow rate and water temperature-based control logic.*
Automatic operation	*The operator determines the speed (Hz) value and sets it to the system, and the mixer automatically starts/stop due to the flow rate of the raw water.*
Manual operation	*Operator moves/stops the mixer separately in the central control room and on-site.*
Manual operation on site	*Operator moves/stops the mixer individually in the field*

Fully automatic operation

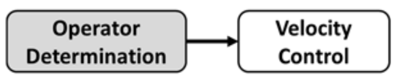


Manual operation

4) Coagulation

Automation level	*Definition*
Fully automatic operation	*Automatically start/stop/speed (Hz) control of the coagulator by raw water flow rate and water temperature-based control logic.*
Automatic operation	*The operator determines the speed (Hz) value and sets it to the system, and the coagulator automatically starts/stop due to the flow rate of the raw water.*
Manual operation	*Operator moves/stops the coagulator separately in the central control room and on-site.*
Manual operation on site	*Operator moves/stops the coagulator individually in the field*

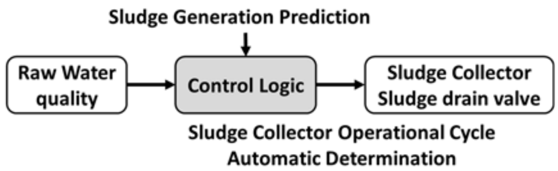
Fully automatic operation



Manual operation

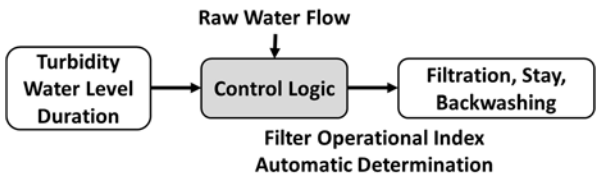
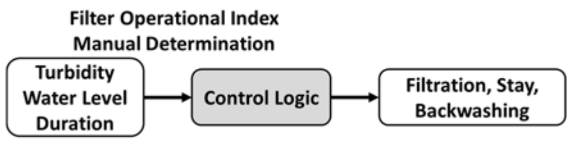
5) Sedimentation

Automation level	*Definition*
Fully automatic operation	*The operation cycle of the sludge collector is determined by predicting the amount of sludge generated by control logic according to the water flow rate and water quality condition, and the sludge drain valve is interlocked.*
Automatic operation	*The operator controls the sludge collector in the central control room and operates the sludge drain valve interlocking operation by operating time and limit switch.*
Manual operation	*Operator controls sludge collectors and sludge drain valves separately in central control room and on site.*
Manual operation on site	*Operator controls sludge collectors and sludge drain valves separately on site*

	
Fully automatic operation	*Automatic operation*

6) Filtration

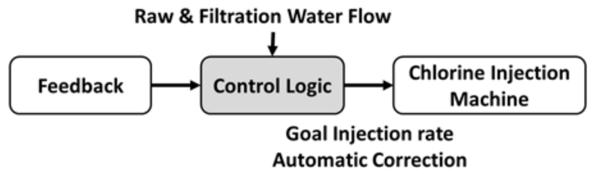
Automation level	*Definition*
Fully automatic operation	*The pump and valve facilities are interlocked by the control logic based on the filter turbidity/level/duration time, and the operation index of the filter is automatically determined according to the raw water flow rate.*
Automatic operation	*The operator determines the station point by referring to the filter accuracy/level/duration time, and the backwashing process automatically determines the pump, valve facility interlocking operation, and filter operation index manually by control logic.*
Manual operation	*Operator controls valves and pump facilities separately in central control room and field with reference to filter turbidity, water level and duration.*
Manual operation on site	*Operator controls valves and pump facilities individually in the field with reference to filter turbidity, water level and duration.*

	
Fully automatic operation	*Automatic operation*

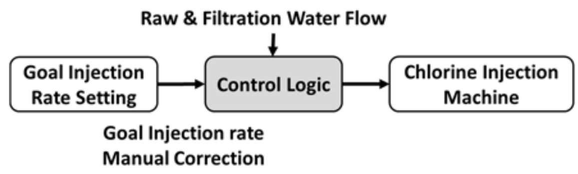
7) Disinfection

[pre-chlorination]

Automation level	*Definition*
Fully automatic operation	*Control logic automatically corrects the target injection rate by controlling the inflow flow rate of the water purification plant proportionally and feedbacks residual chlorine at the rear of the chlorine input point, and the chlorine injection facility is interlocked.*
Automatic operation	*Operation of chlorine injection facilities in proportion to the flow rate of the water purification plant by setting the chlorine injection rate in the central control room*
Manual operation	*Operator controls individual chlorine injection facilities in central control room and on site.*
Manual operation on site	*Operator controls chlorine injection facilities individually in the field*



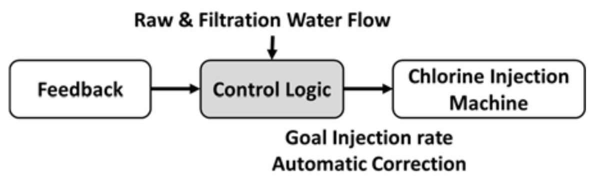
Fully automatic operation



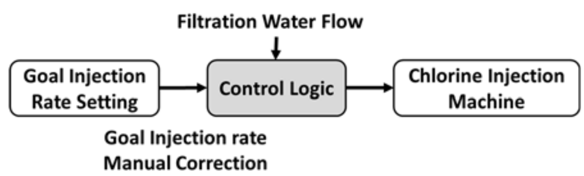
Automatic operation

[post chlorination]

Automation level	*Definition*
Fully automatic operation	*Control logic automatically corrects the target injection rate by controlling the inflow flow rate of the water purification plant proportionally and feedbacks residual chlorine at the rear of the chlorine input point, and the chlorine injection facility is interlocked.*
Automatic operation	*Operation of chlorine injection facilities in proportion to the inflow rate of the water purification plant by setting the target injection rate and compensating for the difference between the target injection rate and the residual chlorine at the rear end.*
Manual operation	*Operator controls individual chlorine injection facilities in central control room and on site.*
Manual operation on site	*Operator controls chlorine injection facilities individually in the field*



Fully automatic operation



Automatic operation

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. Comments on the level of automation of water purification plants.** Q2-1. What is the level of automation by process of the water purification plant in operation? Q2-2. What are the improvements to increase the automation level of water purification plants? Q2-3. Why is it difficult to drive a water purification plant automatically?
	Q3. Opinions on data management. Q3-1. What is the quality of the water purification plant data? Q3-2. What affects the quality of the water purification plant data? Q3-3. What are the ways to improve the quality of the water purification plant data?
	Q4. Problems of obtaining measurement values / Opinions on improvements. Q4-1. What is accurate measurement? What is instrumentation to help you operate? Q4-2. Is the installation or measurement location of the instrument in the water purification plant appropriate? Q4-3. Is the measuring cycle or timing of the water purification plant appropriate? Q4-4. What is the solution for stable measurement?

- *Continued on the previous page* -

Index	Contents
In-depth Interview	**Q5. Opinions on the role of water purification operators.** Q5-1. What is the current role of a water purification operators? Q5-2. What is the role of the operator following the introduction of the water purification plant autonomous operation system?
	Q6. The opinions of experts/practical staff on my research topic. Q3-1. Why is the water purification plant not fully automatically operated? Q3-2. What should be done to lay the foundation for autonomous operation of water purification plants?
	Q7. What are the requirements for establishing a water purification plant autonomous operation system? Any other comments?