Solution Creation Methods Utilizing Data Analysis for Social Infrastructure Systems

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Abstract

We focused on supervisory control systems of social infrastructure and developed a method that promotes understanding of operations and the creation of solutions, by analyzing the vast amount of measurement data recorded in such systems. Operations of social infrastructure involve multiple overlapping goals such as safety, economic efficiency, and environmental performance, and it is difficult to systematize them. Accordingly, we developed a method by drawing on operators' cognitive approaches that constructs plant state models from measurement data. By using this method, we can create patterns of a vast amount of value data and more easily discover operational goals and challenges from the data. We also believe that using the analysis results in system requirements analyses will promote shared understanding between operators and developers and lead to the co-creation of solutions.

1. Introduction

Water and wastewater, roads, rivers, railways—social infrastructure operations are not only vital foundations supporting the lives of people, but, due to their scale, are characterized by having a large impact on society through energy use, environmental load, and other factors. Therefore, in these social infrastructure operations, in addition to safe and reliable operations, appropriate operations are also required from economic and environmental perspectives.

Moreover, unlike typical factory production processes, social infrastructure is characterized by being significantly affected by external factors such as weather and citizen dynamics. To handle various potential situations, buffers are provided for each equipment, and operations are carried out based on the flexible judgments of operators; however, this situational judgment and degree of freedom are factors that make the transfer of skills in operations.

To address such challenges, efforts are being considered that leverage rapidly evolving IoT technologies, and initiatives to simultaneously improve the efficiency and enhance safety of infrastructure operations are being examined(1)(2). Various proposals exist, such as operation automation, predictions and anomaly detection, but in this paper we focus in particular on operation data and measurement data accumulated in supervisory control systems for social infrastructure, and describe a technology that, by leveraging this information, quantitatively identifies the decision criteria for operations that had been tacit knowledge of operators. By organizing this information—which had traditionally been accumulated as individual know-how—we can identify important operational conditions and issues. We believe this will lead not only to more advanced operations but also to the creation of a wide range of solutions, such as training young operators.

2. Supervisory Control Systems and Measurement Data

2.1 Characteristics of data accumulated in supervisory control systems

Social infrastructure operations often have extremely large areas as the scope of supervisory control. To collect information efficiently, monitoring systems are installed, and methods are adopted that aggregate and display the value for each equipment; in large plants, the number of display signals can reach into the thousands. Operators set control command values while inferring current conditions occurring at the plant and the device status, based on the wide variety of values displayed on the monitoring system. In general, the evaluation metrics for plant operation include multiple types, such as operating cost, safety and environmental impact. Many of these metrics involve trade-offs, where improving one adversely affects another, so operations are carried out while balancing the whole. Furthermore, when weather changes, disasters or device failures occur, safety may be prioritized more than in normal times; in other words, the priority of evaluation metrics can change depending on conditions.

As outlined above, data accumulated in supervisory control systems encapsulates various operational goals and evaluation metrics that change from moment to moment. When analyzing and interpreting such data, it is difficult to treat them as a single processing or function; only by correctly classifying and organizing the operational goals according to conditions does it become possible to extract information that reflects the reality of operations. This approach can be applied across various operations, and analyses and evaluations are being conducted in fields such as water and wastewater, river management, electric power, railways, and building management.

2.2 Classification and modeling of measurement data

In interpreting the time-series data accumulated in supervisory control systems, we conducted modeling while referencing the cognitive methods operators use through system operation. Using reservoir water level in water and wastewater as an example, operators not only read the value displayed by the system, but simultaneously add interpretations such as “water level is high” or “water level is low.” Here, by applying statistical methods to each value, we automatically set ranges such as “high water level” and “low water level,” and we developed a method that defines plant states by combinations of those ranges(3). With this method, even for the same event of the water level dropping by 1m, if the change occurs within the “high water level” range, the change in the plant state is small, whereas a change from “high water level” to “low water level” represents a large change in state—enabling a nonlinear expression. This kind of plant state model is particularly effective when observing changes before and after an operational input, making it easier to identify the intent and purpose of the operation from an overarching perspective.

Figure 1 shows the method for classifying measurement data. When the operator intentionally controls the reservoir water level, the distribution is not uniform; it often splits into several clusters. Thus with this method, we automatically determine boundary values between clusters using statistical techniques, and by labeling each cluster, we classified the plant’s states. By treating changes in time-series data not merely as numerical differences but as state transitions, it becomes easier to express even complex plant operations.

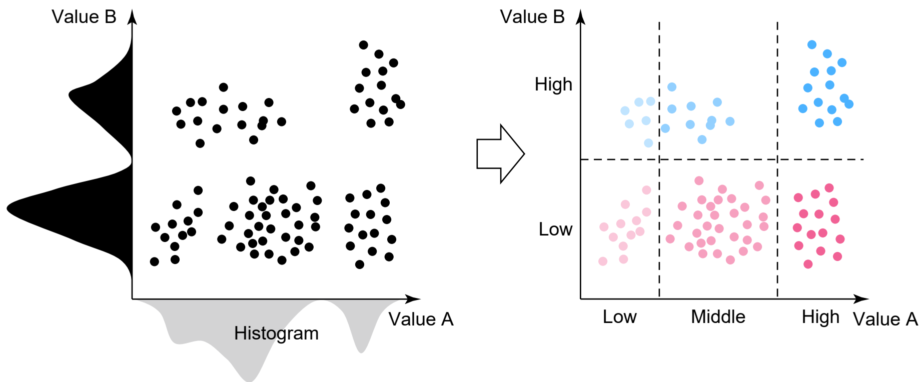

Fig. 1 Measurement data classification method

3. Understanding Operations and Extracting Issues

3.1 Data visualization

Data recorded in supervisory control systems of social infrastructure—such as water and wastewater, electric power, and buildings—often exhibit patterns synchronized with the life rhythms of the end users, namely citizens. This data is characterized by being based on a 24 hour periodic pattern, while fluctuating under factors such as weather and day of the week. By applying the analysis method described in 2 to long-term data recorded in the supervisory control system, it becomes possible to extract typical patterns, such as weekdays against holidays, or fair weather versus rainy weather. Moreover, since there are patterns that do not belong to the typical pattern classifications, investigating them makes it possible to comprehensively find events that occurred as exceptions. Such exceptional patterns often include cases where operation differs from normal due to device inspections or failures, as well as responses to sudden weather changes such as localized heavy rain.

Figure 2 shows the results of pattern classification at our office, using 8 months of electric power usage data. The same color in the figure indicates similar power-consumption states, and X-axis direction represents dates, Y-axis direction represents times, in a 2 -dimensional graph. In almost all periods, 0:00

to 5:00, and 21:00 to 23:00 are the same color, which indicates that employees have left the office. 5:00 to 21:00 shows increased power consumption; in particular, 8:00 to 17:00 shows higher consumption, which matches working hours. Holidays are indicated with 24 hours across the Y axis where the same color continues, with every 7 days appearing as similar patterns.

From a long-term perspective, the appearance pattern of colors also changes over spans of several months, indicating seasonal variation.

Indeed, the electric power consumption of air-conditioning units varies greatly between summer and autumn, and these changes are reflected as changes in the color patterns.

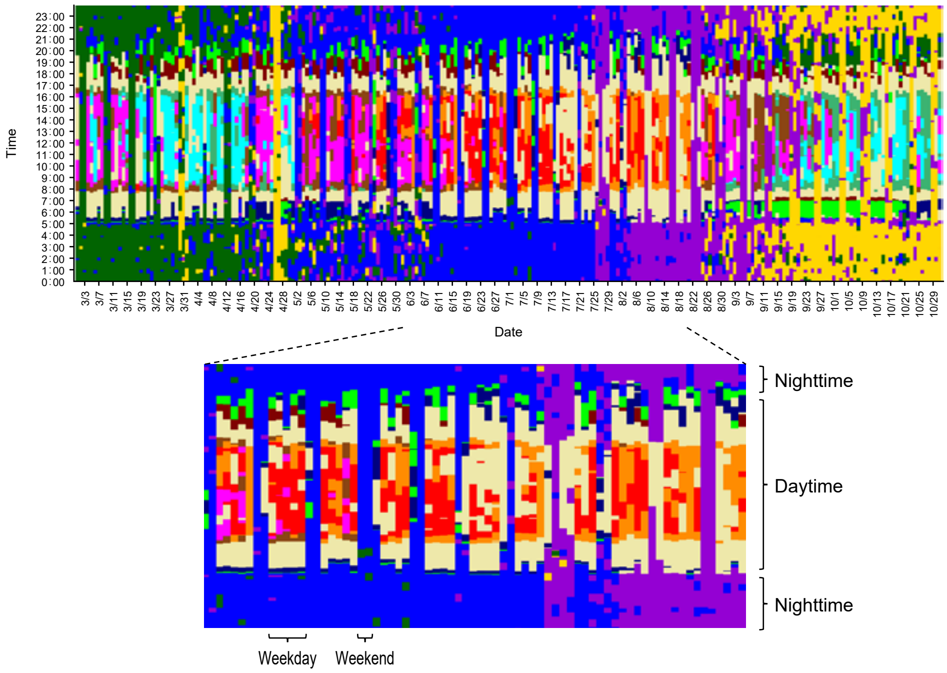

Fig. 2 Visualization of office building power consumption

3.2 Understanding operational objectives

In social infrastructure operations, evaluation indicators include not only cost reductions such as power and chemical costs, but also multiple items such as impacts on water quality and the environment, and safety. And depending on various conditions such as weather and events, the objectives considered particularly important also change. When interpreting operations from data, the goal settings for each period need to be understood correctly. Traditionally, to understand social infrastructure operations, investigations were conducted by conducting interviews with operators. However, it was difficult to comprehensively identify goal settings that change by period, and, given differences in individual viewpoints, it was also difficult to consolidate all opinions.

Therefore, to understand operations, we decided to use the visualization method outlined in 3.1. Using this method, we can aggregate and display changes over time and modifications to operating methods due to seasons. By classifying patterns on a daily basis, we were also able to quantitatively determine what operations were carried out, and how frequently. Figure 2 uses an office building as an example, allowing identification of when weekday–holiday differences and seasonal changes occurred. Given that periods such as “summer” can be defined from operation patterns, it has become possible to accurately estimate how much effect might be obtained from operational improvements during “summer” and what impacts there would be.

As outlined above, creating patterns using a plant state-transition model makes it possible to more clearly identify operational goals and issues. Furthermore, using these analysis results in interviews with operators is expected to help extract tacit knowledge and recall issues, enabling the discovery of issues that occur infrequently but have significant impact when they do occur, without overlooking them.

4. Exploring Solutions

Operational support solutions implemented in supervisory control systems generally often provide direct information, such as prediction functions and guidance functions. While these functions are effective for pre-assumed issues, for goals that need to be addressed in the future, such as population decline and environmental considerations, it has been difficult to guarantee output accuracy, and application and adjustment have been time-consuming.

For goals that require long-term efforts, the PDCA cycle is generally often used to drive continuous improvement. Going forward, as we transition from an era of infrastructure construction to one of maintenance and management, a similar approach is needed for supervisory control systems, and we believe that support functions will need to be implemented for each phase of the PDCA cycle. Examples of this are supporting the identification of issues through analysis of measurement data, or impact assessments when operations are changed—solutions that go beyond conventional guidance functions—can be considered; however, in developing these functions, rather than simply brainstorming, we believe that we can identify the issues that truly need to be solved and propose effective functions, by first understanding actual operations.

Using water supply as an example, the following outlines a case of exploring solutions using measurement data. Here, we applied the analysis method outlined in Chapter 2 to water supply data, visualized operation patterns, and classified them into patterns such as “fair weather” and “rainy weather.” Here, “rainy weather” refers to a period in which river water quality (turbidity) temporarily worsens due to rainfall, and differs from the actual rainfall period. Typically, increases in river turbidity continue for a certain period even after the rain stops; therefore, in water treatment processing, “rainy weather” is defined as “the period during which operations for rainy weather continue.” Using the analysis results, interviews with water supply utilities revealed a need for operational support for chemical injection control during rainy weather, leading to the start of concrete solution discussions.

Figure 3 shows examples of solutions created through discussions between our company and water supply utilities. In the functional study, we created various use cases and ideas, not limited to presenting guidance information, but also including functions for reviewing past cases and evaluating impacts associated with changes in operation patterns. All of these were obtained by sharing understanding between operators and developers based on information derived from value data analysis, and we found that measurement data analysis and patterning were also effective for facilitating communication among stakeholders.

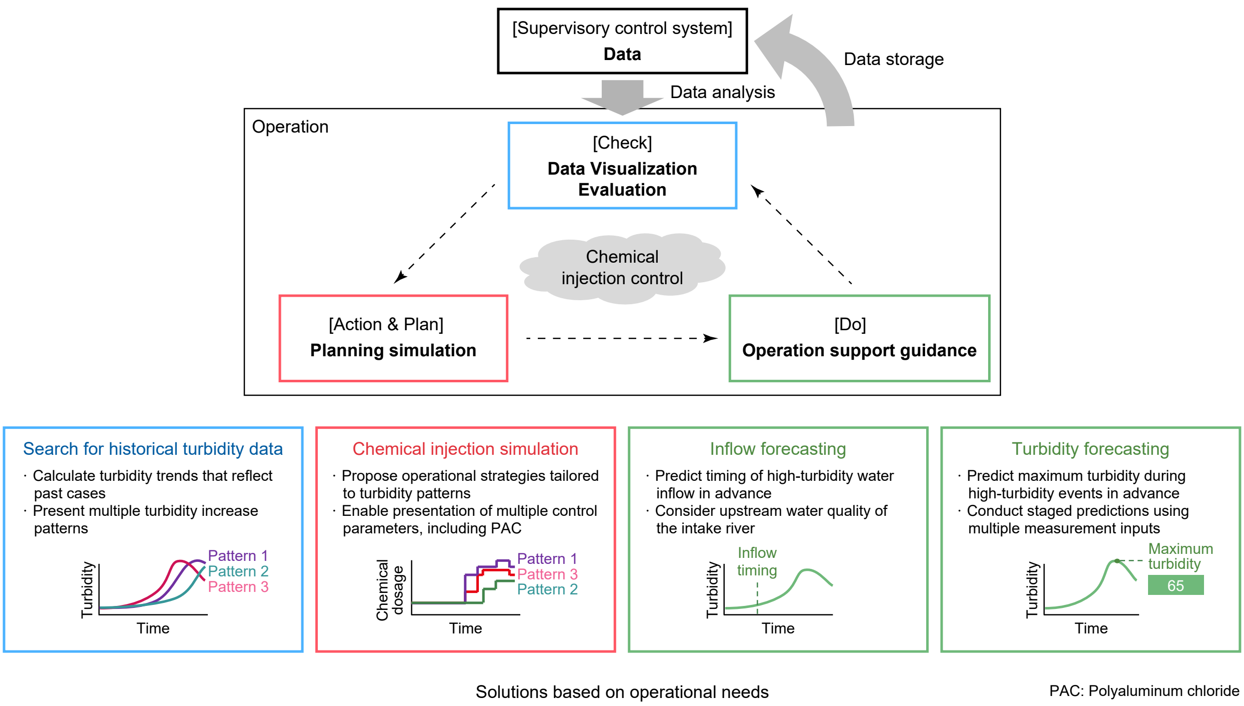

Fig. 3 Chemical injection solutions for water supply systems

5. Conclusion

In the social infrastructure business field, we introduced here a method for creating plant state-transition models based on time-series data accumulated in supervisory control systems, and case examples of solution creation using the state-transition models. Needs related to social infrastructure operations change daily, and we believe that quantitatively identifying and understanding the operations currently being performed through data analysis is effective for extracting new needs and creating solutions. We have also started examining solutions that apply this analysis method outside the water and wastewater business introduced here, and will continue to improve the method and develop tools as foundational technology for solution creation.

References

(1) Gotoda, K., et al.: Data Utilization Solutions for Water and Wastewater, Mitsubishi Denki Giho, 97, No. 7, 5-01-5-07 (2023)
(2) Nishida, K., et al.: Development of a Raw-water Turbidity Prediction and Operational Support System During Heavy Rain, 2024 National Conference (Water Supply Research Presentations) Proceedings, 190-191 (2024)
(3) Imai, K., et al.: Study on the Applicability of Plant State Classification Technology to Supervisory Control Data at Wastewater Treatment Plants, Proceedings of the Sewerage Research Presentation Conference, 60, 1192-1194 (2023)