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The Role of Operator Training Simulator in Sustaining XYZ Plant Performance in the Digital Era

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Abstract

Background: In digital and highly dynamic business contexts, sustainable performances are essential to meet customer's expectation and to keep plant running smoothly and safely. However, many companies still adopted traditional training methods which are not sufficient enough to develop talent to reach expected competency level. XYZ plant faces multiple challenges to maintain its performance, yet continues to strain to speed-up talent development by adopting Operator Training Simulator (OTS) – high-fidelity digital imitation of real process plant.
Aims: This study aims to evaluate the role of OTS in sustaining XYZ plant performance and how the learnings can be documented and accessed readily by employees.
Methods: A case study uses a quantitative approach with a descriptive method was adopted in this research. Data were collected through quantitative direct observation to gain data on actual training sessions and document analysis related to OTS and plant performance.
Result: The findings show that despite from high dynamic business environments particularly manpower disturbances, the OTS support the company to develop its talent by enabling experienced-based learning to operate the plant in several scenarios and handling emergency situation in a free risk context, test and certify operator, and support the plant knowledge management system improvement. OTS application enhanced the employee knowledge and skills including problem-solving skills, emergency handling skills and communication skills.
Conclusion: The study concludes that OTS plays a critical role in sustaining plant performance by developing talent to reach its designed competency, improving knowledge preservation and information management, contributing to digital knowledge repositories, and learning archives.

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INTRODUCTION

In the petrochemical, oil, and gas companies that operate high-technology and high-risk chemicals, the role of panel operators, supervisors, and engineers is critical to ensure the plant runs safely, smoothly, and stably. Since an unstable plant operation can lead to quality issues, plant upsets, plant shutdowns, or even incidents in the plant.

Additionally, in the digital era, access to information is widely open to everyone; both employees and employers have unlimited access to resources, information, and opportunities. Consequently, changes in personnel in control room operations are inevitable. In this case, the company is at risk, operating the process production by inexperienced engineers and inexperienced panel operators who tend to have human error.

Human error may affect the process stability, product quality, and production rate that eventually will increase the production cost, delay the product delivery, downgraded the quality. Human errors lead to safety or operation incidents that will increase the production cost (Mariana et al., 2018). On the other hand, customers demand a high-quality product, delivered on time with an affordable cost. Accordingly, a traditional training method is no longer sufficient to meet these needs. Consequently, there is a need to have a training system and knowledge management system that allows engineers and operators to have experienced-based learning through an Operator Training Simulator (OTS) and a continuous learning system that can be accessed by the trainee / employee at any time within company information system.

LITERATURE REVIEW

OTS is an accurate-realistic digital that shaped as a replica of real process plant, operate an industrial process using dynamic simulation model through computer-based training system. OTS designed to imitate the real plant behaviour that enable trainees experience normal plant activities including, start-up, normal shut-down, troubleshoot plant issues, product grade transition, and respond properly to an emergency scenario, equipment malfunctions without having risk of loss of quality, production loses, safety incident and downtime (Kallakuri & Bahuguna, 2021; Philip, 2022**;** Lee & Ma, 2023; Aljaberi & Abd Rahman, 2023; Bělohlav et al., 2024).

Training with OTS will allow trainee to practice and develop their skills in realistic and evidence-based way to remove the gaps between theory and real-life industries (Cech & Vosahlo, 2022; Herink et al., 2022; Miska et al., 2022), in a risk-free circumstance. For students, OTS is a very important tool to display the interlink between many subjects of learning including physic, chemistry, chemical engineering, process control and automation (Belohlav, et al., 2024).

Currently the OTS technologies are moving rapidly, motivated by human error reduction, digital transformation, and increasing of industrial systems complexity. Moreover, the learning is not limited during the learning sessions, more importantly, it can be accessed by the DCS operator, Trainee, Engineers and Supervisors any time. It is critical to have a robust and reliable knowledge management system that store the learnings outcomes, operation scenarios, and training records or learning archives.

RESEARCH METHOD

This research adopts descriptive study that evaluate the role of the OTS in helping the company to develop the manpower to reach the expected level of competency. This investigation systematically reviews literature regarding operator training simulators to assess their efficacy in minimizing human errors and enhancing productivity within the hydrocarbon sector (Kallakuri & Bahuguna, 2021). By integrating Operator Training Simulators into the certification pipeline, facilities can provide a controlled environment for personnel to master process dynamics and disturbance handling without compromising actual plant safety (Cuypers et al., 2025; Yang et al., 2021). This architectural integration of digital twins and AI-driven decision support allows operators to practice mitigating complex transient states and pre-emergency scenarios that are otherwise inaccessible during routine production (Abbas et al., 2024; Abdullaeva, 2025).

Data were collected through quantitative direct observation to gain primary data including OTS training sessions, plant performance, and knowledge management system and documentation. Furthermore, these digital training environments facilitate the analysis of operator performance through the modeling of cognitive behaviors, ensuring that personnel are adequately prepared to manage abnormal situations and systemic risks (Balaji et al., 2023; Nizamova & Yashkina, 2025). By utilizing Human-Hardware-in-the-Loop simulations, these training frameworks effectively capture the interplay between operator decision-making and system performance, particularly during high-stress operational disturbances (Simone et al., 2026). The collected data was analysed using descriptive statistics to see the relationship between OTS training sessions and plant performance.

The study supports the previous study stated that OTS implementation will support the company to sustain it performances (Kallakuri & Bahuguna, 2021; Philip, 2022**;** Lee & Ma, 2023; Aljaberi & Abd Rahman, 2023; Bělohlav et al., 2024). These performances reflected by having high competent

manpower, high production target achievement, less off-grade product, less safety and quality incident that caused by human error, and continuous improvement. Consequently, the role of the OTS will be examined through three performance indicators including:

a. Manpower competency that was measured based on the number of certified DCS operators.
b. Effective emergency handling that was evaluated based on the total number of incidents that caused by human error.
c. High production target achievement assessed based on ratio between actual production and target production and ratio between off-grade product and total production.

A certified DCS operator will be granted to the employee who passes both the theoretical and practical tests and has been working independently without supervision from a superior. They are expected to run the plant smoothly and safely. While an incident in this case is an unplanned, often undesired event or occurrence that disturbs the normal procedures and has the potential to cause process disruption, damage, or harm. While an off-grade product is a product that is out of the quality specification. To mitigate these risks, operators must utilize abnormal situation management to identify precursor events before they escalate into significant incidents or accidents (Liu et al., 2023).

Furthermore, the integration of advanced technologies such as predictive maintenance and digital twins serves to augment the operator's decision-making capabilities during these critical transitions (Onyekwe et al., 2022). Moreover, simulation-based training integrated with digital twins has proven instrumental in enhancing human reliability, as it allows personnel to master complex transient and pre-emergency operating modes that are otherwise difficult to replicate (Abdullaeva, 2025). Such training environments enable operators to refine their disturbance rejection tasks and diagnostic accuracy through repetitive exposure to abnormal scenarios (Balaji et al., 2023, p. 1). Consequently, these simulation-based learning frameworks facilitate the acquisition of essential process safety skills and operational proficiency, ultimately reducing risks and improving overall plant efficiency (Cuypers et al., 2025). By implementing these standardized, simulation-driven qualification methods, organizations can effectively address the industry-wide "brain drain" and ensure consistent operational knowledge across all shifts (Alaa, 2024).

CASE STUDY IN XZY PLANT

XYZ company is a multinational manufactu company that adopts high-technology and involves hazardous chemical. The company operates at high pressure and temperature that producing polymer product through polymerization exothermic reaction. Recently, the company struggle to maintain high level competency of employee due to volatile business environment and high employee turnover, some employees were reaching retirement period, some others moving to others companies. Meanwhile, customer demand high quality products in short time period.

As a part of digital transformation strategy to cope with this situation, OTS was applied to train new engineers, supervisors and operators using a high accuracy replica of real-life industries. Additionally, the OTS also adopted to conduct study for plant improvement and simulate the incident for incident investigation purposes.

OTS consist of four stations, one station is dedicated for Trainer with super user access, the remaining three stations are used for trainees which displayed like the DCS operator stations. The model of the OTS was developed as an imitation of the real process of XYZ plant. The participants were trained in three different level starting from introduction, operation, problem solving and emergency handling. Following is sample of training sessions.

Table 1. Training Session Example.

No.	Module	Situation	Response
1	Process Control Basic	Display the basic of process control of polymerization	Trainee locate the controller and practice how to control the level, pressure and temperature in simple process / equipment
2	Interlock	Explain the interlock Type, function and	Trainee locate the interlock location on the DCS page and identify the consequences when it activated.

No.	Module	Situation	Response
		location in Operator Station	
3	Alarm and Trends	Display alarm and create the necessary Trend	Locate the DCS and System Alarms, take action to normalize the process and communicate to Field Operator

In practical assessment or certification test session, trainees were asked to complete various tasks starting from a simple of operation task such as open and close manual valve, start and stop pumps, until handling a complex plant operation including plant start-up, grade transition, and handling normal and emergency shutdown.

Table 2. Problem Solving Scenario Example.

Case No.	Scenario	Emergency Situation	Response
1	Automatic Valve malfunction	Feeds Valve Close Suddenly	Adjust the production rate and feed ratios, communicate to Field Operator and Instrument Technician to fix the issue
2	Compressor Failure	Recovery Compressor Stop due to snubber high high-level alarm	Check the first out alarm, Communicate to Field Operator to drain the level in discharge snubber, re-start the compressor
3	Quality off spec	MFR test result from LAB is out of spec	Check the H2/C2 ratios in reactor, check the analyser performance, adjust the H2 feeds to

While completing tasks, the trainees assessed the problem, decided the solution, and took a proper action by involving field operator, superior, technicians from difference disciplines including laboratory, instrument, electrical, analyser and mechanical. Accordingly, it allows operator developed their problem-solving skills, communication skills and handling emergency effectively. The problem solving communication diagram can be seen at figure 1.

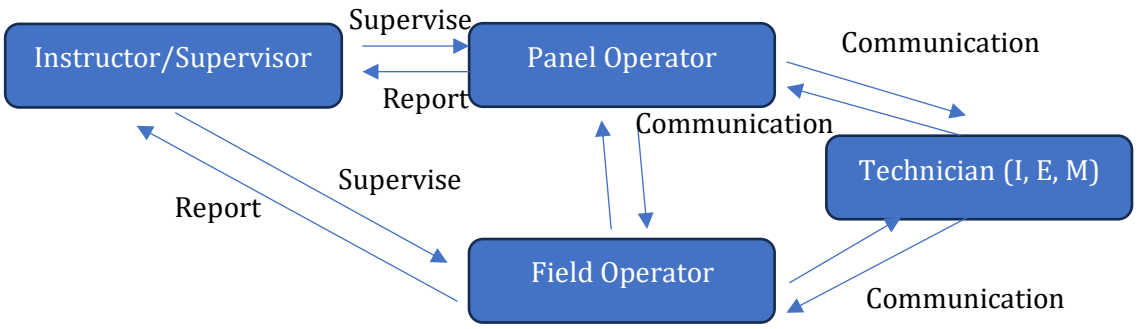

Figure 1. Problem Solving Communication Diagram.

Additionally, OTS is use to provide refresher training and testing, certifying operator to reach required competencies based on their personal development plan, and support to define and review the different kind of operating conditions starting from design till enhancement of current condition.

XYZ company has built an online learning platform where all learnings documented and kept in the shared folder that can be accessed by the employees using credential password. The learnings gained from the OTS is also recorded and documented and integrated to this online learning system. Accordingly, OTS learnings outcome enriches company's digital knowledge repositories, and when the trainee back to their shift team, or back to their office, they can review and discuss it with their mentor or superior. The online learning platform structure or digital knowledge assets can be seen at figure 2.

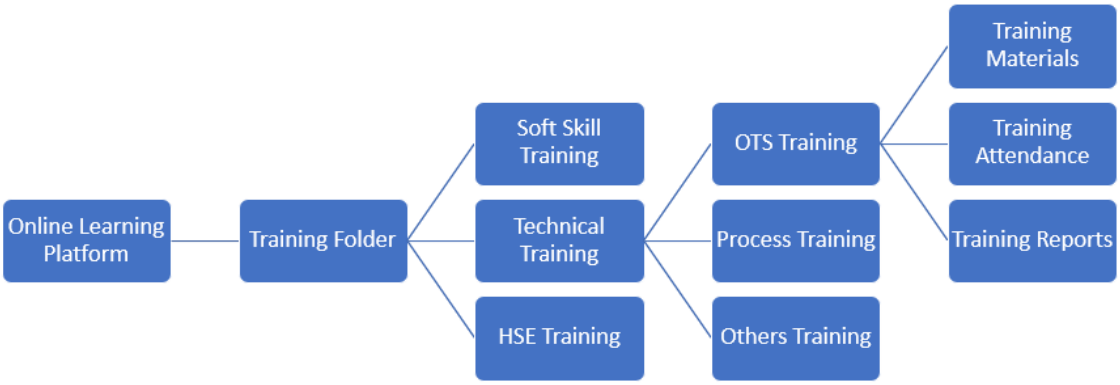

Figure 2. Online learning platform

The training attendance data have been recorded, documented and stored in the digital online learning platform that can be used by management to assess the employee for performance management and also can be accessed by auditor for any audit or re-certification purposes.

Moreover, OTS learning sessions' outcomes support the company to enrich its digital knowledge assets by documenting, storing the learnings, training records, training data/attendance in an online learning platform and shared folder. Leverage digital information management and knowledge preservation by allowing respected employee to access it anytime and involving employee on knowledge improvement.

RESULTS AND DISCUSSION

Results

A total of 100 employees were attended OTS training sessions from difference positions. On the first year 24 operators were trained, however only 2 operators got certified. The number of certified operators increased in next three consecutive years, 18, 22, 25 and in 5th year 20 operator were certified, a total of 87 from 105 trained operator that accounted 83% as displayed at Figure 2. These results displayed that OTS support the company to develop talent to the expected level of competency.

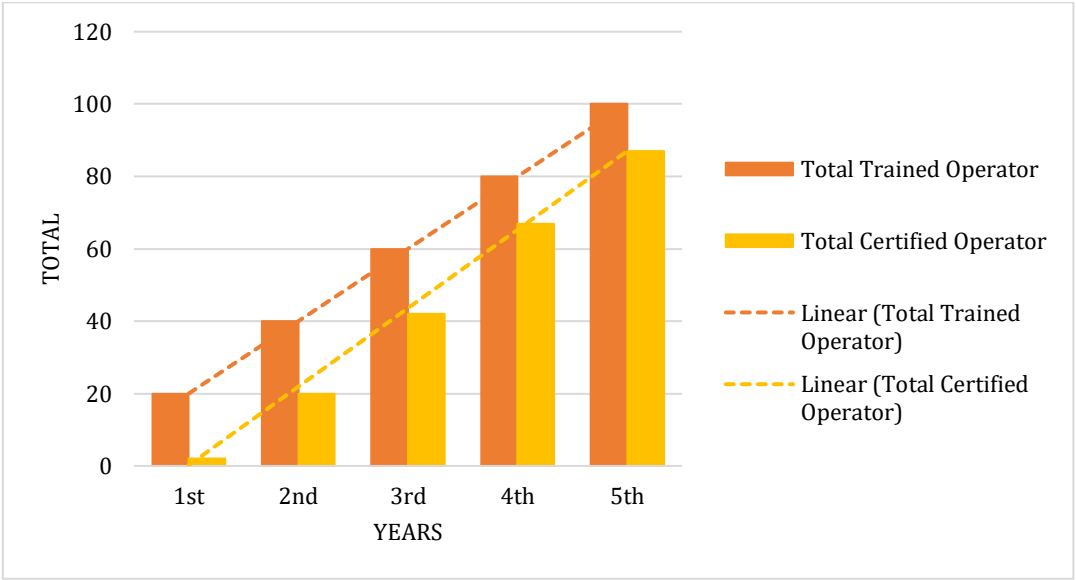

Figure 3. Employee Certification

There were 116 total process incidents occurred in XYZ plant were investigated, only 49 were due to human error, even though the total incidents increased but the incidents due to human error decreased significantly every year as displayed at figure 3. In 1st year, human error account 56%,

decreased to 55% on the following year, and it continue decreased to 41%, 35%, 25%. These results tell us that OTS help DCS operators to handle process upset properly.

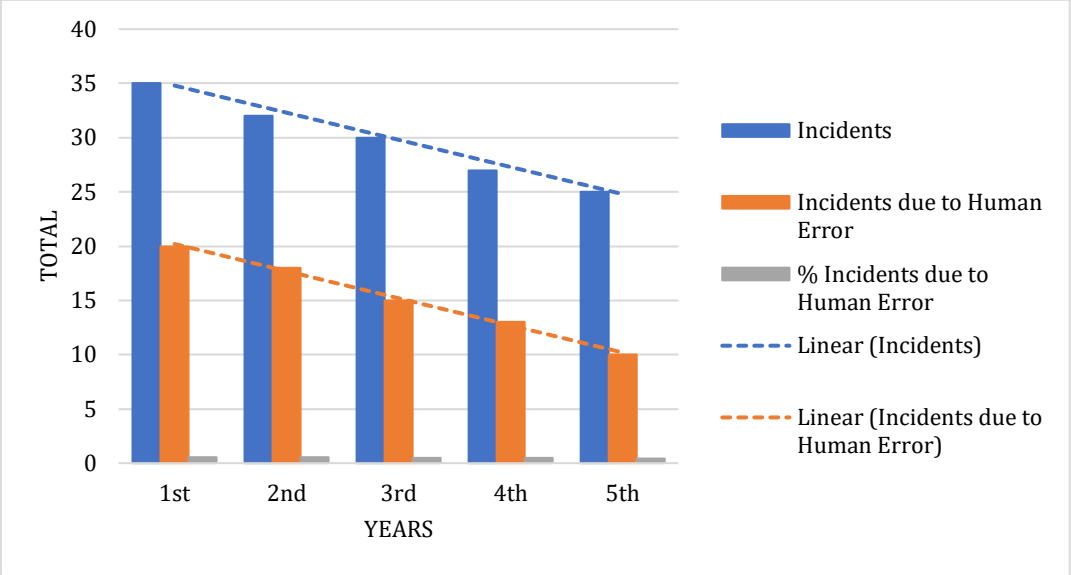

Figure 4. Incidents in XYZ Plant

The actual production volume was collected and compared with the targeted production volume on respected year. The results displayed that production achievement was increasing from the first year of implementing OTS it reached 95.4% followed by 96.2%, 101.2 %, 103.8%, and 106.4%, as displayed at figure 4. Similarly for product quality achievement as displayed on the figure 5 was increasing slightly on average of 2.75% yearly. These, results shed the light that OTS support the company to achieve company goal.

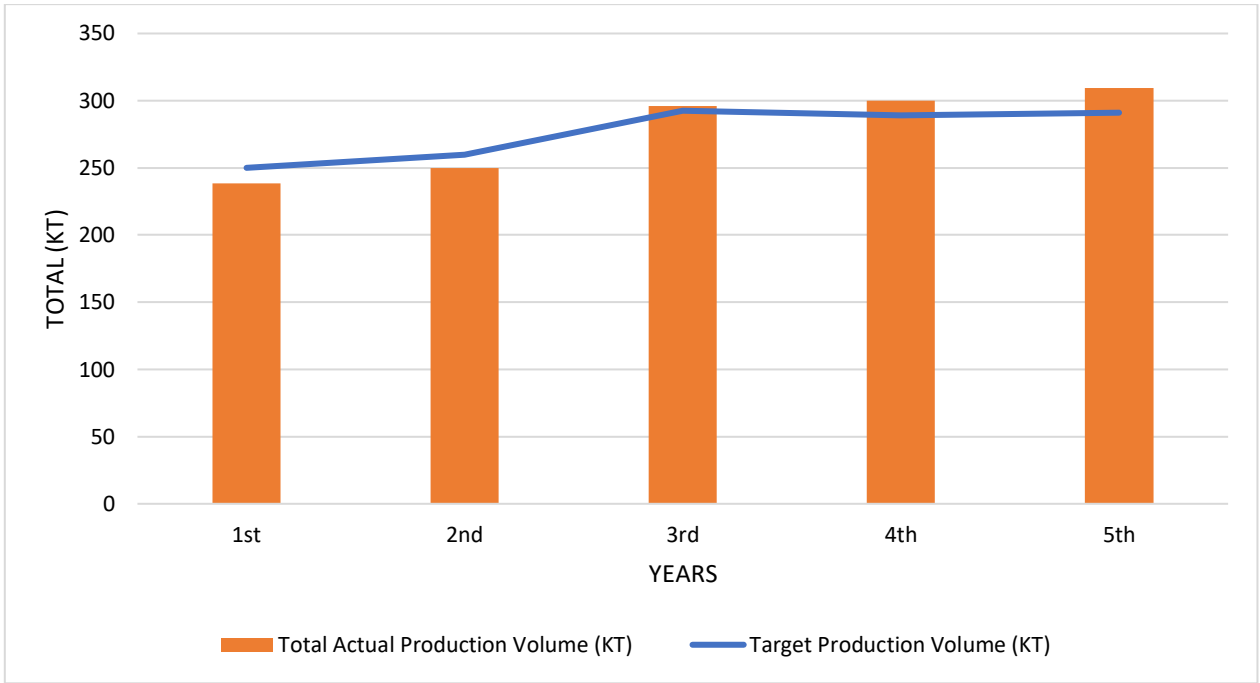

Figure 5. Target Vs Actual Production

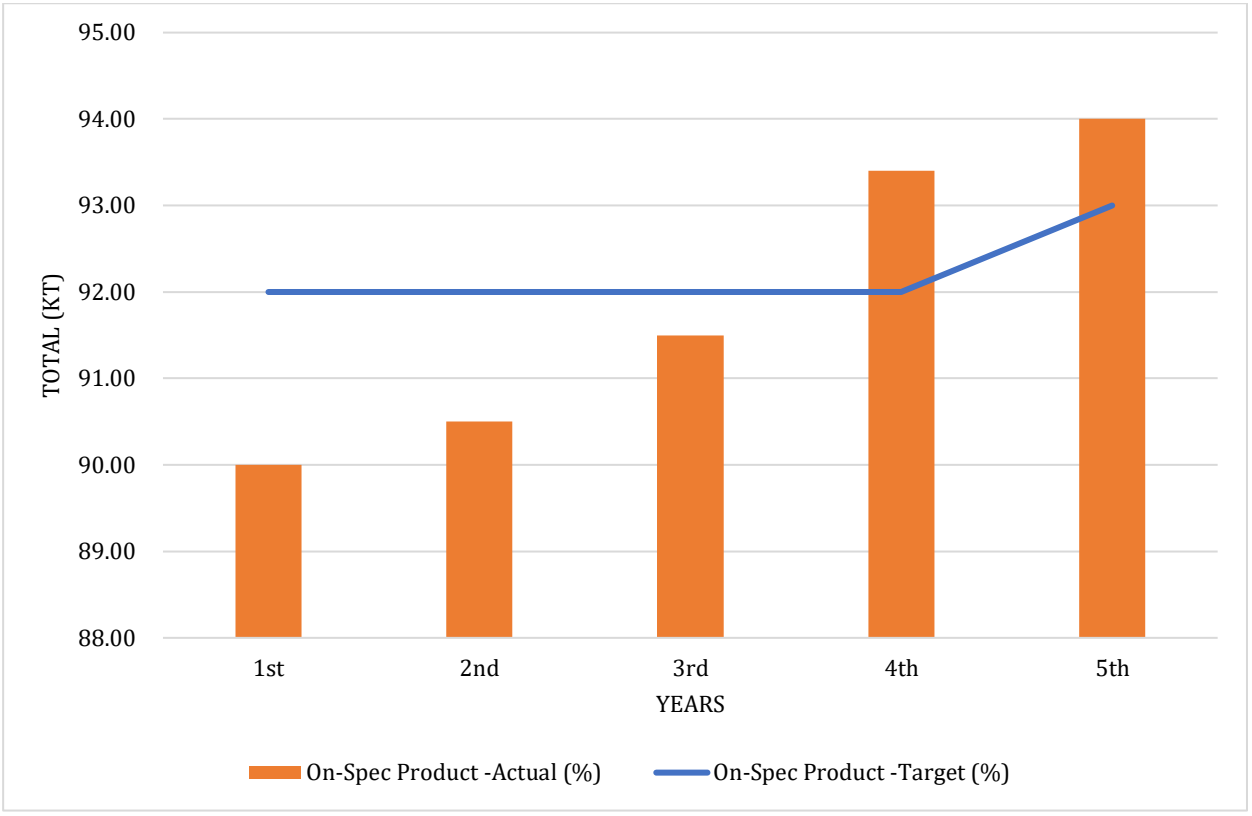

Figure 6. Product Quality

From the above-mentioned results, it is demonstrated that the application of OTS in XYZ company improves employee competency, reduces operational errors, improves emergency response and enhances knowledge preservation.

Discussion

The results of this study reinforce previous findings that Operator Training Simulator (OTS) plays a strategic role in improving operational reliability and organizational performance in high-risk industries such as petrochemical and oil and gas plants. OTS provides a realistic and risk-free learning environment that allows operators to gain practical experience before handling real plant operations. This experiential learning process is particularly important in the digital era, where operational complexity and workforce mobility continue to increase. In line with this, the development of training simulators embedded with instructional design models has been shown to support lifelong learning, improve training transfer to the workplace, and help prevent human errors in plant operations (Kallakuri & Bahuguna, 2021).

The improvement in employee competency demonstrates that digital twin technologies can shorten the learning curve for newly recruited operators and engineers. Through repetitive scenario-based exercises, trainees become more familiar with abnormal conditions, process disturbances, and emergency situations. Consequently, operators are better prepared to respond effectively during actual plant operations. Empirical evidence supports this claim: a study integrating Digital Twin technology into an active learning environment demonstrated a significant improvement in trainees' accuracy and efficiency, with a 38% reduction in task execution time, attributed to the system's capability to simulate actuator and sensor behavior under real-world conditions (Ortiz et al., 2025). Additionally, a cognitive ACT-R-based human digital twin approach developed for process industries proved capable of providing a holistic assessment of operator performance and supporting timely decision-making under dynamically changing process conditions (Balaji et al., 2023).

The decrease in incidents caused by human error also underscores OTS's contribution to operational safety and reliability. Human error remains a primary cause of industrial accidents in the

process industries. Therefore, continuous simulator-based training strengthens operational discipline, communication effectiveness, and coordination among multidisciplinary teams. In this context, OTS not only functions as a training tool but also as a preventive safety management instrument. Recent data reinforces the urgency of this matter: human factors have been identified as the primary cause of more than 80% of accidents in the chemical and petrochemical industries, where human and organizational factors play an essential role in most incidents (Huang et al., 2024). Gonyora et al. (2024) further emphasized that process safety incidents rarely stem from a single cause. Rather, they typically arise from an interplay of contributing factors, among which inadequate workforce training, poor hazard control practices, and routine operational mistakes have been repeatedly documented as the most prevalent triggers across the chemical process industry.

Additionally, integrating OTS learning outcomes into the company's online learning platform strengthens organizational knowledge retention. Documenting training scenarios, incident simulations, operator assessments, and operational best practices creates digital knowledge repositories that support continuous organizational learning. This capability is highly relevant in the digital transformation era, where knowledge management and information accessibility are becoming critical organizational assets. The oil and gas industry is increasingly embracing knowledge management processes in response to the Fourth Industrial Revolution (Industry 4.0), which drives the adoption of digital technologies to foster innovation, enhance production, and enable more efficient operations; in this context, knowledge has become an indispensable element of organizational success (David & Gupta, 2024). Moreover, knowledge management integrated within a learning organization framework has been shown to significantly contribute to organizational performance in the digital era, where information accessibility and knowledge transfer serve as the foundation of long-term competitive advantage (Firmansyah et al., 2022). Therefore, the digital knowledge repositories built from OTS training outcomes function not merely as operational archives, but as strategic assets that sustain the organization's long-term competitive excellence.

Implications

This study has practical implications for petrochemical and oil and gas companies that aim to sustain operational excellence amid workforce changes and digital transformation. The findings suggest that companies should invest in OTS technology not only as a training facility but also as part of strategic knowledge management and operational risk reduction initiatives.

From a managerial perspective, OTS can support competency certification programs, succession planning, and workforce readiness. Furthermore, integrating simulator learning outcomes into digital repositories enables organizations to preserve tacit operational knowledge from experienced employees before they retire or leave.

Research contribution

This study contributes to the existing literature by providing empirical evidence regarding the role of OTS in sustaining plant performance through competency development, operational reliability improvement, and digital knowledge preservation. Unlike previous studies that mainly focused on technical simulation aspects, this research emphasizes the integration between OTS, organizational learning, and digital knowledge management systems.

Moreover, the study enriches the discussion on how digital twin technologies can support long-term organizational sustainability in high-risk industries through continuous learning and information management practices.

Limitations

This study has several limitations. First, the research was conducted at a single petrochemical company, which may limit the generalizability of the findings to other industries or operational contexts. Second, the study primarily employed a descriptive, quantitative approach, without advanced statistical analysis, to assess causal relationships between OTS implementation and operational performance indicators. Additionally, some operational data on safety performance and financial impacts could not be disclosed in full due to the company's confidentiality policies.

Suggestions

Future studies are recommended to apply more comprehensive statistical methods to evaluate the direct impact of OTS implementation on operational efficiency, safety performance, and financial outcomes. Comparative studies involving multiple companies or industries would also provide broader insights regarding the effectiveness of simulator-based training systems.

In addition, future research may explore integrating artificial intelligence, virtual reality, and predictive analytics into OTS platforms to further enhance immersive learning experiences and operational decision-making capabilities.

CONCLUSION

This study concluded that Operator Training Simulator (OTS) provide essential aids to develop talent to meet the required employee competency by enabling experienced-based learning to operate the plant in several scenarios and handling emergency situation in a free risk context, test and certify operator, and support the plant knowledge management system improvement. Further, the case study from XYZ plant shed the light that OTS plays a significant role in maintaining company performance in digital era, accelerating talent development, leveraging the worker readiness, enhancing problem-solving skills and emergency handing capabilities, by using the digital twin technology OTS, integrating the OTS learnings' outcome, operation scenarios, simulation training records into an online learning platform and shared folder within industrial information system that can be accessed by employee anytime.

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AUTHOR CONTRIBUTION STATEMENT

The author was responsible for the conceptualization, data collection, methodology development, analysis, interpretation of findings, and manuscript preparation. The author also conducted the literature review, case study analysis, and final revision of the manuscript.

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