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# Design and Evaluation of AR-Based Maintenance System for a Steam Jet Ejector of a Geothermal Power Plant

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***Abstract* — This research aimed to explore the design and evaluation of Augmented Reality (AR) system for maintenance activities in a Geothermal power plant. In addition, AR system was implemented through HoloLens 2 and integrated with digital manuals to determine the maintenance procedures and machine condition parameters. The evaluation of this system was conducted by comparing the effectiveness of smart maintenance using AR with traditional manual maintenance activities. Based on the maintenance effectivity scale of 0-4, the implementation of AR-based system was 2.38. The result showed that AR system partially improved maintenance activities, reduced the data collection process, and enhanced the visibility of the manual procedures.**

***Keywords — augmented reality, stem jet ejector, Gunung Salak geothermal power plant, maintenance***

## I. INTRODUCTION

The quality of output products in any industrial setting is directly associated to the optimal condition of facilities and machinery. This optimal quality relies on the implementation of suitable equipment and machinery maintenance processes [1]. Therefore, the maintenance function uses digital technology to transform industrial processes, which offers effective solutions to related challenges [2]. The digital integration into maintenance processes is known as smart maintenance (SM). It is defined as an organizational framework that uses digital technology to manage maintenance in the manufacturing plant environment [3]. One digital technology that can be used for maintenance functions is augmented reality (AR), which effortlessly combines real-world and virtual objects in real time [4]. The application of this technology is considered suitable for maintenance functions because it serves as a guide for workers in factory environments, identifies hazardous areas, and makes hidden issues visible [5]. The main goal of implementing AR is to enhance the quality and efficiency of facility and machinery maintenance in the industrial sector [6].

Gunung Salak Geothermal Power Plant, currently rated as an INDI 4.0 level 2 (intermediate level) facility [1], needs to undertake comprehensive digitalization improvements in various aspects, such as human resources [2] and industrial facilities. One of the critical elements of this digital transformation is the Gas Removal System (GRS), which is used to maintain vacuum conditions in the condenser, thereby facilitating the efficient condensation of steam generated by the turbine. The significance of maintaining these optimal vacuum conditions lies in the fact that deviations led to a higher boiling point of steam. This reduced steam condensation, thereby disrupting the performance of the turbine and the entire system in the power generation facility. In July 2023, the average absolute pressure in Gunung Salak Geothermal Power plant condenser was recorded at 13 bar. However, this pressure fluctuated within the month, with vacuum levels being lower at the start. One of the available methods that can be used to correct this is by improving the GRS through digitalization to address these variations and improve performance [3][4]. This is achieved by conducting appropriate maintenance on critical components, such as the steam jet ejector.

Maintenance refers to all activities and actions taken to preserve or restore equipment to the desired operational level, enabling it to perform the necessary functions [5]. Effective maintenance planning is a crucial process and a determining factor of success in the manufacturing sector [6]. Neglecting maintenance can result in production losses, reduced efficiency, and machine lifespan [7]. In addition, there are two main types of maintenance, namely corrective and preventive. Corrective Maintenance (CM) is conducted in response to damage or failure in industrial facilities. It is performed to identify and rectify the root causes of failure in system that has malfunctioned [8]. These activities become necessary when unexpected failure occurs, as it aids in restoring failed machines to the original condition [7]. The CM activities rely on the knowledge and decisions of human resources to identify and repair damaged components, reducing downtime. Challenges tend to arise, particularly when the activities are carried out by inexperienced operators, such as newly hired employees, making automation technology a viable solution [9].

The second type of maintenance is called Preventive Maintenance or PM, which is a scheduled activity carried out on machines to keep them at the desired operational level and reduce the likelihood of failure [7]. PM consists of activities aimed at improving the condition of a system, optimizing its performance, and preventing unwanted failure or collapse [10]. The activities include inspection, servicing, repairing, or replacing physical components of factory machinery and equipment following a predetermined schedule. Three main resources are required to schedule it, namely labor (technicians), materials (spare parts), and equipment [11].

In the context of Industry 4.0, maintenance is integrated into production planning, to maximize production capacity, ensure prompt product delivery to customers, and prevent unexpected failure [12]. One significant type of maintenance that uses core technology of Industry 4.0 is Predictive Maintenance (PdM). Furthermore, PdM makes use of predictive tools to precisely determine when maintenance actions are required [13]. The use of digital technology for maintenance activities in industry, often termed SM, represents an organizational design that enhances the efficiency and effectiveness of the maintenance function. It is also responsive to both internal and external factors and aims to facilitate informed decision-making [14].

Another component used for fluid mixing and pressure enhancement is steam jet ejector [15]. According to Mathew and Robinson Smart, it is a design that increases a low-pressure fluid (secondary fluid flow) at high pressure (primary fluid flow) through a nozzle with a convergent-divergent shape [16]. Steam jet ejector is widely used in power generation, petrochemicals, metallurgy, cooling systems, thermal engineering, and food processing industries due to their simple structure, ease of modification, cost-effectiveness, reliability, and safety [17]. In Gunung Salak Geothermal Power Plant, this device is used to maintain low pressure (vacuum) in the condenser. This is realized by directing high-pressure steam from geothermal heat (motive steam) to draw steam from the low-pressure condenser due to the pressure difference.

Zlatanova defined the fundamental objective of AR system as the process of blending the interactive real world with computer-generated to create a unified environment. Therefore, as users move in the real world, virtual objects generated by computers respond and interact effortlessly with the physical surroundings [18]. AR has the capacity to assist maintenance activities in several fields [19], including navigating workers to the workplaces, indicating hazardous areas, and making previously invisible areas visible. Henderson and Feiner conducted research with specific focus on designing and developing AR system intended for maintenance purposes. Their research classified this system into four distinct levels, namely the base, intermediate, application, and user levels. Base level focuses on visualization, while the intermediate level uses authoring tools for software integration. Application level refers to implementing AR system using custom programming software designed to the intended purpose. User level is characterized by the active role played by users [20]. These levels are shown in Fig. 1.

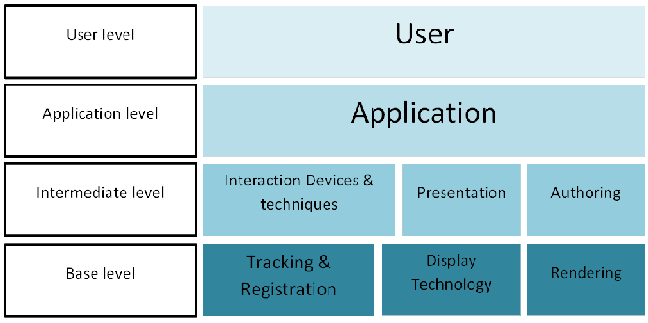


Fig. 1 General design for AR application [20]

Preliminary research reported a significant gap in the evaluation of AR system design on the SM activities in power plant industrial facilities. Furthermore, these studies focused on the design and implementation of AR system for maintenance but neglected the evaluation of the SM concept when AR was integrated. Others only discussed the general concept of SM without specifying the use of AR technology. To bridge this gap, this research focused on the design and evaluation of AR system in the context of maintenance activities, in line with SM principles. The evaluation would be based on directly discussing the maintenance unit of Gunung Salak Geothermal Power Plant. It also conducted practical testing of AR technology in maintenance activities to measure the extent of its implementation in this field. Furthermore, the evaluation process comprised both the assessment of features and the feasibility under various testing conditions.

## II. MATERIAL AND METHOD

### *A. Research Flow*

The research flowchart is shown in the following Fig. 2.

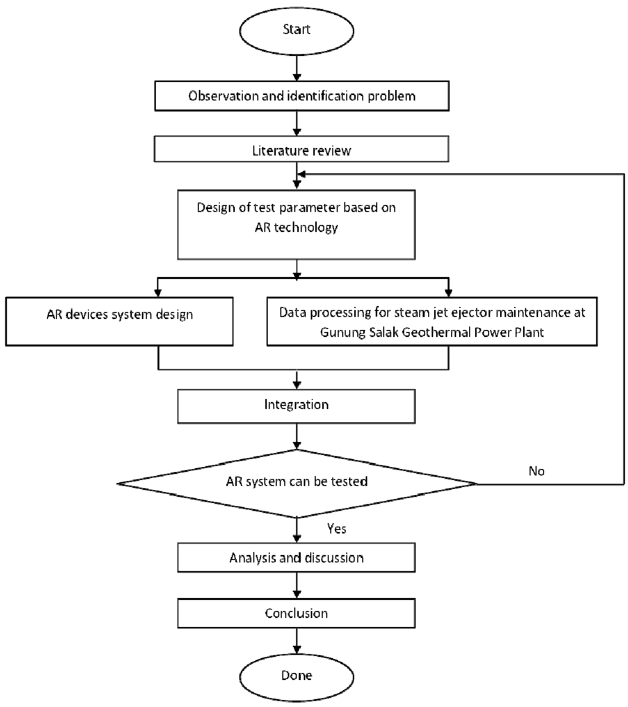


Fig. 2 Research flowchart

Based on Fig. 2, the first step includes observation and identification of the research problems by visiting and discussing with the maintenance unit of Gunung Salak Geothermal Power Plant. Through the observation, it was evident that there is a need for an enhanced maintenance system for the power plant steam jet ejector components, and this improvement is to be facilitated by digital technology. Subsequently, an extensive literature review was conducted, with a focus on methods used in SM and the implementation of AR system. This review served as the basis for designing specific test parameters which act as indicators for the successful integration and maintenance of the procedures. Following the parameter design, this research evaluates the hardware and software components of AR in addition to the display contents. After the design completion, all components are integrated into a unified system, which is then tested during actual maintenance process. The results obtained from these tests are thoroughly evaluated based on the predetermined parameters, forming a critical component of the ensuing analysis and discussion of the research results.

### *B. Design of Test Parameters Based on AR System*

This section focuses on AR integration and the design of the test parameters. The main objective is to integrate SM concepts with AR system effortlessly. This general approach considers both hardware and software aspects, with detailed design requirements shown in Table 1. The designed hardware concept contains hands-free designs, enabling users to operate AR system without interruption during maintenance activities. This was achieved using Hololens 2, effortlessly integrated into a safety helmet, as shown in Fig. 3. The user interface of the Android application developed after the configuration process, is shown in Fig. 4. The evaluation of this system design and testing assessment was conducted based on predetermined parameters. These parameters were divided into two categories, namely those used to assess the system in line with SM concepts and those for evaluating its effectiveness in maintenance activities. The parameters are in line with SM concepts and correspond to SM dimensions [14], including data-driven decision-making (six categories), human resource (six categories), internal (three categories), and external integrations (three categories). The evaluation process is carried out by assessing the design and the actual field conditions at Gunung Salak Geothermal Power Plant. The range of evaluation scores assigned was from 0 to 4. A value of 4 shows both AR system design and field conditions have effectively implemented specific predictive maintenance principles. However, a value of 3 indicates AR system design and field conditions have applied semi-predictive PM principles. A value of 2 shows that the system design and field conditions have successfully implemented PM principles in the context of that category. Meanwhile, a value of 1 indicates that AR system design and field conditions have integrated CM principles in that specific category. A category receiving a value of 0 means neither AR system design nor the field conditions are in line with the SM concept.

TABLE 1 AR system design components

| No | *Hardware Components* | *Software Components* |
|---|---|---|
| 1. | Safety helmet | Unity |
| 2. | Laptop | Vuforia |
| 3. | Smartphone | 3D Blender |
| 4. | Hololens 2 | CAD Software |

Fig. 3 AR system hardware design

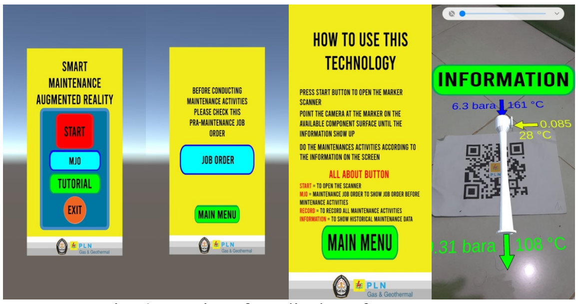


Fig. 4 User interface display of AR system

The evaluation parameters for AR system in the context of maintenance activities are categorized into two groups. These include content evaluation and trial test parameters. Content evaluation parameter is established based on the proficiency levels of the system, in line with the general design of AR application [20]. Features in the content are assigned scores based on the proficiency level. Scores 1, 2, 3, and 4 are assigned to basic, intermediate-level, application-level, and user-level designs, respectively. The next parameter for assessing the performance of AR system in maintenance activities is a trial test. The parameter takes into account various field conditions such as internet connectivity, the state of AR design, and other issues commonly encountered in AR systems. A trial test parameter is determined by measuring the time it takes to access hyperlinks from both the WhatsApp application and Notes to the Google Chrome browser. This procedure is repeated 20 times to gather data on the fastest (minimum point), average, midpoint (which falls between the minimum and maximum points), and longest access durations (maximum point) for each hyperlink feature. This feature was awarded scores of 4, 3, 2, 1 and 0 when the hyperlink was quicker, falls between the fastest and average durations, average and midpoint, the midpoint and longest durations, as well as longer than the lengthiest duration.

### C. Testing Method

AR design was tested using the following predefined procedure:

- Preparation: Before starting the testing process, it is important to ensure proper preparation by setting up the testing environment, and confirming the readiness of AR design, such as its hardware and software components. Furthermore, the configuration of the hardware should be tested, along with the functionality, which comprised of Android AR application. The maintenance dashboard or server need to be also verified, with the availability of a stable internet connection confirmed in the testing area.
- Installation: Ensure AR hardware design is properly installed to prevent any potential disturbances or disruptions during the testing process.
- Press the Start button with the monitor frame facing downward. First point it towards Marker A, then downward, to Marker B, and to both markers simultaneously before directing it downward. Observe the condition of AR system during each of these movements.
- When the monitor frame is directed at a marker, closely observe whether it can be detected by AR system.
- Determine whether the information displayed by the marker is in line with the predefined setup. Check for any potential errors, such as content from Marker A displayed on B, or vice versa. Additionally, take note of instances where one marker is not detected or when neither of them is detected at all.
- Note how long it takes to access Information and Records.
- After completing the initial run, replicate the procedure, commencing from step c, with successive adjustments to the distance of the tester, namely 0.5 meters, 1 meter, 1.5 meters, and 2 meters from the marker, then record and evaluate the obtained data in accordance with Table 3.18.

Summarize the evaluation results as an assessment of the implementation of AR design in maintenance activities.

## III. RESULT AND DISCUSSION

### A. AR System Design Result

AR system design consists of several features, such as:

- Maintenance condition monitoring feature. This feature can be accessed through the maintenance dashboard by clicking the Information button when the scanner detects the marker. The dashboard contains the historical record of maintenance activities performed on the steam jet ejector. To update the data, the Record button is used to complete the After Maintenance form, specifically designed for documenting the outcomes of maintenance tasks. The maintenance unit processes the updated data while considering various secondary factors, such as costs and failure symptoms, during the analysis.
- Maintenance manual procedure feature. This feature is accessible through Maintenance Job Order (MJO) button in AR user interface. The button leads to MJO dashboard, providing technicians with essential instructions to follow before carrying out any related tasks. Furthermore, there is another manual procedure feature that offers guidance on the correct operation of steam jet ejector. This feature usually appears when the scanner detects a specific marker.
- Components visualization feature. This feature uses a 3D Object element to showcase animated representations of the ideal operating conditions for steam jet ejector at Gunung Salak Geothermal Power Plant. It provides visual insights into the main parameters such as motive inlet, suction, and discharge pressure and temperature requirements for the proper functioning of the equipment.

### B. Results of AR System Evaluation of SM Concepts

In the context of Gunung Salak Geothermal Power Plant, the assessment of AR system obtained a score of 2.38/4.00. This indicates that SM concepts at the plant predominantly follows PM approach. Further elaboration on each dimension is stated as follows:

Regarding data-driven decision-making, Gunung Salak Geothermal Power Plant had incorporated PM criteria, with the potential to transition towards a semi-predictive PM approach. The maintenance unit partially evaluates related activities, enabling field decisions to be informed by insights from the data analysis. The results of the detailed evaluation of AR system with respect to the data-driven decision-making dimension are shown in Fig. 5.

In terms of human resource dimension, this power plant has generally implemented PM criteria. The workforce has strong ICT skills, although there is room for improvement in analysis and social skills. The design of AR system facilitates maintenance data analysis and connectivity between maintenance units and the control room, incorporating best practices in data processing and analysis management. AR system has the potential to improve communication among technicians and units, contingent on further AR technology development.

The detailed results of the evaluation of the human capital resource dimension are shown in Fig. 6. In terms of the internal integration dimension, this Power Plant has implemented criteria for semi-predictive PM. Decision-making processes in the maintenance function are well-connected and synchronized across different operational areas. This cohesive approach enhances the efficiency of maintenance data processing and analysis while also enabling an assessment of its broader impact on the company. The detailed results of the evaluation of the internal integration dimension are shown in Fig. 7.

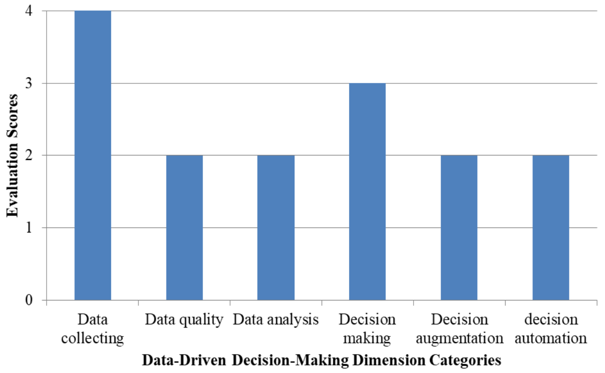


Fig. 5 Data-driven decision-making evaluation

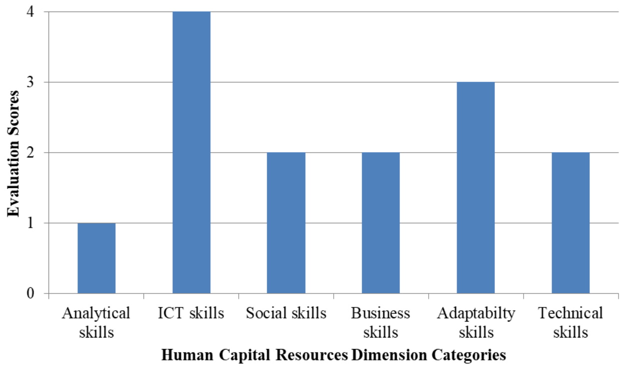


Fig. 6 Human capital resources evaluation

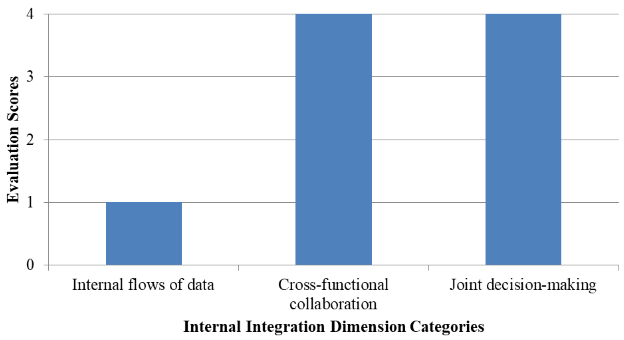


Fig. 7 Internal Integration evaluation

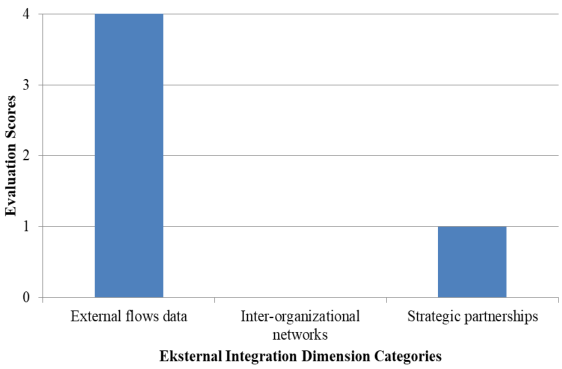


Fig. 8 External integration evaluation

Regarding the external integration dimension, Gunung Salak Geothermal Power Plant is currently implementing CM criteria and has the potential to be upgraded to PM criteria. To foster stronger inter-organizational networks, it is essential to initiate benchmarking efforts, particularly in the context of maintenance functions. Additionally, collaboration with external parties was needed to share knowledge about the maintenance strategies designed for AR system. The detailed results of the external integration dimension evaluation are shown in Fig. 8.

### *C. Results of AR System Evaluation of Maintenance Activities*

AR system evaluation for maintenance activities obtained a score of 2.46/4.00. In general, AR system fell into an intermediate category, with the capability to implement features such as visualization, manual procedures, and condition monitoring. However, it has not reached the stage of real-time and interactive mode. The detailed explanation is stated as follows:

The Content evaluation was awarded a score of 2.50. AR system design provides support for technicians in terms of condition monitoring, mainly through dashboard features rather than direct integration into the user interface. It has internet connectivity, while manual procedures are presented exclusively in text format on the dashboard. However, the component visualization feature in this system can be displayed in 3D. The results are related to the content of its designed features are shown in Fig. 9.

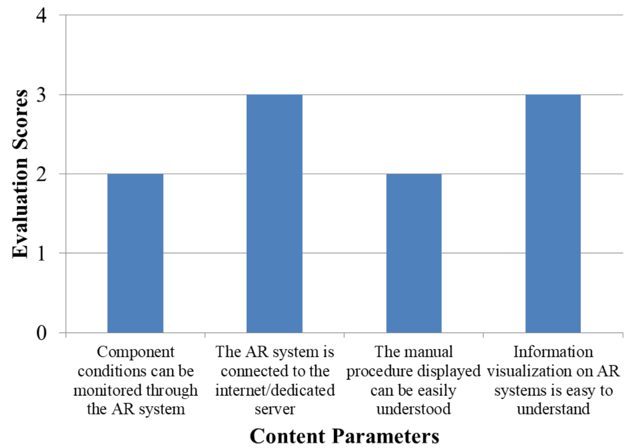


Fig. 9 Evaluation results of the content

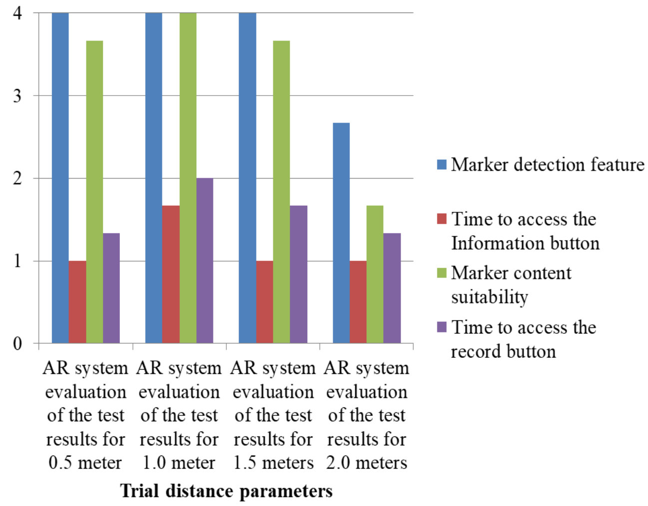


Fig. 10 Trial evaluation results

AR system evaluation comprised several main aspects, namely marker detection tests and content suitability assessments, evaluating the time required to access the dashboard and after-maintenance form using the testing method previously mentioned. The general trial results yielded an evaluation score of 2.42/4.00. The optimal scanning distance was determined to be 1 meter from the marker, which resulted in a higher trial evaluation score of 2.92/4.00. The lowest evaluation score was recorded at a distance of 2 meters. In detail, during the tests at various distances, the scanner successfully detected the marker, except at the 2-meter mark, where there was a scanning disturbance leading to detection failure.

In the content suitability test, it experienced issues related to the merging of content between one marker and another. The duration for accessing hyperlinks, both for the maintenance dashboard and the after-maintenance form, remained below the average hyperlink access duration. A comprehensive breakdown of AR system evaluation results from the conducted trial is shown in Figure 10.

## IV. CONCLUSION

In conclusion, this present research focused on the design of AR system comprising both hardware and software components that were integrated with processed maintenance data. AR design was developed with a hands-free design concept, which enabled users to operate the system during maintenance activities. The design included features for condition monitoring, manual procedures, and component visualizations. The process of assessing AR system against SM concept in the Gunung Salak Geothermal Power Plant, produced a score of 2.38/4.00. This showed that the plant was well-prepared to implement AR-based SM system, as most of SM concepts were applied at the facility. Additionally, PM practices were potentially upgraded to semi-predictive PM. The evaluation of AR system performance with respect to maintenance activities was assigned a score of 2.46/4.00. On closer examination, the content and trial evaluations were awarded scores of 2.50/4.00 and 2.42/4.00, respectively. AR system had reached an intermediate level, capable of implementing features such as visualization, manual procedures, and monitoring conditions, but not in real-time and interactive mode. This was evident in the content, which comprised an internet-connected dashboard, manual procedures presented in text format, and 3D visualization of steam jet ejector components. These available features were not connected in real time to the maintenance database.

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