AI-Applied Operation Support for a Sewage Treatment Plant

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Abstract

The decrease in skilled engineers due to population decline, the succession of skills, and the reduction of greenhouse gas emissions in anticipation of the realization of carbon neutrality are pressing issues for local governments with sewerage treatment plants. We are working to solve these problems by applying Artificial Intelligence (AI) to the skills relating to sewage treatment plant operation. Such high skills had been demonstrated in the past by experienced engineers. This AI technology is characterized by the linkage of AI for image processing, water quality prediction, response judgement, and facility operation. The AI for image processing can detect anomalies by indicating the number and area ratio of scum floating in the final sedimentation tank. AI for Response Judgement visualizes the judgement of facility operation and assists the realization of passing on the skills to the next generation. As an example of AI-applied facility operation at an actual sewage treatment plant, we demonstrated the stability and validity of AI-applied water quality judgements in setting the Dissolved Oxygen (DO) level in reaction tanks.

1 Preface

Due to Japan's aging and declining population, the number of sewerage service workers in local governments has fallen to about two-thirds of the 1997 peak. Although the outsourcing of sewage facility operation and management to the private water service providers has been in progress against the background of the retirement of baby boomers, it is thought that there are still issues to be addressed in terms of passing on to next generations and human resource development the skills relating to sewage facility operation and management. In addition, sewerage services account for about 0.7% of Japan's total greenhouse gas emissions, and the sewerage industry has begun working to achieve carbon neutrality by 2050[(1)].

To solve these challenges, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) in Japan is working to accelerate the research and development of innovative sewage technology through digital transformation (DX) through funding projects. By drawing on the Artificial Intelligence (AI) technology that we have cultivated from the past feasibility studies, we are now conducting "Demonstration Project on Advanced Support Technology for Operation of Sewage Treatment Plants Using AI" together with three other parties: Hiroshima City and Funabashi City and NJS CO., LTD. Hiroshima City and Funabashi City have concerns about passing on the skills of sewage facility operation to next generations. NJS CO., LTD. is a consultant company which promotes the spread of new AI-based technology. Four parties formed a joint research group for this project. This demonstration project was commissioned by National Institute for Land and Infrastructure Management (NILIM), MLIT for the full-scale demonstration under the 2021 Breakthrough by Dynamic Approach in Sewage High Technology Project ("B-DASH Project")[※1]. In relation with the demonstration project, this paper introduces our AI technology concepts for sewage treatment plant operation and some of the project results.

2 AI Technology for Facility Operation

Skilled engineers in charge of proper facility operation and management at the sewage treatment plant performs operation based on their own expertise, taking into accounts of the conditions of sewage at the facility and the characteristics of the operational settings of the facility. To be able to respond to the retirement of skilled engineers, personnel changes in local government officials, and changing of any outsourcing contractors for facility management service, local governments need to share advanced facility operation skills and strive to maintain them.

Considering these characteristics of facilities management of sewage treatment plant, we developed related AI technologies. **Fig. 1** shows operation support guidance by AI. In the AI technology, four AI technologies are at work together to provide the operation support guidance. An overview of each AI technology is provided below.

(1) AI for Image Processing

It detects processing status and anomalies from images such as the water surface of the final sedimentation tank, replacing the inspection by the human eye.

(2) AI for Response Judgement

AI visualizes the relationship between causes and countermeasures based on water quality and images, and narrows down the countermeasures that should be taken.

(3) AI for Facility Operation

AI estimates the setting value of the facility operation based on the countermeasure indicated by the AI for Response Judgement.

(4) AI for Water Quality Prediction

AI predicts the effluent quality under the current operation and the operation under setting a value predicted by AI.

Anomaly detection by AI for Image Processing is taken over by AI for Response Judgement and the output results are used to determine facility operation policy. The facility operation strategy suggested by the AI for Response Judgement is taken over by the AI for Facility Operation and the output results are used to determine the setting values. The AI for Water Quality Prediction can predict the future water quality based on the current values of the plant operation and the values predicted by the AI for Facility Operation. AI for Response Judgement visualizes the reasons for decision-making and enables the passing on of skills to the next generation. In the future, it will be able to do the operation that can reduce greenhouse gas emissions compare to conventional operation due to learning from past data. A feature of this AI technology is that it can realize technical support for such advanced operations.

An AI inference system was installed in sewage treatment facilities in Hiroshima City and Funabashi City. By acquiring data online such as process data, water quality data, and image data, AI provides guidance for facility operation. After validating the AI guidance for better operation, skilled engineers reflect on the AI output (how to operate) on actual operation of the sewage treatment plant. In the demonstration project, it was confirmed that the quality of effluent was stabilized even when operation was performed based on the AI guidance

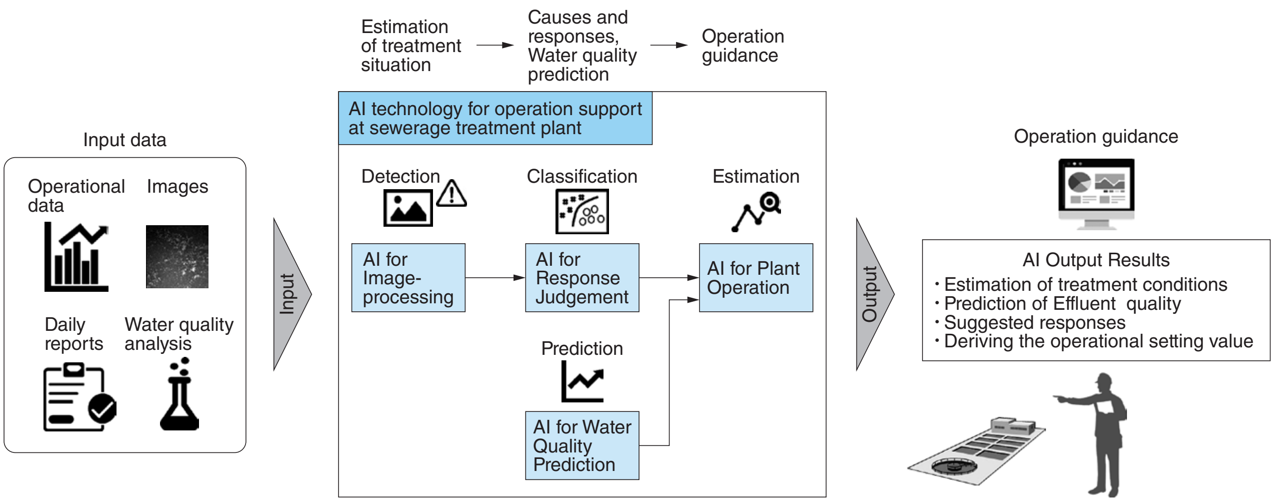

Fig. 1 Operation Support Guidance by AI

By linking four types of AI, the system provides guidance regarding the operation policy and the operational setting amount, the judgement of water processing conditions, and the prediction result of water quality based on past data obtained from daily operation and control.

of better operation. It indicated that the reduction of both power consumption and chemical usage that contribute to the reduction of greenhouse gas emissions were maintained or reduced.

Sewage treatment plants use a variety of treatment methods, including the conventional activated sludge process, the anaerobic-anoxic-aerobic process, and the oxidation ditch process which is often used on a small scale plant, and the sequencing batch process. We are planning to make AI technologies that handle the above methods. It is expected that the AI technologies discussed in this paper can be applicable to approximately 80% of sewage treatment plants nationwide in Japan.

3 AI for Image Processing

In the sewage treatment plant, daily patrol inspections of the facilities are carried out, and the condition of the tank is checked in the process. For example, because of patrol inspection, if it is found that the scum in the final sedimentation tank floats, there is a concern that the bottom layer will become anaerobic. In this case, excess sludge removal is performed.

Visible anomalies include scum floatation, abnormal foaming, and the outflow of Suspended Solids (SS). It is important to grasp the condition of such final sedimentation tank to manage the operation of a sewage treatment plant.

We developed an AI for Image Processing[2] that grasps the condition in final sedimentation tank and presents the information necessary for operating policies. Fig. 2 shows an overview of the AI for Plant Operation. It detects scum floating in final sedimentation tank with a camera and judges it with AI for Image Processing. This is an example of images captured by a camera processed with an algorithm that can compress and decompress image data called a Convolutional Autoencoder (CAE). Here, the CAE adopts a technique called "background modeling" that learns to restore normal water surface conditions without restoring minute scum. The position, number, and area of the scum can be identified from the subtracted image obtained by comparing the CAE-produced output image and the input image. An anomaly detection threshold value is set for the number and area, and an anomaly is judged when the threshold value is exceeded.

The advantages of this method are that there are so very few image anomalies compared to

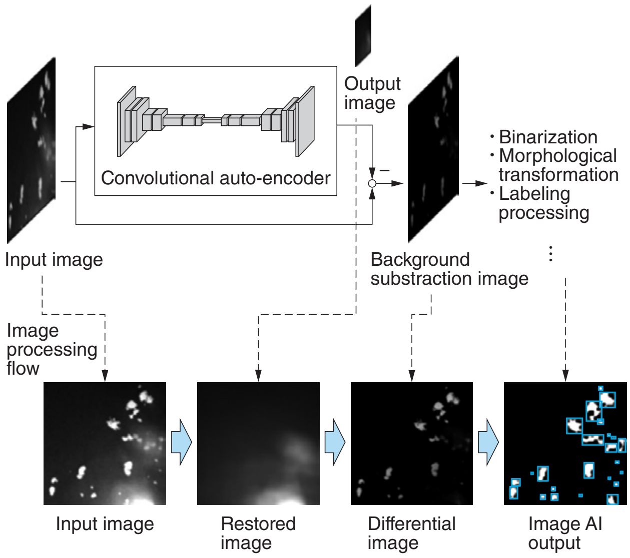

Fig. 2 Overview of AI for Plant Operation

As a result of image processing performed by a core device of convolutional auto-encoder, it is possible to determine the quantity of suspended solids at the final sedimentation tank and the ratio of areas to the identification range.

almost normal condition images, that it saves the trouble of selecting image anomalies during the learning process, and it is not affected by color changes due to external light. It is a suitable method for monitoring a few sewage treatment plants.

Images taken every 30 minutes were processed by AI for image processing to detect anomalies in floating substances in the final sedimentation tank. While only the background of the scum contained in the original image is restored by CAE, the scum is extracted from the subtracted image, and the number and area can be extracted by the blue frame. It is possible to detect the number of scum and its ratio to the photographed area, and from this condition, it is possible to judge the current condition of the final sedimentation tank and use it to make operational decisions.

4 AI for Response Judgement and AI for Plant Operation

We digitized data for AI inference which includes the monitoring equipment data, water quality analysis data accumulated in daily operation management, the history of past plant operations, and the thinking process that led to the judgement of plant operations. Combining AI for Response Judgement and Plant Operation, and providing the operation status reporting make it possible to make judgements about plant operations and visualize

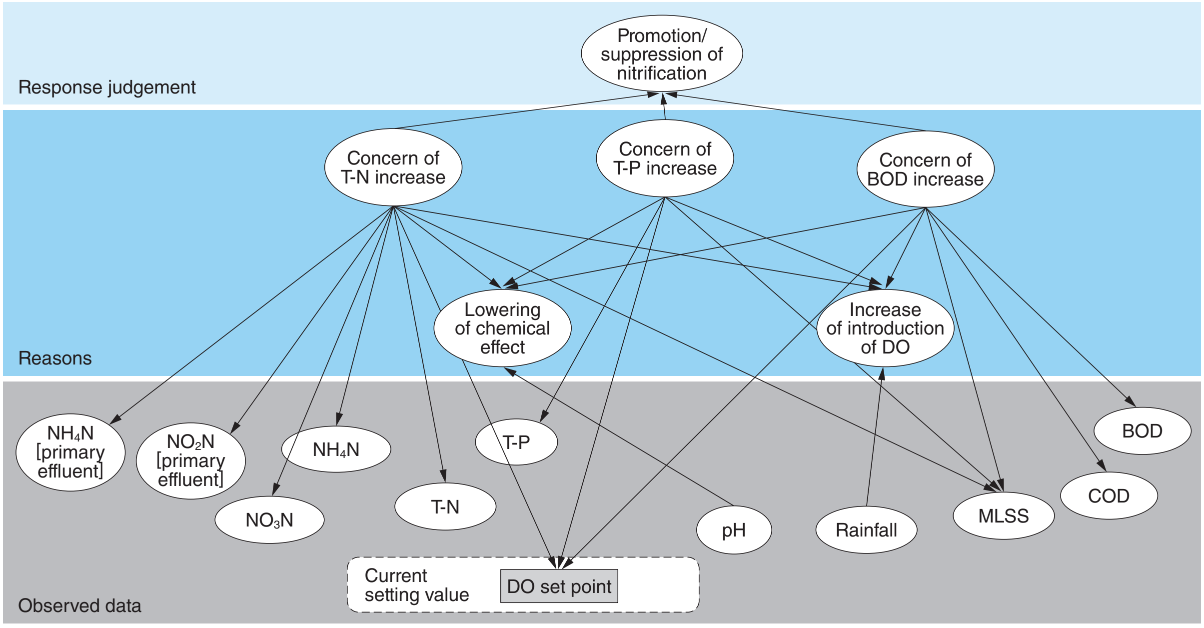

Fig. 3 Clarification Image of Operation Policy by AI for Response Judgement

To determine and clarify the operation policy, the observation layer shows the observed data, and the reason layer shows the cause for the operation.

the thinking process.

AI for Response Judgement derives a plant operation policy from the provided data. The operation policy is, for example, if the total phosphorus concentration is high because of the water quality analysis, the operation policy is "to reduce phosphorus, reduce the blowing air volume". When the total nitrogen concentration is high, however, the operation policy is that the "nitrification is promoted and denitrification is performed, so not reduce the blowing air volume".

As a method of associating such observed data and operation policy with the past plant operation history, we adopted a graphical model and a method that can express the causal relationship with probability. The advantage of this method enables learning the fluctuations of past operations as probabilities and to visualize the relationship between the data and the operational response at the same time. Fig. 3 shows a clarification image of the operation policy by AI for Response Judgement. The operation policy, which is the execution purpose of the AI for Response Judgement, is presented in the response judgement layer. The observation layer incorporates various types of measured data, such as process data and water quality analysis results. Based on these data, the reasons that contribute to change in the plant operation are represented in the reason layer. By connecting the operation with high probability and the operation deciding factors by the lines, the relationship between the observed items, the basis for judgement, and the required response to the operation can be clarified. Successor engineers (talents for future generation) can inherit the operating skills by imitating the results suggested by our AI that represent the operation by skilled engineers.

The operation response recommended by AI for Response Judgement is passed on to the AI for Plant Operation, which also uses other data to derive operational setting value. Deep learning has been attracting attention in recent years, but considering the operation history of sewage treatment and the low frequency of water quality analysis, it is difficult to secure the data necessary for deep learning. We, therefore, adopted a machine learning method different from deep learning.

Fig. 4 shows an operation example of Dissolved Oxygen (DO) setting by AI. This is an example of applying the operational setting value derived by combining AI for Response Judgement and AI for Plant Operation for DO setting value in aeration tank at Seibu Water Resources Reclamation Center operated by Hiroshima City[3]. Current data, such as daily reports and water quality analysis, are given to AI for Response Judgement and AI for Plant

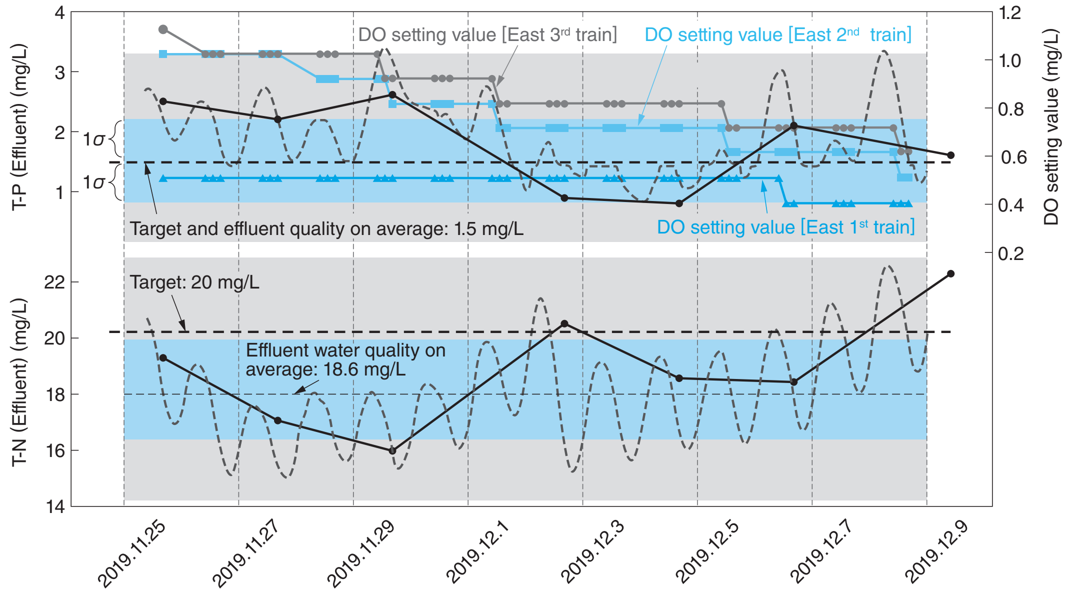

Fig. 4 **Operation Example of DO Setting by AI**

By operating with the DO settings derived by AI, T-P and T-N in the effluent can be kept within the operating range.

Operation. These AIs went through the machine learning of such current data in advance. Collectively, these AIs derived the DO setting values for 2 tanks at East 1st train, 2 tanks at East 2nd train, and 5 tanks at East 3rd train. The effluent quality was monitored. AI inference for the DO setting values were conducted 3 times a day and for a total of 40 times, and the judgements of the skilled engineers were compared simultaneously. The judgements of AIs and skilled engineers agreed 32 times out of 40. For the remaining 8 times, AI's judgement was slightly delayed, but according to the skilled engineer's judgement, that setting value derived by AI was reasonable and acceptable. The DO setting value recommended by AI was applied to the plant operation as it was. At the beginning of November 25, 2019, the Total Phosphorus (T-P) concentration of the effluent was higher than the target value of 1.5 mg/L, but AI repeatedly decided to lower the DO setting. As a results, T-P came down to near the target value. The total nitrogen (T-N) concentration increased to near the target water quality by lowering the DO setting value and reducing the air volume. The on-site demonstration ended on December 8, 2019, two weeks after the start. On December 9, immediately after the end, an AI decision was made, however, to increase the DO setting.

In this way, it is considered that we could demonstrating that AI can be used to determine the operation of sewage treatment plant by utilizing the past operation history that skilled engineers performed and operation/water quality data.

5 Postscript

AI technology for the operation of sewage treatment plants was introduced. In addition to the DO control introduced this time, AI can also be applied to various settings such as the amount of excess sludge removal and the coagulant and disinfectant dose determined by skilled engineers. We plan to work on such settings by AIs in the above-mentioned full-scale demonstration of the B-DASH Project. By using AI for Water Quality Prediction as a basis for making judgements by skilled engineers, it is also expected to reduce the amount of excess air volume and chemicals. Using the AI's better operation results by utilizing past operation data, we will not only pass on the skills to next generation, but also show results that will lead to the reduction of greenhouse gas emissions.

Finally, we would like to thank the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan for giving us the opportunity to demonstrate this AI technology on a full-scale project at a sewage treatment plant. Our special thanks also to Hiroshima City and Funabashi City for giving us the permission to use the facility and providing us with operation policies and data. We would like to express our appreciation to the project members in

NJS CO., LTD. for your cooperation in formulating the strategy to popularize AI technology.

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(Note)

※1. B-DASH Project: Innovative Technology Demonstration Project of Sewerage Works implemented by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan since Fiscal 2021. (B-DASH: Breakthrough by Dynamic Approach in Sewage High Technology Project)

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