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Application of 5s Methodology: A Case Study Towards Enhancing Spare Parts Processing Efficiency

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Abstract: *This study investigates the significance of the 5s methodology and its applications in the efficient development of spare parts logistics and the handling of warehouse processes in the petroleum industry. The Delphi approach was used to obtain expert judgment opinion through a series of questionnaires. The information collected was assessed by a selected panel of experts to gather their consolidated opinion and propose their weighted final judgment. The Gemba walk approach was also used as a tool to describe the personal observation of the executed tasks based on random cross-checks of the interaction between senior staff and their employees to explore opportunities for continuous improvement. The results indicate that employee commitment toward implementing the 5s methodology contributes significantly to improve the processing of spare parts in a warehouse. Furthermore, the analysis exhibited 90.1% efficiency in the spare parts logistics in successive months. The results shows that 5s methodology improve the efficiency of the spare parts processing time in the warehouse and recommend the standardize pillar to be implemented weakly compared to the other four 5s pillars. The study shows the relevance of employees' commitment toward using the 5s methodology to enhance the continuous improvement initiatives of the spare part logistics. This study explores the significance of the 5s methodology in improving the spare parts logistics in a warehouse and its use to overcome their deficiencies and improving the maintenance activities. It also seeks to eliminate downtime cost while improving safety, quality, and efficiency within the available resources. The research could help managers, operations professionals, and researchers investigate warehouse issues in many other industries.*

Keywords: *5s Methodology, Delphi Technique, Gemba Walk, Spare Parts, Lean Manufacturing.*

I.INTRODUCTION

Most business organizations struggle to enhance continuous improvement of their assets to ensure customer satisfaction.

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Therefore, the lean manufacturing concept is widely adopted by engineering organizations to maintain their position in the competitive business arena. This has prompted organizations to evaluate their challenges continuously and use appropriate techniques to improve their efficiency [1]. Effective spare parts inventory management practices are necessary to execute all maintenance activities promptly with minimum cost. Several companies store numerous spare parts without an appropriate inventory process to maintain their availability, classification, and quantity based on management needs. Moreover, the reorder time of spare parts may result in longer lead times. Additionally, equipment breakdowns can lead to production losses when critical spares are unavailable. Thus, the importance of spares in equipment maintenance and production sustainability requires a deeper understanding to implement an accurate process to manage spares effectively [2]. The 5s methodology, comprising of sort, set in order, shine, standardize, and sustain, is the fundamental pillar of total productive maintenance. It handles the creation and maintenance of a well-organized, clean, highly productive workplace that can help in the establishment of a standard process. This methodology eliminates time and cost wastes while improving safety, quality, efficiency, and employee morale [3]. The philosophy of 5s aims to minimize all types of wastes, and non-value add activities by reducing human effort and spare parts processing time, using minimal inventory, avoiding item damage, ensuring prompt response to customer demands, and maintaining the products efficiently in an economic environment [4]. Although the 5s is a lean manufacturing tool that provides necessary workplace improvements, such as cleaning, sorting and, organizing, commitment and participation from both top management and employees of the organization are necessary for its successful implementation. This study reports the implementation of the 5s methodology in a petroleum company spare parts warehouse and presents the performance improvement observed to ensure continued improvement of spare parts processing. The Delphi technique in [5] was used and extended further in this investigation to attain a consensus through several rounds of questionnaire surveys, wherein the collected information and results were communicated back to the panel members between each round. Typically, the Delphi survey uses experts in the field being studied and allows them to express their judgments and opinions freely [6] and [7]. In this study, the panel comprised experts from three different management levels.

The feedback acquired during multiple rounds of surveys included the opinions and judgments of all the experts and provided information on the progress achieved in the processing of spares. The expert judgment was considered as a statistical average (mean, median, and standard deviation) of the panelists' estimates in the final round, which reflects the weight of improvement observed in the maintenance of warehouse processes similar to the approach used in [8]. Section 2 of this paper explain the problem statement and the reason for choosing a warehouse of the petroleum industry for our case study. Section 3 presents the literature review of the various techniques employed in this investigation, and Section 4 describes the research methodology in detail. Finally, Section 5 presents the results of the case study and discusses their implications, followed by the paper conclusions in Section 6.

II.PROBLEM STATEMENT

The effective management of warehouse spare parts efficiency is crucial, particularly in the oil and gas industries, to execute all maintenance activities promptly and avoid machine breakdowns owing to a lack of spare parts is a major challenge as highlighted by [9]. Therefore, incorporating the 5s methodology can help eliminate the existing wastes and develops a strategy to process the spare parts. A maintenance warehouse of a reputed petroleum company is selected is this study. An investigation is conducted to evaluate the effectiveness of their existing spare parts management process. Several deficiencies, such as the absence of a distinguished place for damaged spare parts, incorrectly labeled items, unused old spares, and surplus spares, were identified in the warehouse. Furthermore, the spare parts were not sorted systematically, and their identification based on tags, colors, or labels was difficult to identify. The availability and quantity of each item were unknown, certain items were not stocked, and the technical details of several spare parts were absent or incomplete. The initial analysis shows evidence of inadequate existing practices that could result in certain maintenance activities exceeding the planned date owing to the unavailability of spare parts. The inadequate processing of spare parts can affect the employees' performance, as they struggled to obtain specific spare parts based on management needs. Further analysis conducted show that the lack of spare parts caused the breakdown of eight machines in a particular year (2019–2020) with an estimated revenue loss of approximately US$17000 per hour, impacting the company's reputation and resources. To overcome the problems, applied the 5s lean manufacturing approach, assessed using the Delphi technique to create a new work environment with enhanced spare parts processing while eliminating the associated wastes. The 5s methodology was selected owing to its effectiveness in spare parts management, easy implementation, and effortless understandability among the employees to instill a suitable work culture in their daily activities. Figure 1 illustrates the warehouse condition before the implementation of the 5s methodology. This study presented the key findings of the application of the 5s methodology for spare parts management and addressed the existing spare parts processing deficiencies.

Fig. 1 The warehouse before implementing the 5s methodology

The main challenge faced while improving the spare parts process is the lack of storage spaces in the warehouse due to the plenty of unidentified spares lying on shelves and the floor. In addition, searching for the missing or uncompleted technical details of some spares takes more time and effort.

III. LITERATURE REVIEW

3.1 The 5s Methodology

The application of the 5s methodology can benefit small and medium companies to improve productivity and their product quality. However, significant changes, such as reduced risk in the working area, increased effectiveness of machine maintenance and process efficiency, and establishment of an improved organizational climate need to be observed [10]. [11] conducted a study on spare management and inventory control using lean manufacturing principles.

They discussed the flow control of spare parts and the elimination of associated wastes. Additionally, the paper shows the significance of lean manufacturing techniques in improving the process efficiency, operational time, inventory, and cost. Another study implemented the 5s methodology to identify the weakest pillar in the system that affects the overall efficiency [12]. The study also measured the accomplished rating of each component, thus demonstrating that the total performance is achieved based on the appropriate application of the entire 5s methodology. The results obtained after applying the 5s methodology increased the system efficiency by approximately 75.64%.

Furthermore, [13] presented the results of an empirical investigation of various manufacturing organizations to evaluate the inter-relationship between different 5s application success factors and competitive dimension parameters using various statistical techniques. The study proved that the initiatives of the 5s program enabled a significant competitive dimension achievement from the first phase to the maturity phase. Additionally, [14] stated that skill auditing could aid the organization in realizing its target by evaluating novel perspectives to generate added values, which are utilized in continuous improvement and can also help avoid failures and errors.

3.2 Lean Manufacturing (5s)

Several manufacturing facilities are affected by disorganization that can lead to machine breakdowns, lower productivity and efficiency, higher costs, and safety hazards. The implementation of a 5s system can overcome these issues as it is relevant to a systematic lean production. The sequential implementation of the 5s system is essential to correctly address warehouse process efficiency issues and transform it into a visual process where the environment is self-explaining, self-ordering, and self-improving. [15]. [16] investigated the effect of sorting activities on manufacturing throughput using 5s system dynamics to assess the system performance outcomes by improving 5s practices. The simulation results recommend further improvements and reveal the relationship between the 5s methodology, system performance, and other lean practices. [17] stated that employers and employees tend to adopt lean manufacturing philosophy to reduce waste, increase productivity, and optimize the available resources during global economic crises. They proposed a game response to understand the 5s methodology effectively and provide a practical approach that enables learning based on trial and error. The information displayed in the response enhanced the learning efficiency of the players in terms of 5s concepts. Furthermore, [18] explored various lean manufacturing principles within a green manufacturing framework to protect the environment and provide safety to workers and consumers. Their study improved the product quality, eliminated waste, reduced costs, control environmental pollution, minimize human effort, and reduced product manufacturing time.

3.3 Delphi Technique

The Delphi technique analyzes the ideas of a group of experts specializing in a specific field, seeking a consensus opinion. The advantage of this technique is that experts from different management levels, each with a different focus, reach a consensus considering all their opinions [19]. According to [20], the Delphi technique is used to obtain the most reliable consensus of the opinions of experts in a group based on a series of intensive questionnaires interspersed with controlled feedback [21]. This technique was overlooked by academic researchers despite its applicability in practice. [22] observed that spare parts classification may improve decision-making, which constitutes an opportunity to increase spare parts availability and reduce inventory costs significantly. [23] used the Delphi technique to identify the challenges perceived by 18 senior service managers from different industries. The absence of a system or holistic perspective to control the spares, inaccurate service parts forecasting, and the inability of the system integration between the supply chain parties were identified as the three primary challenges. This highlights the need to improve the integration of spare parts management processes at both internal and external levels.

3.4 Gemba Walk

Gemba walk originates from the Japanese word Gembutsu, meaning "the real place." This technique requires the management to visit the place where the actual work is performed (e.g., the warehouse in this study) to observe the methods followed by the employees to execute the work and understand the reason for following those methods [24]. Taiichi Ohno developed the Gemba walk as a part of the Toyota Production System, which is the cornerstone of the lean manufacturing philosophy. Professionals adopting the Gemba walk technique can acquire knowledge outside the area of concern to apply unique perspectives of problem-solving when challenges arise. [25] described the Gemba walk as the observation of and interaction with the people at their work location to learn the methods they are accustomed to while executing the work. Moreover, it provides a deep insight into behaviors and actions, serving as a powerful tool to identify the process improvement opportunities and novel approaches to support the team. Additionally, it enables the management to identify the employees' abilities and values. This technique requires a small group of management members to assess a specific part of the company and cross-check the safety concerns, waste issues, efficiency of workflow, best practices, and any other factor that can remarkably add to the organization [26]. The involvement of all associated parties in the Gemba walk enriches the discussion and creates team spirit, generating ideas that focus on innovating the existing practices to enhance the 5s system process further.

3.5 Waste Minimization

[27] conducted a study in the healthcare sector to identify and minimize waste, assisting in decision-making to improve service quality. They implemented lean tools to reduce cost and provide a high quality of service as this sector consumes approximately 40% of the entire healthcare budget. Their research expanded the knowledge regarding supply chain management and sustaining continuous improvement within the budget constraints. Furthermore, [4] investigated lean methods to eliminate the waste generated from construction activities and improve productivity based on the determinant of cost-efficiency.

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As the construction industry faces several challenges, they concluded that the application of lean construction can achieve the objectives of value-adding and waste reduction up to 50% in some cases. Additionally, [28] conducted a study to reduce the defects in the readymade garments industry in Bangladesh using the 5s and plan-do-check-act (PCDA) methods. The Pareto analysis identified sewing defects that represented approximately 80% of the entire factory defects. Their research identified the root cause and its effects, before proposing certain recommendations to eliminate the sewing problems effectively and improve the productivity of the factory.

IV.RESEARCH METHODOLOGY

Effective management of spare parts is a challenge for several companies owing to their concerns that spares may affect the control of operating costs. Poor maintenance of spare parts may lead to inefficient inventory storage and a shortage of spare parts, resulting in unplanned downtime and unforeseen expenses [29]. Moreover, poor workplace conditions increase the possibility of accidents. The 5s methodology can establish and maintain a quality workplace environment with less operational time, lower cost, and available resources. The pillars in the 5s originate from the Japanese words, seiri, seiton, seiso, seiketsu, and shitsuke. They intend to minimize the associated wastes in the process and improve quality and safety while creating an effective work environment [30]. Figure 2 depicts the structure of the 5s pillars.

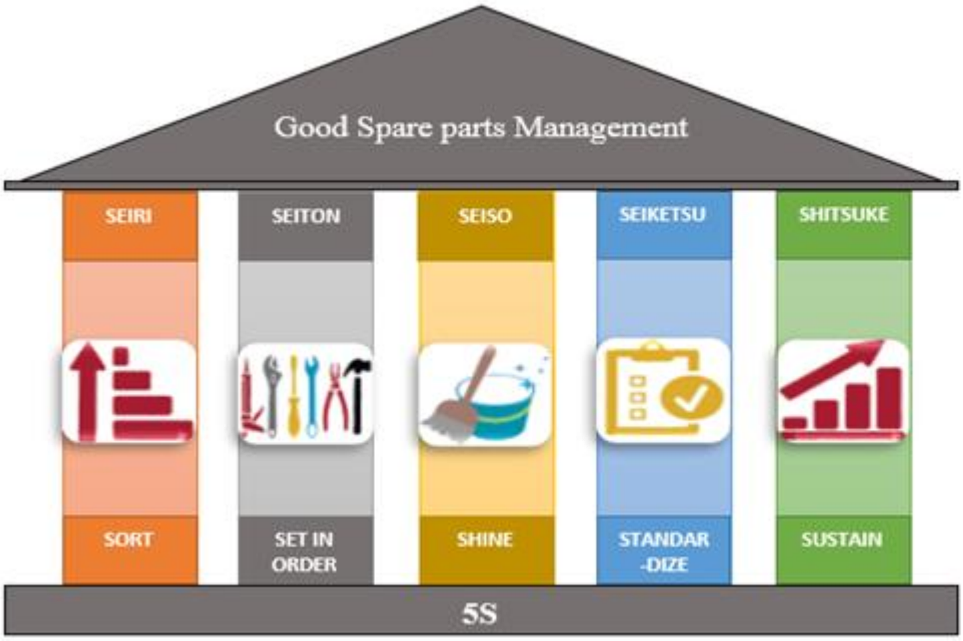

Fig. 2 5s pillars structure (source: http://qcfitraining.com)

In this paper a scale of scores from 1 to 5 is used to measure the 5s pillars and their contributions toward improving the spare parts management process in the maintenance warehouse. The spare parts processing performance was evaluated by three levels of expert supervisors, coordinators, and team leaders to assess the performance from multiple perspectives. The judgment value was based on the following guidelines: 1 = poor compliance, 2 = slight compliance, 3 = moderate compliance, 4 = strong compliance, and 5 = extreme compliance. The Delphi technique was used to collect auditing data from three different management levels to ensure research validity. A Delphi study is an iterative process with controlled anonymous judgments and systematic refinement to extract a consensus view from a heterogeneous panel of experts from different backgrounds [31]. Moreover, it affords a broad perspective as an open question is used as a starting point, which can be developed into a set of issues [32]. The rating of the 5s system was scored from 1 to 5 for each pillar to understand the development criteria for spare parts processing. The total rating of 110 scores was divided into five scores, which is the highest score for each evaluation point (Appendix A). The keywords used in the checklist for all five pillars can be described as follows:

SORT (SEIRI): The first pillar in the 5s methodology aims to identify the status of spare parts in terms of availability, quantity, condition, technical details, and determine whether the spare parts are in use. Additionally, it improves the efficiency of searching for the spare parts and receiving them, reduces the operational time, and maintains workplace cleanliness [33].

a) Spare parts availability: Ensure all spare parts are available in minimum stock.
b) Defective spare parts: Eliminate all damaged and broken spare parts.
c) Relevant information: Ensure all information pertaining to the spare parts, such as System Applications and Products number, labels, tags, and spare parts manuals or guidelines, are in place.
d) Elimination of wastes: Ensure all unused items, such as outdated spare parts, unnecessary items, and documents that are no longer in use are placed in red tag areas.
e) Classification of spare parts: Place all spare parts in groups based on system type, manufacture type, or process type.

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SET IN ORDER (SEITON): This pillar aims to arrange the spare parts properly to reflect the visual appearance of the warehouse. It aids in distinguishing the location of each spare part easily using labels and tags. Additionally, it establishes an efficient and convenient layout for the arrangement of spare parts [34].

a) Spare parts arrangement consistency: Correctly arranged storage shelves, racks, trays, and cupboards must be labeled clearly with actual part number, model number, and SAP number for a convenient future reordering.
b) Visual workplace: Shadow markings must be used to identify aisles, execution zones, and storage areas. In this study, different colors were used for identifying these areas.
c) Conveniently shelved spares for Corrective Maintenance/ Preventive Maintenance activities: These shelves are in a conveniently visible area, wherein spare parts of daily activities are placed based on the execution plan, thus reducing the time required to search for the spare part. Additionally, it aids in tracking and monitoring these activities.
d) Spare parts sequence: Spare parts must be placed in the proper sequence for ease of access when needed. Furthermore, the heavy and light objects must be placed on the bottom and top shelves, respectively.
e) Work efficiency: Setting the spare parts in order results in a smoother and more manageable workflow processing time.

SHINE (SEISO): This pillar is essential to maintain the warehouse clean and free from disorder and wastes, such as dust, damaged spare parts, empty containers, and other undesirable items. Additionally, it assists in updating the existing spare parts data and undertaking necessary actions, such as placing an order for a minimum stock of spare parts. Furthermore, it eliminates all hazardous sources and ensures a safe work environment in the warehouse [34].

a) Spare parts condition: All stocked items must be fit for use and in suitable conditions. For instance, the spare parts must be undamaged, uncontaminated, and unbroken.
b) Process path cleaning: Maintain the path clean, tidy, and free from any obstacles, such as boxes, empty containers, tools, and spare parts that can affect the process.
c) Working environment condition: This includes understanding the ergonomics of the worker to ensure a comfortable working environment with adequate facilities, such as sufficient sources of light, air ventilation, and air conditioning. This ensures the workers are energetic and alert, avoiding mistakes during the operation.
d) General cleaning: All storage areas, including floors, shelves, and cupboards, must be free from dust, garbage, oil, chemical, and water spillage and maintained in good condition.
e) Safety: All spare parts must be organized and stored securely with the stock of heavy items placed in the correct location to avoid tripping hazards. Moreover, obstacles at the head height, sharp edges in racks or shelves, and spillages on the floors must be avoided.

STANDARDIZE (SEIKETSU): Typically, this pillar considers the standards and procedures that all employees must follow to maintain efficient spare parts processing based on clear communication. This pillar requires all participants to improve the warehouse process as they understand the activities well owing to their knowledge of each processing aspect in the entire operation. The obligatory standards must be easily accessible to all employees and posted in allocated areas [35].

a) Warehouse standard operation procedures (SOPs): Standards to be followed must be clear, communicative, and easy to understand. Moreover, it should identify the required levels of cleanliness, labeling process, proper storage practices, visual management, and safe operation.
b) Warehouse management process: The aforementioned standards must be achieved based on the SOP in place, which includes stocking, re-stocking, maintaining spare parts conditions, red tag process, CM/PM activities, and all cleaning processes.
c) Visual maintenance board: The board that comprises information on all CM/PM daily activities for the department must reflect the execution plan and display the assigned technician and the spare part required for each task.

SUSTAIN (SHITSUKE): The final pillar in the 5s system applies the concept of 5s to review and update the standards regularly and ensure that the requirements are satisfied to achieve the desired target. Additionally, it requires commitment from all employees to obey the rules and standards to maintain the warehouse processes systematic. Moreover, it increases the alertness of workers, minimizes processing errors, and improves internal communications. This pillar is crucial to understand the feedback of routine inspections, which provides a platform for future improvements [36].

a) Visual management board: The board contains all the necessary information to sustain the standards achieved. Furthermore, it depicts the feedback of all audits, improvement actions, and solutions identified that must be updated regularly.
b) Audit process: This process is used by the management team to ensure that the SOP is working appropriately and satisfying the organizational goals. The management team can review the SOP and recommend improvements accordingly to achieve the desired target gradually.
c) Team compliance: All employees, including the members of top management and shop-floor workers, must be committed to this new work culture. They must inculcate these practices as part of their job to support the 5S strategy and comply with all relevant regulations and procedures. Thus, the team should discuss challenges transparently and generate creative ideas to achieve continuous improvement.

   Continuous improvement: All previous audit actions must be addressed to implement the corresponding solutions.

V. RESULTS AND DISCUSSION

Based on the aforementioned methodology, established the checklist used by the experts to perform a monthly evaluation of spare parts in the warehouse, as presented in Appendix A. Each expert submitted scores based on the improvement achieved through the employees' compliance toward the 5s methodology. The total scores collected in 10 months of the evaluation were utilized as weights to measure the contribution of each pillar. The subsequent sections explain the results in detail.

Computed the weights determined by the supervisor based on the expert (supervisor) evaluation checklist scores. The score submitted by the expert was divided by the total score, and the sum of all pillars determined the value for each pillar (Table I). For instance, the supervisor scored the first pillar (S1) 22 of 25 in round 1, which was divided by the total score determined in this round to obtain the actual weight for pillar one. Thus, determines the aggregate scores for each pillar from three rounds to obtain the actual weights presented in Table I.

Table I: Evaluation scores submitted by the supervisor in three rounds

Pillar	Round (1)	Round (2)	Round (3)	Actual weight (Sup) *
S1	22/94=0.2340	19/87=0.2183	22/89=0.2471	0.2331
S2	23/94=0.2446	22/87=0.2528	19/89=0.2134	0.2370
S3	22/94=0.2340	16/87=0.1839	20/89=0.2247	0.2142
S4	12/94=0.1276	12/87=0.1379	11/89=0.1235	0.1297
S5	15/94=0.1595	18/87=0.2068	17/89=0.1910	0.1858
Sum	**94**	**87**	**89**	

*Sup: Supervisor.

Subsequently, each element of the table is divided by the sum of its column to obtain the normalized relative weight. Table II presents the pillar weights after normalization; the sum of each column is 1.

Table II: Normalized weight

Pillar	Round (1)	Round (2)	Round (3)
S1	0.23407	0.218366	0.247174
S2	0.244673	0.252876	0.213464
S3	0.23407	0.183955	0.224767
S4	0.127638	0.137941	0.123537
S5	0.159548	0.206862	0.191057
Sum	**1**	**1**	**1**

Thereafter, obtained the normalized principal eigenvector by calculating the average across the rows.

$$W_S = \frac{1}{3} \times \begin{bmatrix} 0.23407 + & 0.218366 + & 0.247174 \\ 0.244673 + & 0.252876 + & 0.213464 \\ 0.23407 + & 0.183955 + & 0.224767 \\ 0.127638 + & 0.137941 + & 0.123537 \\ 0.159548 + & 0.206862 + & 0.191057 \end{bmatrix} = \begin{bmatrix} 0.233203 \\ 0.237004 \\ 0.214264 \\ 0.129705 \\ 0.185822 \end{bmatrix}$$

where W_s denotes the weight determined by the supervisor in all three rounds.

Thus, applied the aforementioned method to calculate the weights determined by the remaining two experts, namely the manager and the maintenance coordinator. Appendix B presents the calculation of these weights.

Table III summarizes the results of all three experts, based on the mean, median, and standard deviation values. Thus, the weights of the 5s pillars that contribute to the improvement of warehouse processing were judged by three different levels of experts, and the value of each pillar weight was determined on a scale of 0 to 1.

Table III: Weights of the five pillars determined by three experts

5s pillars	Weights determined			Mean	Median	Standard deviation
	Supervisor	*Coordinator*	*Manager*			
S1	0.233203	0.227446	0.242249	0.234299	0.702898	0.0075
S2	0.237004	0.212609	0.210914	0.220176	0.660527	0.0146
S3	0.214264	0.235247	0.222748	0.224086	0.672259	0.0106
S4	0.129705	0.123291	0.128776	0.127257	0.381772	0.0035
S5	0.185822	0.201407	0.195313	0.194181	0.582542	0.0079

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The values of arithmetic mean, and median were used simultaneously to analyze the potential of each value. Although the arithmetic mean, which is the measure of central tendency and used commonly for calculations, is highly intuitive for the expert group, it may be affected by the outliers. Hence, used the median value for rigorous statistical analysis of the data, similar to the analysis in [37]. Measures of central tendency, namely the mean, median, and standard deviation, were used to determine the consensus in the Delphi technique in this study. Furthermore, it represented the group opinion and consensus while indicating the degree of agreement between the experts on a certain pillar of the 5s methodology. The computation of the standard deviation of each item verified the strong consensus observed in the expert panel when determining the minimum value. The responses obtained from each round concurred well with the results. Most feedback pertained to the priorities of different factors in each pillar within an iteration. Additionally, several comments, arguments, and specific items were added by the experts to narrow the gap between their judgments.

5.1 Measurement of the 5s Methodology

The 5s methodology aims to eliminate wastes from every aspect of the warehouse spare parts processing with less operational time, human effort, and storage space while avoiding zero-spare-stock to be efficient and effective. The evaluation points for all the 5s pillars ranged from “poor compliance” to “extreme compliance” with a middle anchor point of “moderate compliance.” Each evaluation point had a maximum of five scores varying from 1 to 5, which was awarded based on the spare parts processing improvement. Therefore, the highest score is 5 for each evaluation point, and each indicator can be 5 × n, wherein n denotes the number of evaluation points in each pillar. The progress of each 5s pillar depends on employees’ compliance and their response in each indicator, which contributes to warehouse process improvement [38] and [39]. To determine the relative weights, applied the Delphi technique to estimate the knowledge and experience of the experts to generate precise judgments [32]. Each parameter was evaluated independently by three experts, including the site manager, maintenance coordinator, and maintenance supervisor, which provided multiple perspectives of the development in the 5s implementation and employees’ commitment. Computed the weight contributed by each 5s pillar toward the warehouse process improvement using an eigenvector and obtained the normalized value [40]. To calculate the pillar weight, select three checklists of each expert to obtain the sum of judgment scores of each pillar and divided the sum by total scores as indicated in equation (1).

$$\text{Pillar weight } \boldsymbol{S_i} = \frac{\sum Sji}{T_{js}} \qquad (1)$$

where $\sum Sji$ represents the sum of the judgment scores of the i^{th} pillar as determined by the experts and T_{js} denotes the total number of judgments scores, calculated using equation (2).

$$\boldsymbol{T_{js} = S1 + S2 + S3 + S4 + S5} \qquad (2)$$

The maximum total scores in this case study were 110, and the mean weights were calculated for all three management levels using equation (3).

$$\text{Mean weight} = \frac{SW+CW+MW}{3} \qquad (3)$$

where SW, CW, and MW indicate the weights determined by the supervisor, coordinator, and manager, respectively.

All experts in this study were equally important as each of them participated in three iterations (rounds) to arrive at the comparable results. The mean of the estimated values of the expert panel was used in the final judgment with equal weighting on each expert’s opinions. The mean values of the three experts were used to obtain Figure 3 as it provides the average of all experts’ opinions and reflects the improvement in the existing spare parts processing. Figure 3 depicts a radar diagram illustrating the contribution of each 5s pillar toward the improvements in the warehouse processes within ten months of implementing the 5s methodology.

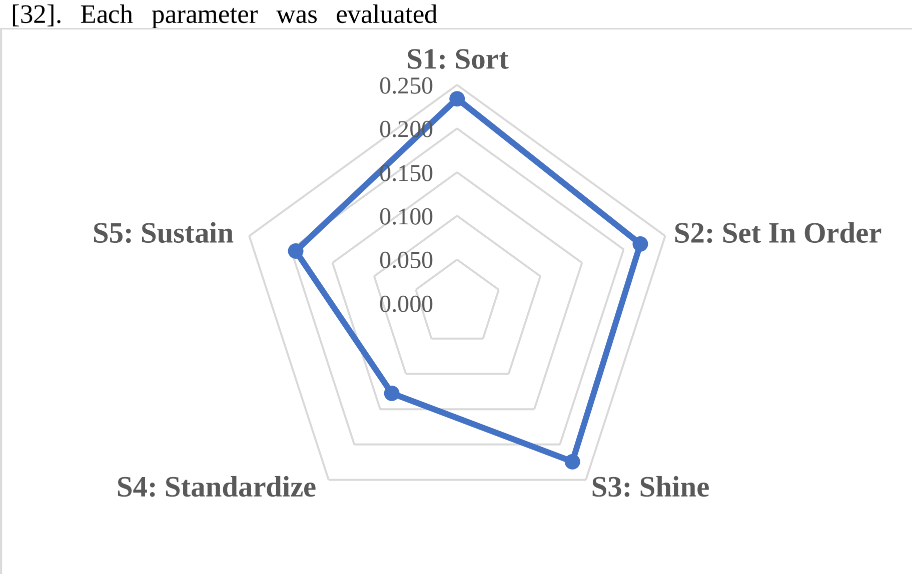

Fig. 3 Contribution of the 5s pillars to improve the warehouse processes

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The spiderweb graph illustrates the efficiency of each 5s pillar in the warehouse processes and helps identify the weakest implemented pillar. The experimental results concluded that all experts' judgments in the fourth pillar (S4) are extremely close to each other, with a standard deviation of 0.0035. The expert's consensus demonstrates that the weakest implemented pillar in the 5s methodology is standardize (S4). This must be investigated further to determine whether the existing standard is lacking, or a misunderstanding exists among the workers and analyze the reasons accordingly. By contrast, the second pillar (S2) recorded the highest standard deviation, indicating that the three experts' judgment values slightly more deviate from the mean value than the other four pillars.

Furthermore, the slight bend in the standardize pillar curve affects the total warehouse spare parts processing performance as the overall 5s methodology is performed concurrently. As the standardize pillar exhibits the lowest rating in comparison with the other four pillars, more effort in this pillar can improve the entire efficiency of the 5s system. The efficiency of warehouse spare parts processing in the tenth month after the application of the 5s system reached approximately 90.1%. Furthermore, regular follow-ups with operational process standards and procedures to sustain the 5s methodology are expected to improve the performance of spare parts management further. Additionally, regular responses to the auditing feedback can maintain the 5s system stable at its peak level. Moreover, employees reflected that this approach promotes neatness of the spare parts and provides sufficient space in the warehouse, which are essential for better planning of maintenance activities and housekeeping. Based on the SAP system available within the workplace, estimate that the application of the 5s methodology could potentially save an approximate revenue of US$ 14.7 million per year for the company, owing to the minimized maintenance wastes and non-value add activities that simplify the spare parts processing. This significant improvement in the spare parts processing was achieved based on the valuable feedback from experts owing to their proficiency in the field and commitment from the employees to fabricate a reliable and effective process. Moreover, the application of Gemba walk along with the experts' opinions, closed the gaps, and accelerated the process improvement.

5.2 Effectiveness evaluation

The Gemba walk evaluates and audits the effectiveness of the organization based on the commitment toward the 5s methodology. It describes the personal observation of the executed work. Applied the Gemba walk as an additional method, wherein the senior staff evaluated the application of the 5s methodology to support the expert panel with their findings and feedback. A senior employee, such as a foreman, arranged random inspection tours to the maintenance warehouse every two weeks to observe the implementation of the Standard Operating Procedure (SOPs) at the actual place of work. Owing to the direct interaction with the employees, valuable insights were gathered on reducing the existing wastes, and several opportunities for improvement were identified. This exercise provided a platform for open discussions with frontline employees executing the work and identified the challenges faced, such as safety hazards, redundancies, non-value-added steps, bottlenecks, and inefficiencies. Their shared ideas accelerated the improvement process. Moreover, these walks ensured that the existing process aligned with the SOPs, and the feedback acquired during the walks was shared with the management (experts) as part of the process improvement. The observer (foreman) reviewed the feedback during the final walks in the tenth month and ensured that appropriate measures had been adopted. This process continued until a sustainable stage was attained. Thus, with a thoughtful and structured approach, Gemba walks can improve collaboration and communication, resulting in a ***positive*** change for the company. Figure 4 depicts the warehouse arrangement and consistency after the implementation of the 5s methodology.

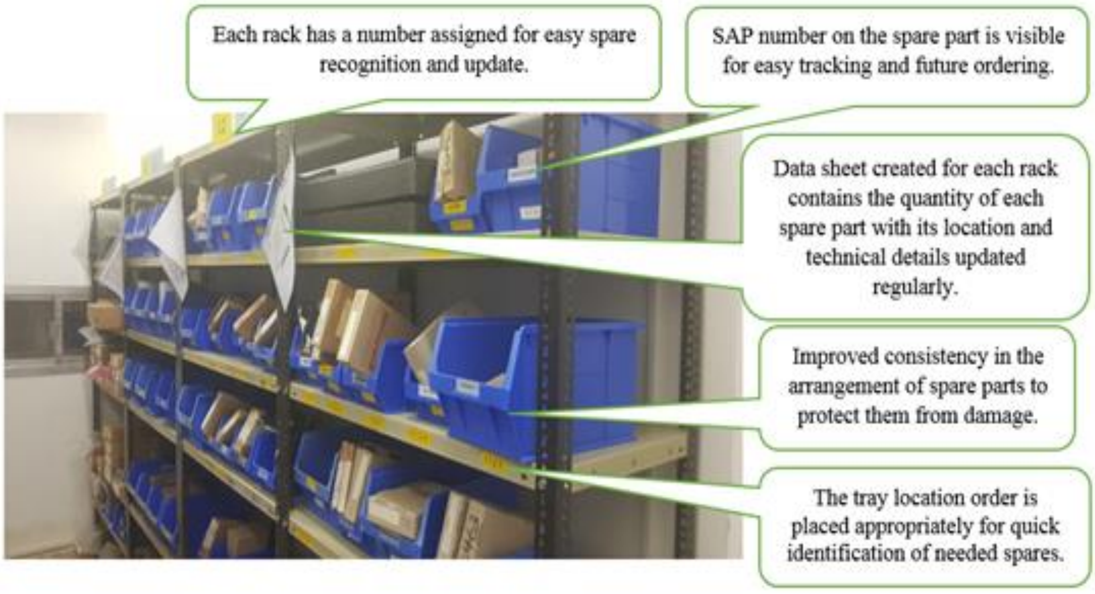

Fig. 4 Warehouse after applying the 5s methodology

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VI. CONCLUSION

This study presents the results of an investigation and analysis conducted of existing maintenance practices of spare parts management in a warehouse at a petroleum company and the improvement observed in the workplace efficiency after the implementation of the 5s methodology. A significant improvement was observed in the process over time owing to the reduced human effort, minimal inventory, less spare parts processing time, increased spare parts life with fewer damages and increased availability of spare parts. The Delphi technique was employed to consolidate and capture the opinions of three experts in the petroleum industry from different management levels. The experts' judgment scores in the Delphi technique aided the assessment of the real-time scenario after the application of the 5s methodology. This technique validated the importance of 5s pillars in improving the warehouse spare parts processing performance. Additionally, the application of Gemba walk to ensure consistent improvement in the performance.

A gradual improvement in the system efficiency was observed from the first month to the tenth month of this study owing to the expert feedback in each round to ensure the correct implementation of the 5s methodology. Furthermore, it concludes that providing adequate training to the employees and motivating them through incentive programs results in exceptional adherence, impacting the company positively. The employees' commitment toward the 5s methodology increased over time. The warehouse spare parts processing efficiency improved from less than 35% to 90.1%. The reduction of mistakes in the process, minimized chances of accidents, spare parts damage, and appropriate usage of workplace validates the importance of 5s system implementation toward sustainable improvement with minimum wastes and variations in the warehouse.

The first limitation of this study is people's resistance to change to the new warehouse process because many people are not responsive to changes to what they are doing. Secondly, the lack of awareness between workers about 5s methodology and their importance to increase productivity and improve work efficiency. Lastly, the limitation of continual commitment from all management levels to maintain sustainability in the effective maintenance of warehouse process efficiency improvement.

Appendix A

Month number	**S1: SEIRI (Sort)**					**S2: SEITON (Set in Order)**					**S3: SEISO (Shine)**					**S4: SEIKETSU (Standardize)**				**S5: SHITSUKE (Sustain)**			**Total rating**
	Availability of spares	Defective spares	Relevant information	Elimination of wastes	Classification of spares	Spare arrangement consistency	Visual workplace	Conveniently shelved spares for CM/ PM activities	Spare sequence	Work efficiency	Spare condition	Process path cleaning	Work environment condition	General cleaning	Safety	Warehouse (SOP)	Warehouse management process	Visual maintenance board	Visual management board	Audit process	Team compliance	Continuous improvement	
M (1)	2	1	1	1	1	1	2	1	1	1	2	2	2	1	3	1	1	1	1	1	1	1	**29**
M (2)	2	2	2	2	1	1	3	1	2	2	2	1	2	2	3	1	1	1	1	1	1	1	**35**
M (3)	3	3	2	3	2	2	3	2	2	2	2	2	3	2	3	2	2	1	1	1	1	2	**46**
M (4)	2	3	2	3	3	2	2	2	2	2	3	3	2	3	3	2	2	2	2	2	2	2	**51**
M (5)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	3	3	3	2	2	2	2	**63**
M (6)	3	4	3	4	3	3	3	3	3	3	3	3	3	3	4	3	3	3	3	3	3	2	**68**
M (7)	3	4	3	4	4	3	4	3	4	3	4	4	3	4	4	3	3	3	3	3	3	2	**74**
M (8)	4	4	4	4	4	4	3	4	3	4	4	4	4	4	4	3	4	4	3	3	4	3	**82**
M (9)	4	5	4	4	5	4	4	4	4	4	5	5	4	5	5	4	4	4	4	4	4	3	**93**
M (10)	5	5	4	5	5	4	5	4	5	4	5	5	4	5	5	5	5	4	4	4	4	4	**100**

Checklist form to evaluate the spare parts processing improvement in the maintenance warehouse.

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Appendix B

- **Weights for the 5s spare parts processing determined by the coordinator**

Pillar	Round (1)	Round (2)	Round (3)	Actual weight (Cord)*
S1	22/92=0.2391	19/86=0.2209	20/90=0.2222	0.2274
S2	20/92=0.2173	18/86=0.2093	19/90=0.2111	0.2126
S3	21/92=0.2282	21/86=0.2441	21/90=0.2333	0.2352
S4	10/92=0.1086	11/86=0.1279	12/90=0.1333	0.1233
S5	19/92=0.2065	17/86=0.1976	18/90=0.2	0.2014
Sum	**92**	**86**	**90**	

*Cord: Coordinator

Pillar	Round (1)	Round (2)	Round (3)
S1	0.239172	0.220944	0.222222
S2	0.217365	0.209342	0.211121
S3	0.228268	0.244149	0.233323
S4	0.108633	0.127926	0.133313
S5	0.206562	0.19764	0.20002
Sum	**1**	**1**	**1**

$$W_C = \frac{1}{3} \times \begin{bmatrix} 0.239172 + & 0.220944 + & 0.222222 \\ 0.217365 + & 0.209342 + & 0.211121 \\ 0.228268 + & 0.244149 + & 0.233323 \\ 0.108633 + & 0.127926 + & 0.133313 \\ 0.206562 + & 0.19764 + & 0.20002 \end{bmatrix} = \begin{bmatrix} 0.227446 \\ 0.212609 \\ 0.235247 \\ 0.123291 \\ 0.201407 \end{bmatrix}$$

where W_c denotes the weight determined by the coordinator in all three rounds.

- **Weights for the 5s spare parts processing determined by the manager**

Pillar	Round (1)	Round (2)	Round (3)	Actual weight (Man)*
S1	21/86=0.2441	20/82=0.2440	21/88=0.2386	0.2422
S2	19/86=0.2209	17/82=0.2073	18/88=0.2045	0.2110
S3	18/86=0.2093	19/82=0.2317	20/88=0.2272	0.2227
S4	11/86=0.1280	10/82=0.1220	12/88=0.1363	0.1288
S5	17/86=0.1976	16/82=0.1951	17/88=0.1932	0.1953
Sum	**86**	**82**	**88**	

*Man: Manager

Pillar	Round (1)	Round (2)	Round (3)
S1	0.244124	0.243976	0.238648
S2	0.220922	0.207279	0.204541
S3	0.209321	0.231677	0.227245
S4	0.128013	0.121988	0.136327
S5	0.19762	0.19508	0.193239
Sum	**1**	**1**	**1**

$$W_M = \frac{1}{3} \times \begin{bmatrix} 0.244124 + & 0.243976 + & 0.238648 \\ 0.220922 + & 0.207279 + & 0.204541 \\ 0.209321 + & 0.231677 + & 0.227245 \\ 0.128013 + & 0.121988 + & 0.136327 \\ 0.19762 + & 0.19508 + & 0.193239 \end{bmatrix} = \begin{bmatrix} 0.242249 \\ 0.210914 \\ 0.222748 \\ 0.128776 \\ 0.195313 \end{bmatrix}$$

where W_M denotes the weight determined by the manager in all three rounds.

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