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LNG2023 FINAL PAPER

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PAPER TITLE: Mirror Plant System for LNG receiving terminal operation

Abstract (250 words):

Tokyo Gas Co., Ltd. is supplying city gas to the Tokyo metropolitan area by 4 LNG terminals.
Our LNG terminals have been in operation for more than 50 years, and the plant configuration has become more complex because of repeated expansions, requiring a high level of operational skills. We have established “Mirror Plant System” which is a unique Digital Twin technology and developed an "automatic evaluation system" for training results that can be applied to plant operation training.

This “Mirror Plant System” can calculate the unmeasurable internal temperature, pressure, and the gas quality such as calorific value, and their predicted value near future in the equipment and pipelines using dynamic process simulation model by the data collected from control system real-time. The gas quality near future is predicted and displayed when demand-supply balance changes by the start-up/shut-down of vaporizer, the abnormality of facility, and so on.

"Automatic Evaluation System" can evaluate training status automatically and quantitatively, which is effective in improving operator skills. This system realizes comprehensive evaluation including "confirmation by visual inspection or vocalization which is an important element in preventing human error by using eye tracking and voice recognition technology.

1. Introduction

Tokyo Gas has four city gas production terminals (LNG receiving terminals) and supplies city gas to about 11 million customers in Tokyo and eight prefectures, mainly in the Tokyo metropolitan area and to fuel for power generation. At the LNG receiving terminal, LNG is vaporized with seawater and mixed with LPG to adjust the calorific value. Distributed Control System (DCS) is used for the operation control, and the efficient operation is realized by automation. As a result, the number of facility troubles has decreased significantly compared to the early days of LNG terminals, but it will not be zero and will not occur at regular intervals. Therefore, we introduced Operator Training Simulator (OTS) to continuously maintain operation skills in the abnormal conditions. Regular trainings are conducted to start and stop equipment, as well as respond to abnormalities that are not normally experienced. It is also used as emergency response training, such as a total power outage at an LNG terminal, with the aim of strengthening team collaboration. The operator training simulator is a digital twin of the process, and it was built before the plant was constructed at the latest LNG terminal and is used to examine and verify the process and control system before operation. To safely meet the dynamically fluctuating demand of city gas in the region, an online digital twin "Mirror Plant" is built to improve and optimize LNG terminal operations. In addition, to continue the operator training effectively, a training evaluation system was constructed with the aim of uniform evaluation. This paper reports these advanced activities on digital twin at Tokyo Gas LNG terminals.

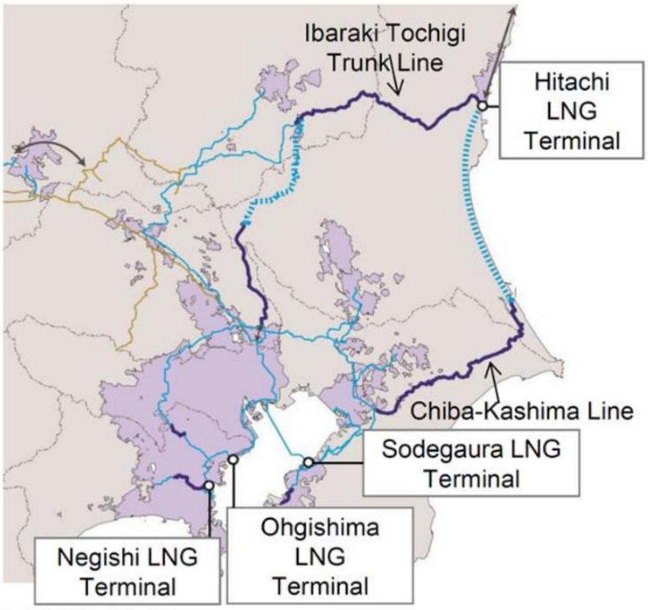


Fig.1 Tokyo Gas Group Supply Area

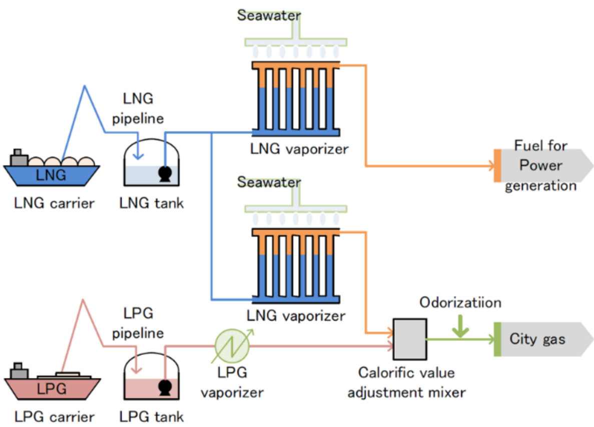


Fig2 Gas Production Process

2. Digital Twin Technologies

Omega Simulation was established in 1997 as a joint venture between Yokogawa Electric Corporation and Mitsui Chemicals, Inc. under the philosophy of “contributing to plant development based on simulation technology” and has provided over 500 OTS projects worldwide. It has achieved high-fidelity real-time simulation technology that reproduces the real plant dynamic behavior. Applications of dynamic simulators are not limited to OTS but are expanding to support systems for the validation of plant operation and the testing and adjustment of DCS before plant construction, and for the planning of energy-optimized and energy-saving operation. As a support system, we provide an online dynamic simulator “Mirror Plant" that simultaneously executes with real-time process data which will guide to safe and optimal operation. In addition, to efficiently produce a high-fidelity dynamic simulator, we are developing a technology that automatically reflects CAD information into the model and a technology that adjusts the model using actual operation data.

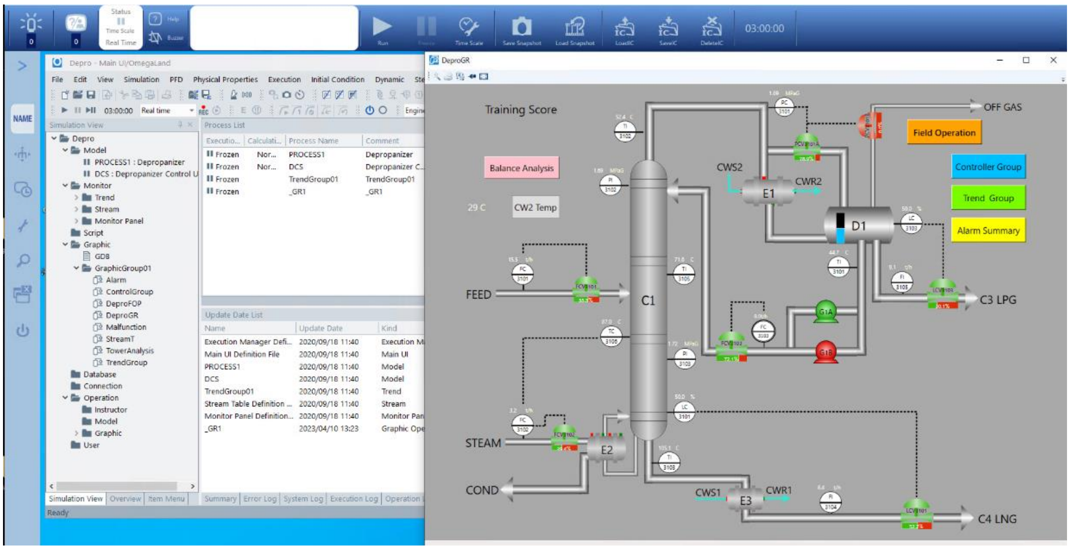


Fig.3 Graphical User Interface of Operator Training Simulator on Integrated Environment for Dynamic Simulation "OmegaLand"

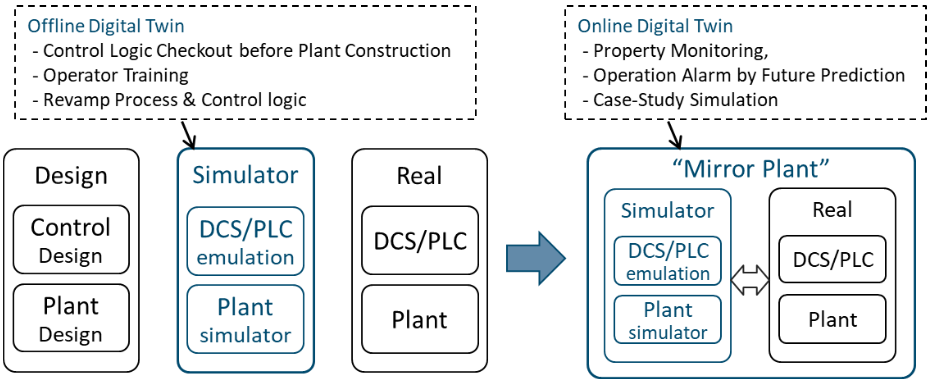


Fig.4 Digital Twin Solutions by Life Cycle Dynamic Simulator

"Mirror Plant" system was developed mainly for achieving the following three features.

1) Real-time estimation and display of the product quality value and fluid compositions that are normally measured with sampling and analysis. It can also display the temperature, pressure and composition distribution that are normally measured only at some points inside the reactor and distillation column.

2) Predict the future process response after the operations such as setpoint changes for controllers and valve operations, and guide operator to prevent dangerous situations such as unexpected high temperatures or high pressures, deviations from the target quality of products, etc. This system notifies the operator as early as possible in advance to prompt corrective action. Near-future prediction, for example, predicts plant dynamic behavior up to 30 minutes ahead with 20x speed simulation every minute and a half.

3) Carry out a case study from the current state of the plant to try out several operation methods to see if the objectives such as cost optimization, energy consumption reduction, and quality stabilization can be achieved or to find the optimal operation.

In addition, it is possible to get the current plant state obtained from Mirror Plant or the past state stored in the HDD and is used as the initial state for OTS offline operation training.

Fig.5 Online Digital Twin "Mirror Plant"

Tease features are achieved by the following technologies.

- ✓ high-fidelity process modeling technology
- ✓ control system connection and virtualization technology
- ✓ multi-simulation technology where the same models for three purposes such as tracking to the actual plant, future prediction, and case study analysis are executed in parallel

3. Digital Twin at LNG terminals

The LNG terminal receives LNG from tankers docked at the berth. After the vaporization process using the heat of seawater, natural gas is mixed with LPG to adjust the calorific value, and the addition of an odorant to give it the unique smell of city gas. It is delivered as city gas to customers through gas pipelines and to fuel for power generation.

3.1 Offline Digital Twin

The training simulator OTS, which was conventionally developed after the LNG terminal construction, was developed in advance during the construction of the latest LNG terminal. The following effects were obtained.

1) Conventional DCS software testing was limited to inspect individual control loop and sequence processing, but by using the OTS as plant simulator, it became possible to check the entire process control behavior.
2) Before commissioning, we were able to perform pre-tuning of the control parameters using the plant simulator.
3) The operators were fully trained in the DCS operation skills before the commissioning, and the contents of the operation procedure manual were reviewed in advance to thoroughly identify the important points.

Risks were minimized in advance, and it contributes to reduce commissioning period and to smooth progress.

3.2 Online Digital Twin “Mirror Plant”

Aiming to further improve LNG terminals operation, we built “Mirror Plant”, an online dynamic process simulator connected to DCS. We will introduce Mirror Plant installed at two LNG terminals in 2016 and 2019.

1) Display Calorific Value and Odorant Concentration

A monitoring overview of LNG terminal is shown below. In the conventional DCS display the calorific value and odorant concentration can only be confirmed at limited points by sampling and analysing system. On the other hand, since Mirror Plant simulates the entire area of the plant real-time, they can be displayed all any points. Since the status of the sent gas can be checked at all points anytime, it is possible to grasp how far the temporarily fluctuating gas has moved, and to take immediate action, such as pull the fluctuating gas back from the pipeline and treat it appropriately.

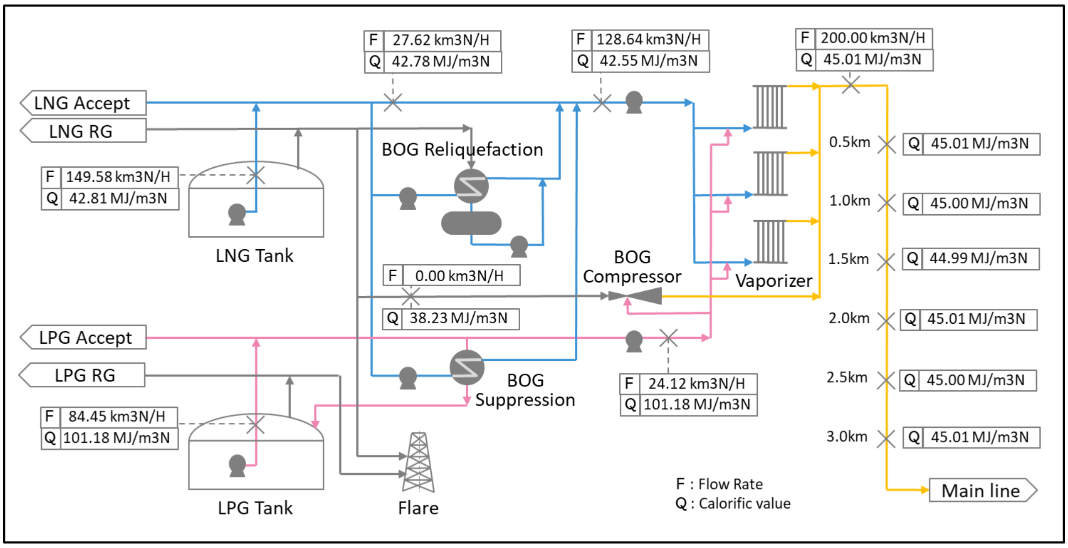
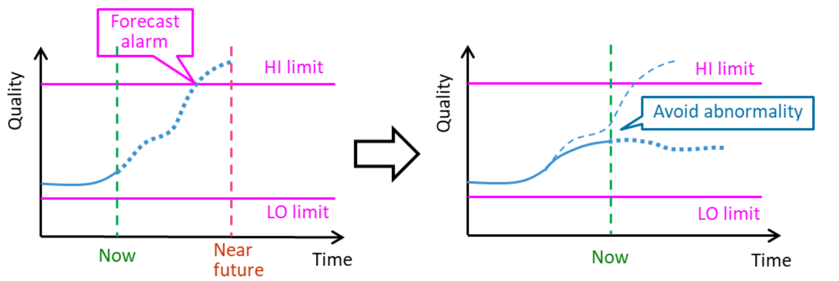


Fig.6 Mirror Plant Process Overview at LNG Terminal
(Odorizing equipment and odorant concentration display are omitted.)

2) Operation Support with Prediction Alarms

Mirror Plant predicts the dynamic behavior of the entire plant near future (several minutes to 10 minutes later) either periodically or at any time when requested. If an abnormal state is predicted to occur near future, it is possible to take prompt corrective action to the plant before the process abnormality occurs by presenting the alarm to the operator.



Forecast alarm shows future abnormality as early as possible, then it can be avoided before it happens

Fig.7 Prediction Alarms avoid abnormal event

This is realized by the multi-simulation technology that copies the process state from Mirror model running concurrently with actual process and predicts the future dynamic behavior by accelerated simulation at Forecasting model which is the same model as Mirror model.

The major monitoring points by prediction alarms are below.

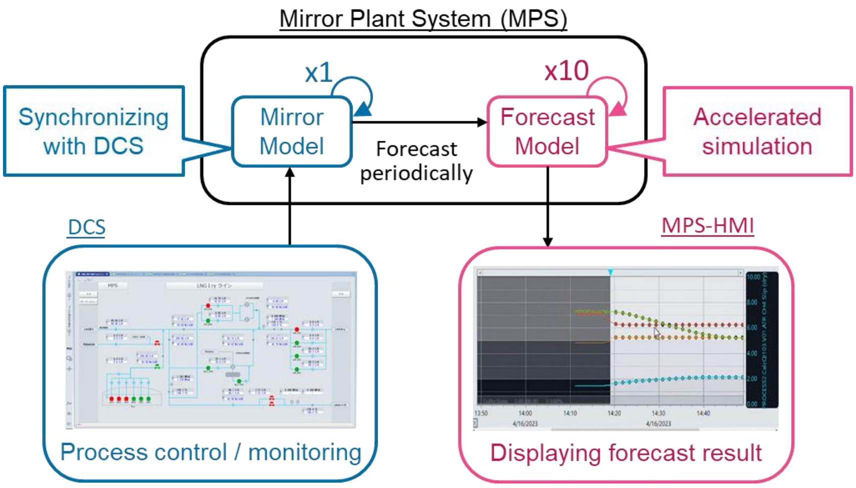


Fig.8 Mirror model and Forecast model by multi simulation

1) Boil of gas (BOG) in a tank: Tank pressure fluctuations by BOG is predicted to guide the start and stop operation of compressors or reliquefaction equipment associated with pressure fluctuations.
2) Calorific value: Calorific value fluctuation is predicted when vaporizer start, stop, or change in treatment volume.
3) Calorific value and odorant concentration of sent gas: They are predicted to support the emergency response.
4) Calorific value when Lorry Shipment starts: Calorific value is affected by lorry shipment.
5) Gas pressure decrease when production system stops: Gas pressure and flow rate to power plant is predicted.

The detail of Item 5 is shown below because it has the greatest impact on gas supply destinations.
If gas is supplied to power generation plant of infrastructure such as transportation, it is necessary to present an appropriate operation guideline when LNG terminal stops.

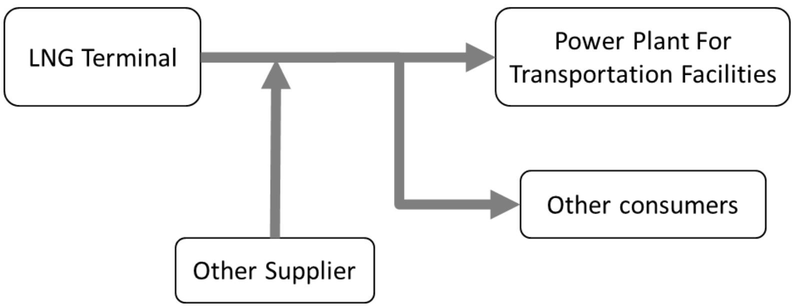


Fig.9 Gas Supply Network

The time until the gas pressure in the tank or in the piping drops to low limit is called “survival time”. The survival time is calculated by pressure and flow rate prediction after gas production facility stops, and the survival time with appropriate action guide is displayed. We consider the suspension of supply to other customers and acceptance from other suppliers. By clearly presenting the survival time, it became possible to respond to emergency appropriately according to exact prediction.

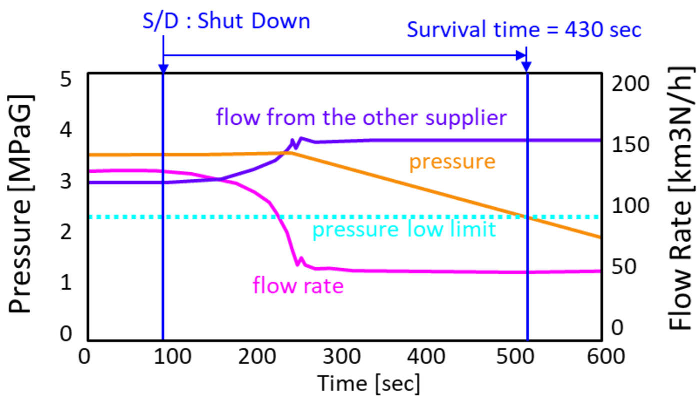


Fig.10 Survival time calculation by gas pressure and flow rate prediction

3) Case Study Simulations

In the case study simulations, the current plant state is obtained from DCS, and dynamic simulation of LNG terminal is executed with some plant operations such as valve opening/closing state, set point changes of controllers and so on. The three cases of plant dynamic response can be predicted and displayed on Mirror Plant HMI on predictive alarms and predictive trends. This function makes it possible to find the optimal operation and confirm the change of operating conditions will not cause process abnormalities throughout LNG terminal.

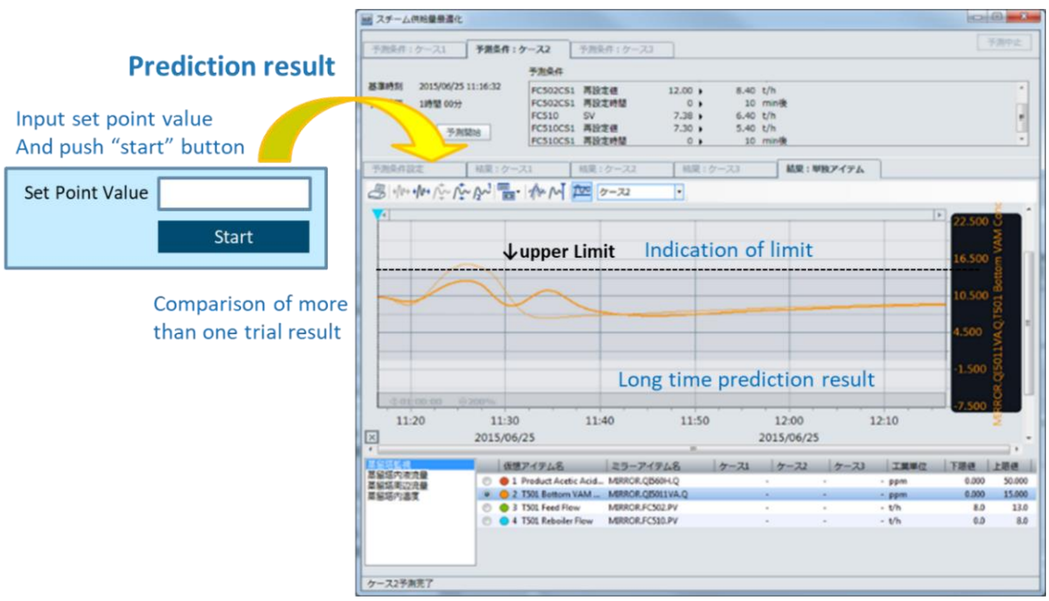


Fig.11 Case Study Simulations

4. Training Evaluation System

Operator Training Simulator is installed to maintain and improve operator skills, but it had some issues. As the training result is feedback to trainees based on instructor's knowledge and experience, the evaluation results are not uniform. It is not always possible to get training with feedback due to the lack of trainers. Therefore, we have developed a training evaluation system that automatically feedback training results quantitatively and concretely to trainees. This system includes a unique attempt to evaluate the visual confirmation and voice confirmation.

Most of LNG terminal operations are automated, if the following three points are correctly performed, stable operations can be continued in normal plant operations.

- ✓ The operating procedure is correct.
- ✓ The process variation by operations is limited within a certain range
- ✓ Pre-operation checks have been performed correctly

However, there are still many cases where these basic operations are missed and some troubles with many human factors occur.

The training evaluation system performs the following five specific evaluations for these items and converts them into the score.

1) Operation procedure
(Demerit point evaluation)

The number and order of operations of the trainee are compared to those of the instructor and evaluated.

As shown in the figure, the score is deducted if trainee performs operations that is not exist or different in the instructor's operation procedure.

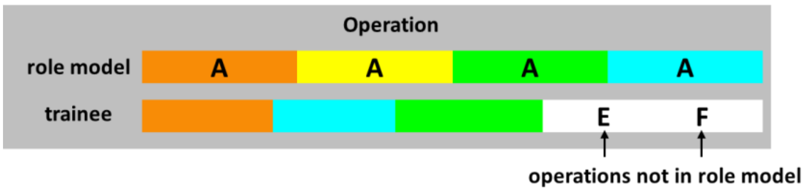


Fig.12 Evaluation of operation procedure

2) Process variation
(Demerit point evaluation)

Based on the instructor's operation, the process variation due to the trainee's operation is evaluated. As shown in the figure, set the target and upper/lower limits, and deduct the score according to the number of deviations from the standard and its area size. The evaluation start/end time can be defined by the operator.

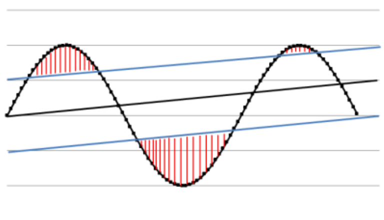


Fig.13 Evaluation of process

3) Operational stability
(Demerit point evaluation)

The number of warnings during the operation by trainee is compared with that of the instructor and evaluated. If the number is higher than the trainer as shown in the figure, the score is deducted. Similarly, regarding the number of operations, the number of operations by trainee and the number of operations by instructor are compared, and if there is a difference, the score is deducted.

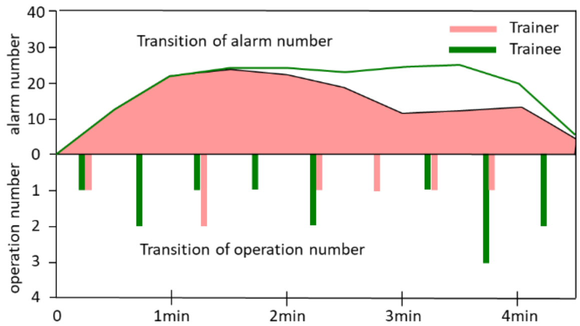


Fig.14 Evaluation of operational stability

Fig.13 Operational procedure and Fig.14 Operational stability are using software provided by Ube Information Systems, Inc.

4) Visual confirmation
(Additional point evaluation)

“Visually confirm the points to be checked” is an extremely important factor in preventing human error. Visual confirmation is evaluated using eye-tracking technology. The device uses technology that tracks the human line of sight and can quantitatively and specifically detect the "viewing order" and "viewing amount". We built a system that adds points when the line of sight of the person wearing eye tracking device captures the point at an appropriate timing.

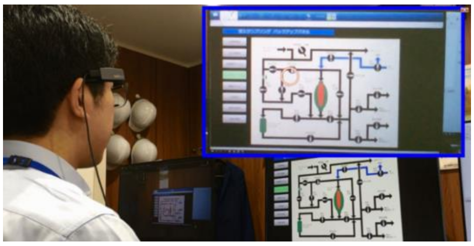


Fig.15 Evaluation of visual confirmation by eye tracking technology

5) Voice confirmation
(Additional point evaluation)

"Pointing and calling" when confirms the object and actions is also an extremely important factor in preventing human error. Voice confirmation is evaluated using speech recognition technology. The device uses technology that recognizes words spoken by humans and converts them into characters. It is possible to appropriately evaluate whether the trainee is confirming aloud. The system is developed in which points are added if a trainee wearing a speech recognition device utters at appropriate objects and actions at an appropriate timing.

Fig.16 Evaluation of voice confirmation

After finishing all the evaluation, the total evaluation result report is output by radar chart. The system also allows trainees to refer the addition/deduction points. Trainees can understand their own strengths and weaknesses by comparing them with the results of registered instructors. Reports are managed on a trainee basis, and it is possible to review the past training results and the history.

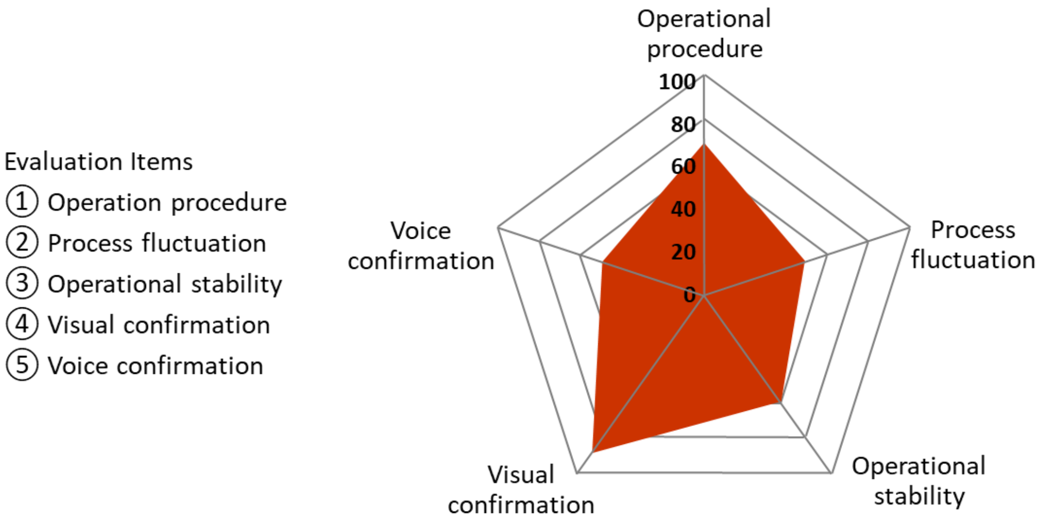


Fig.17 Total evaluation result display by radar chart

5. Conclusions

Online digital twin "Mirror Plant" has contributed to the advancement of LNG terminal operations. Furthermore, a training evaluation system that utilizes advanced technology on Operator Training Simulator was introduced to maintain operational capabilities organically and effectively. They contribute to safer and more efficient city gas production. We will continue to use the dynamic simulator and the related technologies. It is also expected to contribute to other fields and industries, including decarbonization and sustainable societies.

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