A Case of Applying AI to an Ethylene Plant

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Unexpected equipment failures or maintenance may result in unscheduled plant shutdowns in continuously operating petrochemical plants such as ethylene plants. To avoid this, the operation status needs to be continuously monitored. However, since troubles in plants have various causes, it is difficult for human workers to precisely grasp the plant status and notice the signs of unexpected failures and need for maintenance. To solve this problem, we worked with a customer in an ethylene plant and developed a solution based on AI analysis. Using AI analysis based on customer feedback, we identified several factors from numerous sensor parameters and created an AI model that can grasp the plant status and detect any signs of abnormalities. This paper introduces a case study of AI analysis carried out in an ethylene plant and the new value that AI technology can offer to customers, and then describes how to extend the solution business with AI analysis.

INTRODUCTION

When a petrochemical plant is started up, typically it continues to operate on a yearly basis. If an unexpected equipment failure or maintenance occurs, it may cause the plant to shut down, resulting in a significant decrease in production and opportunity loss. To avoid this, the plant state is monitored constantly. However, it is not yet possible to detect signs of unexpected equipment failure in advance, and so maintenance is carried out only after a problem occurs. This is a major drawback in plant operation; there is an urgent need to detect signs of an event.

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Yokogawa has already published case studies on the use of AI technology in plants [(1)(2)(3)]. In this project, we worked on an ethylene plant as a type of petrochemical plant that suffers from the problem described above. Together with the customer, we solved the problem through AI-based analysis. Receiving feedback through workshops held with the customer, we combined Yokogawa's plant knowledge (domain knowledge) and AI to conduct analyses. As a result, we were able to identify causal parameters for each problem from hundreds of sensor parameters. The parameters were used to monitor the operational state of the equipment and create an AI model that can detect anomalies in the equipment and understand the plant state.

This paper introduces a case study of AI analysis in this project and describes the new value offered by AI technology. Furthermore, based on the experience in this project, we describe how to extend the problem-solving business with AI analysis.

Table 1 AI analyses conducted in the project

Case	Target equipment	Analysis
1	Acetylene reactor	Predict the decline in reactor efficiency
2	Ethylene product pump	Predict pump malfunction
3	Quench tower	Estimate the cause of high temperatures at the quench tower outlet
4	Cracking furnace	Create a key performance index (KPI) to determine the state of the furnace
5	Refrigeration compressor	Identify factors at the limit of compressor operation and create KPIs to understand the state
6	Refrigeration compressor	Same as in Case 5
7	Reactor (benzene production)	Create KPIs to understand the state of the reactor’s catalytic performance
8	Butadiene reactor	Predict the decline in reactor efficiency

AI ANALYSIS AT AN ETHYLENE PLANT

Ethylene Plant

Ethylene plants produce petrochemical products such as ethylene through pyrolysis, separation, and refinement of hydrocarbons [(4)(5)]. In a typical petrochemical complex, an ethylene plant feeds materials to other plants, and so must continuously operate on a yearly basis. However, when unexpected equipment problems occur during operation, the plant is forced to shut down. As a result, the annual production plan will not be achieved and ethylene will not be supplied to other petrochemical plants. Therefore, the impact of the shutdown is significant and not limited to the ethylene plant itself.

In an ethylene plant that operates continuously, avoiding unexpected problems that lead to plant shutdowns is a major challenge. Reducing the shutdown period is of great value to the customer.

AI Analysis

Table 1 shows AI analyses conducted in this project. We performed AI analyses on multiple problems in the ethylene plant to detect signs of problems and estimate contributing factors. This paper focuses on the following two analyses among those listed in Table 1.

- Case 7: Create KPIs to understand the state of the catalytic performance of the reactor
- Case 3: Estimate the cause of high temperatures at the quench tower outlet

Create KPIs to Understand the State of the Catalytic Performance of the Reactor

Target process

An ethylene plant produces cracked gasoline, from which benzene is produced. In this process, the raw materials are hydrogenated and impurities are removed in the reactor. To ensure stable, long-term operation of the reactor, it is necessary to change the amount of hydrogen to be added depending on the composition of the raw materials and to adjust temperature during the operation.

Problem at the customer’s plant

The catalyst in the reactor will gradually deteriorate, degrading the catalytic performance. However, since there is no way of knowing this exactly, catalysts are periodically activated or replaced regardless of whether they have deteriorated or not. This means that some catalysts are replaced even though they are still serviceable; such excessive maintenance is a problem.

Conversely, unexpectedly rapid deterioration of the catalyst will increase the concentration of impurities, resulting in defective products. This will affect various aspects of production: loss of raw materials, increased waste, increased costs and reduced production by defective products refluxing and passing through the reactor, and shutdown for emergency maintenance. Emergency maintenance incurs a longer downtime than planned maintenance, and has a significant impact on the annual production plan and makes it difficult to achieve the target.

Task to be tackled

To solve the above problem, we set the task of providing an indicator that can estimate and show the state of the catalytic performance of the reactor (Table 2). With such an indicator, it would be possible to detect signs of a decrease in performance due to catalyst deterioration. This would make it possible to prevent excessive maintenance and determine an appropriate timing, and also to draw up a maintenance plan in advance and thus shorten the shutdown period. We conducted an analysis to develop such an indicator and obtain these benefits.

Table 2 Customer's problem and tasks to be solved

Problem	The extent of performance deterioration due to catalyst deterioration in the reactor is not clear.
Task	Provide an indicator that can show the catalytic performance of the reactor.

Analysis and the results

For AI analysis, information during periods when equipment operated stably and the operation was suspended for maintenance is needed. Over the two-year target period, the reactor was shut down three times to replace the catalyst. Table 3 shows the reasons. The first and third sessions were periodic maintenance, which is carried out every six months. The second was an emergency maintenance, when impurities in the product exceeded the specified value. Information about maintenance only for activation (without replacement of the catalyst) was also obtained from the customer.

Table 3 Shutdown to replace the catalyst in the reactor

No.	Reason
1	Periodic maintenance
2	Emergency maintenance because of impurities exceeding the specified value
3	Periodic maintenance

In the information received from the customer, we used the process data during stable operation and those just before the emergency maintenance (the second shutdown in Table 3) as training data. The training data were analyzed by AI to create a training model, which was used to evaluate the two-year process data. Figure 1 shows the results. The horizontal axis is the time and the vertical axis is the health index, which indicates the catalytic performance of the reactor. A higher health index indicates a higher catalytic performance of the reactor and vice versa. The gray areas are the periods when the reactor was temporarily stopped to replace or activate the catalyst.

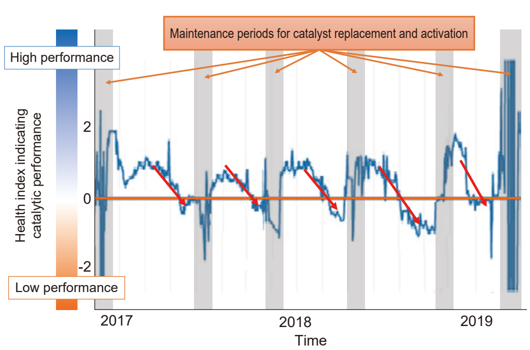

Figure 1 Estimating the catalytic performance (health index) of the reactor

The health index of the reactor estimated by AI shows that, after maintenance, the index became higher and the catalytic performance of the reactor returned to an excellent state. However, the health index decreased steadily over time and the catalytic performance of the reactor declined accordingly. During the period of low health index, the performance of the reactor deteriorated due to catalytic deterioration. This shows that if the reactor is kept running, the concentration of impurities in the product will exceed the specified value. By using AI technology, we identified an indicator that shows the catalytic performance of the reactor and provided it to the customer. We confirmed that this indicator could help customers to avoid excessive maintenance and draw up a maintenance plan in advance, and thus to reduce the maintenance period.

Estimating the Cause of High Temperatures at the Quench Tower Outlet

Target process

In ethylene plants, ethane, naphtha, and other raw materials are heated in a cracking furnace. To prevent excessive cracking, heated materials are sent to the quench tower, where cold water is sprayed for rapid cooling. The water used in this process becomes warm and the heat is recovered by various heat exchangers in the plant, and the cooled water is reused for the cooling process.

Problem at the customer's plant

During summer, the cooling performance at the top of the tower deteriorated and thus raw materials inside were not cooled as expected. The reaction at the top proceeded more than expected, making it difficult to separate necessary components. This was a serious problem resulting in lower yields and quality. To solve this problem, the customer had taken several measures and managed to curb the temperature rise. However, a detailed analysis was not conducted and thus the effect of these measures was not fully understood. Therefore, the customer was not sure which operating conditions affected the cooling performance of the tower.

Tasks to be tackled

To solve the problem, we set two tasks: from the plant data, (1) establish an indicator of an operating condition that presumably causes the temperature at the top of the quench tower to rise, and (2) identify a parameter closely related to this temperature rise (Table 4). By checking the indicator, operators could determine whether the current operation would lead to a temperature rise or not. By changing the parameter, operators could easily improve the operation. We conducted an analysis to address these two tasks.

Table 4 Customer's problem and tasks to be solved

Problem	High temperatures at the top of the quench tower during summer were reasonably solved, but the mechanism of the problem was not clear.
Task	(1) Provide an indicator that can show the operating condition causing the temperature rise at the top of the quench tower. (2) Identify parameters closely related to the temperature rise.

Analysis and results

Figure 2 shows the temperature trend at the top of the quench tower. From April to August in 2018, the temperature at the top of the quench tower exceeded 40°C. No similar trend was observed in the same period in 2019.

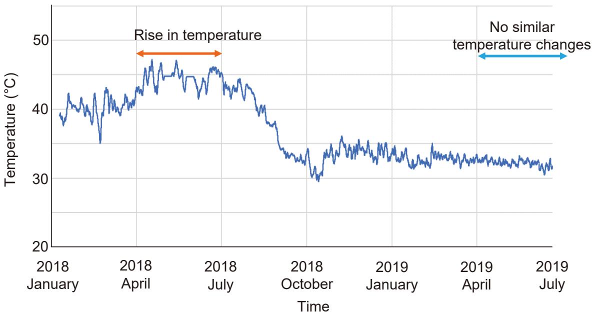

Figure 2 Temperature trend at the top of the quench tower

The customer's measures seem to have successfully suppressed the temperature rise. We used the data in these two periods as training data, performed AI analysis, and created a learning model.

The AI analysis suggested several candidate parameters including quench tower temperature and cooling water flow rate. Yokogawa's process experts checked the potential of these parameters and found that they actually affected the temperature and flow rate of the heat exchanger adjacent to the cooling tower and were closely related to the temperature rise at the top of the quench tower.

Operations over 18 months were evaluated with the developed learning model. Figure 3 shows the results. The horizontal axis is the time and the vertical axis is the health index of operating conditions, which may raise the temperature at the top of the quench tower. A higher health index shows that the operating condition is less likely to raise the temperature while a lower value indicates "more likely." The operating condition was poor during the summer of 2018. In contrast, it did not deteriorate in the following summer. The quench tower seemed to operate stably.

Figure 3 Estimation of quench tower operating conditions (health index)

By performing AI analysis on the plant data, we determined a health index that enabled operators to judge whether the current operating condition will raise the temperature at the top of the quench tower or not. In addition, we identified parameters that are closely related to the rise. When this indicator worsens, the operation can be improved easily and quickly by adjusting these parameters.

FINDINGS FROM THIS PROJECT

In this project, we surveyed the customer's requirements, identified what problem the customer really wanted to solve, and then performed an analysis. Working with the customer, we successfully completed the analysis project. Through this experience, we gained the following two findings:

1. New ways of using AI in plants
2. Need to work with customers for analysis

The following section discusses the details.

New Ways to Use AI in Plants

Customers' common requirement is to detect signs of abnormalities and identify the cause. In this analysis project, however, the customer's request was to make it easier for anyone to know the plant state. Anyone can monitor multiple sensor values, but not everyone can easily determine the state from these values. An appropriate state indicator can solve this problem. Therefore, the value needed in this case was to establish an indicator of the plant state.

In a plant, many sensors are used to continuously measure several conditions. Operators monitor the indications of these sensors to understand the current situation. If any problem occurs, they must respond to it. It is extremely difficult for human operators alone to handle all problems. Therefore, customers need a system that allows any operator to easily understand the state of the plant, identify which sensor to focus on when an error occurs, and make full use of the information for subsequent actions.

Solving this problem is valuable for ensuring the stable operation of the plant. Therefore, we introduced and used AI to identify the main factors of abnormal conditions and locate sensors that show the causes. We also found that an indicator is valuable to customers: with an appropriate indicator, everyone can easily understand the state of the plant without needing to monitor a large number of sensors.

Need to Work with Customers for Analysis

In this project, Yokogawa's experts worked with the customer to solve the problem. These experts included data scientists who analyze data, domain experts who have a wealth of knowledge about ethylene plants, engineers who build a system that incorporates a learning model, and other experts in various fields. In the process of solving the problem, we realized that combining AI with the knowledge of customers and domain experts could help solve intractable problems.

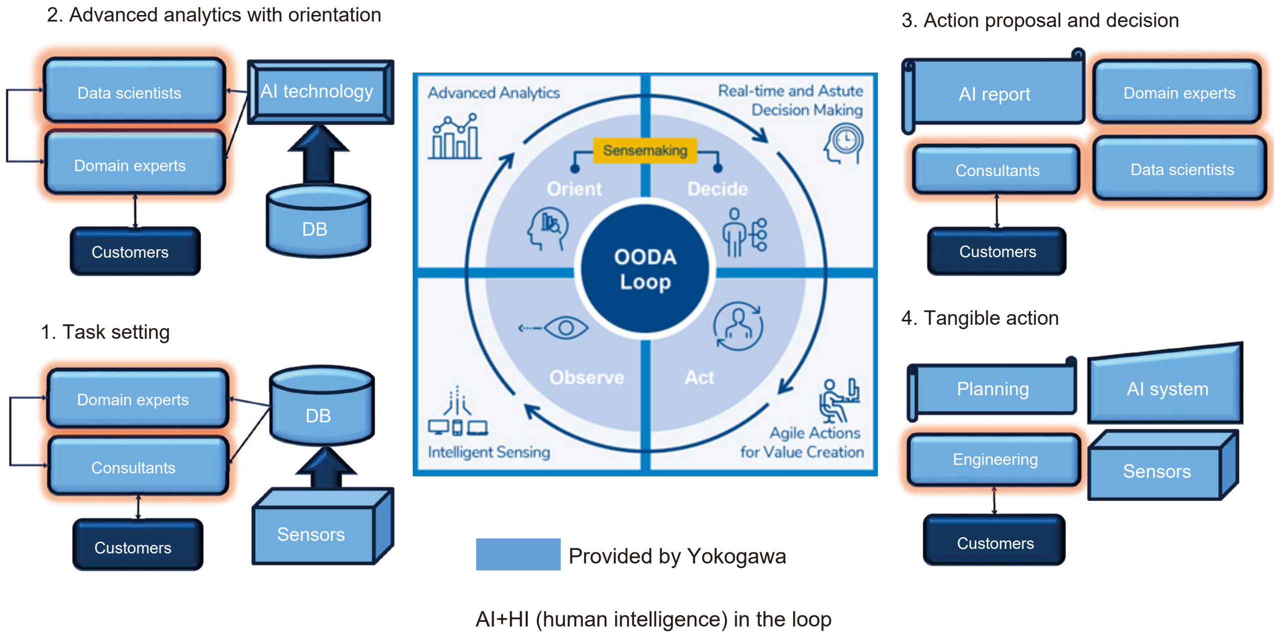

Figure 4 Problem-solving process combining AI and human knowledge

DEFINING THE PROCESS OF AI ANALYSIS

As described above, human knowledge as well as AI technology is an important factor in solving problems. The analysis process using human knowledge can be well explained in the OODA loop, which is attracting attention as an effective decision-making procedure. We combined AI and human knowledge and overlaid this problem-solving process on the OODA loop. This is the "AI+HI (human intelligence) in the loop" (Figure 4).

This process consists of the following four phases, which are carried out as a loop.

1. Task setting
2. Advanced analytics with orientation
3. Action proposal and decision
4. Tangible action

Details of each phase are described below.

1. Task Setting

In Phase 1, clarify the problem to be solved and set the goal (the state in which the problem has been solved). Yokogawa's domain experts and consultants participate in discussions and identify problems that the customer really wants to solve from among the problems that are occurring in the plant. Then, narrow down the process data and maintenance information necessary for analysis and translate the problem into specific tasks.

2. Advanced Analytics with Orientation

In Phase 2, discuss and decide in which direction the analysis should proceed to solve the tasks defined in Phase 1. Yokogawa's domain experts and data scientists clarify the data necessary to analyze the tasks and obtain them from the customer. Combine AI technology, domain knowledge, and data scientists' expertise, and make use of them with the data for analysis. Review the results with the customer in a timely manner and incorporate the knowledge of the customer into the analysis for better results.

3. Action Proposal and Decision

In Phase 3, based on the data analysis results agreed upon with the customer, examine and propose actions that use the results. If any new problem is found in the analysis results, propose returning to Phase 1 and carrying out the loop again. To systematize the results, propose the specifications of a system that can visualize the state and monitor the signs of anomalies based on the analysis results. For either proposal, agree with the customer on whether or not to implement it.

4. Tangible Action

In Phase 4, take actions in accordance with the proposal and decision agreed upon with the customer in Phase 3. To redefine tasks, return to Phase 1. To systematize the analysis results, based on the agreed system specifications, offer Yokogawa's total solutions including AI systems, edge computers, cloud environment, and their engineering.

By carrying out these four phases of the AI+HI approach in the loop, we will solve customers' problems.

CONCLUSION

This paper introduced a case study in which we worked with a customer to solve a problem in an ethylene plant by using AI technology. In this case study, AI analysis was extremely effective and we were able to offer value to the customer. Some values were found through discussions with the customer. To pursue the value that customers really seek, we will continue to work with them and help them improve their operations.

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