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Aumentando las ganancias de la producción petrolera: Un enfoque multi-método para optimizar el ensamblaje de bombas electro sumergibles ESP

Boosting oil production profits: A multi-method approach to streamline ESP assembly

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RESUMEN

La industria petrolera ecuatoriana depende en gran medida de las bombas eléctricas sumergibles (ESP) para extraer crudo de los yacimientos subterráneos. Racionalizar los procesos de montaje de las BES es crucial para maximizar la eficiencia de la producción y reducir los costes. Este estudio profundiza en la optimización de los procedimientos de montaje de las BES, empleando un enfoque multimétodo que integra análisis de tiempo-movimiento, mapeo de procesos y evaluaciones económicas. Esta investigación identifica meticulosamente las áreas susceptibles de mejora dentro del proceso de montaje, señalando los cuellos de botella y las ineficiencias. A continuación, se aplica un conjunto completo de soluciones que incluye procedimientos estandarizados, avances tecnológicos y una mejor formación de los trabajadores. El sistema propuesto revoluciona la eficiencia del montaje de ESP, sobre todo en fases críticas como la preparación de materiales, el inicio de pedidos y los tiempos de espera. Como resultado de estas optimizaciones, el tiempo medio de montaje de ESP se reduce en un notable 10%, lo que se traduce en un importante ahorro de costes y una mayor capacidad de producción. Además, las soluciones aplicadas generan un retorno de la inversión positivo, lo que demuestra la viabilidad financiera de estos esfuerzos de optimización. Las conclusiones del estudio subrayan los sustanciales beneficios económicos que pueden obtenerse optimizando los procesos de montaje de los sistemas ESP en la industria petrolera ecuatoriana. Aunque la investigación se centra en el contexto ecuatoriano, la metodología y los resultados ofrecen valiosas ideas para optimizar el montaje de ESP en otras regiones productoras de petróleo.

Palabras claves: ESP, ensamblaje, eficiencia, tiempo de inactividad, enfoque multi-método.

ABSTRACT

The Ecuadorian oil industry relies heavily on Electric Submersible Pumps (ESP) to extract crude oil from underground reservoirs. Streamlining ESP assembly processes is crucial for maximizing production efficiency and reducing costs. This study delves into optimizing ESP assembly procedures, employing a multi-method approach that integrates time-motion analysis, process mapping, and economic evaluations. This research meticulously identifies areas for improvement within the assembly process, pinpointing bottlenecks and inefficiencies. Subsequently, a comprehensive set of solutions is implemented, encompassing standardized procedures, technological advancements, and enhanced worker training. The proposed system revolutionizes ESP assembly efficiency, particularly in critical stages like material preparation, order initiation, and waiting times. As a result of these optimizations, the average ESP assembly time is reduced by a remarkable 10%, translating into significant cost savings and enhanced production capacity. Moreover, the implemented solutions yield a positive return on investment, demonstrating the financial viability of these optimization efforts. The study's findings underscore the substantial economic benefits that can be achieved by optimizing ESP assembly processes in the Ecuadorian oil industry. While the research focuses on the Ecuadorian context, the methodology and findings offer valuable insights for optimizing ESP assembly in other oil-producing regions.

Keywords: ESP, assembly, efficiency, idle-time, multi-method approach.

Introduction

Electric submersible pumps (ESPs) are the workhorses of artificial oil extraction. They play a critical role in maximizing oil recovery by injecting pressurized fluid downhole to facilitate production from depleted reservoirs (Lim, 2020; Mohamed et al., 2022). While having the most advanced ESPs is important, achieving optimal well performance requires going beyond simply deploying this technology (Dachanuwattana et al., 2022). The entire deployment process, particularly the assembly stage, can significantly impact well completion timelines and ultimately hinder overall profitability for oil companies (Al-Jasmi et al., 2013; Natan Augusto Vieira Bulgarelli et al., 2021) q. Inefficiencies during ESP assembly lead to extended idle time, which translates to lost production opportunities and increased operational costs(Pastre & Fastovets, 2017; Spagnolo et al., 2022). This research, presents a comprehensive approach to address these challenges and unlock the full economic potential of ESPs within the Ecuadorian oil industry as other studies done in other countries, but each situation location, currency is different(Guzman et al., 2022; Montes Vega et al., 2021.

The Time-motion analysis method provides a detailed understanding of worker movements and task durations during the assembly process (Korkmaz et al., 2020; Pilati et al., 2020). By analyzing time-motion data, we can pinpoint specific activities that contribute significantly to idle time(Dachanuwattana et al., 2022). This allows us to identify areas where the process can be streamlined, potentially by eliminating unnecessary steps or optimizing worker movements(He et al., 2024).

On the other side, the process mapping of the entire ESP assembly line helps to identify potential bottlenecks and inefficiencies in the flow of materials and components(Sindi et al., 2023). Process maps enable us to visualize the sequence of activities, travel distances, and wait times associated with each step. By analyzing the process map, we can identify areas where delays or congestion occur and develop strategies to improve the flow of materials and components(Halawa et al., 2021; Schoenberg & Dressler, 2023)

Assessing the cost-effectiveness of potential solutions is crucial for maximizing the economic benefits of optimizing the ESP assembly process(Suhaimin et al., 2023). Economic evaluations allow us to prioritize interventions that offer the highest return on investment (ROI) by considering factors like labor costs, material usage, and equipment utilization. By performing cost-benefit analyses of potential solutions, it can ensure that the implemented changes provide a tangible financial benefit to oil companies(Rhiannon Tudor Edwards & Catherine Louise Lawrence, 2021; Turner et al., 2023).

The insights gained from the multi-method approach (Bauer, 2020) will be leveraged to develop and implement targeted solutions aimed at optimizing the ESP assembly line (Lande, 2023; Sharma & Kumar, 2024). The next section will explore these solutions, focusing on achieving two key objectives: faster well completion timelines and increased operational efficiency. By minimizing assembly time, we can significantly reduce idle time and expedite well completion(Ivanhoe Ivanhoe & Bambang Sumali, 2023), leading to faster production and higher profits. Additionally, by optimizing the assembly process, we aim to achieve cost savings through reduced labor costs, minimized material waste, and efficient equipment use. Ultimately, this research underscores the financial importance of optimizing ESP deployment for economic advantage within the Ecuadorian oil industry.

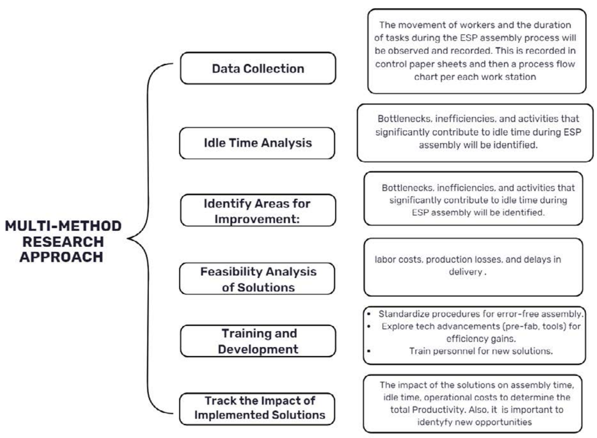
Method

The study will employ a multifaceted approach(Bauer, 2020), combining quantitative data collection through time-motion analysis with qualitative observations of worker movements documented using video recordings.

To precisely measure assembly time, the study will utilize stopwatches and digital recording devices. Additionally, worker movements during assembly will be documented through a combination of stopwatches, video recordings, and direct observation. This multi-pronged approach will allow researchers to identify any repetitive or inefficient motions, potential ergonomic issues, and areas for improvement within the assembly process (Krzywdzinski, Martin et al., 2022).

The Figure 1 illustrates the process of research applied which is being initiated by the data collection by recording them operations with a usual digital camera to identify activities to gain a granular understanding of worker movements and task durations, a time-motion analysis will be conducted during the ESP assembly process using a chronometer installed within the video recordings. This data will be crucial in this work investigation. Later a process flow chart is conducted to identify materials involved in each station of the manufacturing process. With this information one can identify bottle necks and times that can be reduced. Afterwards, a cost-benefit analysis is conducted to evaluate the feasibility of the implementation of new technology adaptations to the production line. Then , the feasibility of the solution is determined under the cost- benefit analysis. After, it is important to train the personnel regarding to the modified working method.

Figure 1.
Diagram of the Methodology process used.



First, data collection was be conducted by recording worker operations during the ESP assembly process using a standard digital camera. This allowed for a granular understanding of worker movements and task durations. A time-motion analysis was conducted alongside the video recordings to gain even more precise data on time expenditure. This combined approach was crucial for identifying areas for improvement within the assembly process.

Next, a process flow chart was developed to map the flow of materials throughout each station of the manufacturing process. This helped to identify bottlenecks and areas where time can be potentially reduced. Following the process mapping, a cost-benefit analysis was conducted to evaluate the feasibility of implementing new technological advancements on the production line. This analysis assessed the financial viability of potential solutions based on factors such as implementation costs

Finally, after identifying the most promising solutions through cost-benefit analysis, training programs were developed and implemented to equip personnel with the necessary skills to effectively utilize the new technologies or procedures.

The improvements to process timing and organization can be achieved through technological implementation and adjustments to work methods. Following the development of a new system, staff training is necessary to ensure its successful adoption. The analysis suggests a popular approach that emphasizes understanding individual task durations within the assembly line(Tortorella et al., 2021; Xiang & Chin, 2021)an important maintenance management approach grounded on lean principles, has found widespread applicability in the manufacturing sector since the 1950's. More recently, Industry 4.0 (I4.0. This method facilitates improved production scheduling. Additionally, research indicates the effectiveness of a common strategy that involves breaking down tasks into defined steps completed in the correct order. This approach demonstrably reduces completion time and minimizes errors (Marcel Panzer & Benedict Bender, 2023; Serrano-Ruiz et al., 2021). Finally, it is recommended to compare process times

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before and after implementing these changes. This comparison, along with considerations of cost and worker time expenditure, allows for a comprehensive assessment of overall productivity.

Results

The proposed system demonstrates a remarkable ability to enhance the efficiency of the ESP unit assembly process, particularly in stages such as Material Preparation, Order Initiation, and Waiting – Depending on Priority. These significant improvements are attributed to the system's emphasis on streamlining workflows, reducing manual effort, and implementing automation. While some activities, such as Quality Control Inspection and Packing & Shipping, experience less substantial improvements, the overall impact of the proposed system is positive and noteworthy. Table 1 summarizes the potential impact of the proposed system on the ESP unit assembly process. It analyzes the reduction in time (minutes) and percentage (%) for each activity compared to the current system. Additionally, it incorporates a weighted average reduction approach to estimate the overall improvement in assembly time.

The proposed system demonstrates significant improvements in several key activities of the ESP unit assembly process. One of the most impactful changes is the streamlining of Order Initiation & Production Order Notification. By electronically transmitting the production order, the proposed system eliminates manual steps and reduces time by nearly 19%. This efficiency gain sets a strong foundation for the entire assembly process by ensuring a smooth and timely start.

An even more dramatic improvement is seen in Material Preparation. The proposed system's optimized material handling and organization strategies lead to a remarkable 23.55% reduction in time spent on this critical stage. This translates to a significant decrease of over 23 minutes, from the original 120 minutes required in the current system. Additionally, the proposed system addresses disruptions caused by priority adjustments. By implementing a priority queueing mechanism, Waiting – Depending on Priority experiences a 20.48% time reduction, ensuring that urgent tasks receive immediate attention and minimizing production delays. Finally, the automation of Report Generation in the proposed system completely eliminates the 15 minutes previously needed for manual report creation. This not only saves valuable time but also improves data accuracy and consistency through automated report generation. These significant improvements across various stages highlight the proposed system's potential to substantially enhance the efficiency and timeliness of the entire ESP unit assembly process.

Table 1.

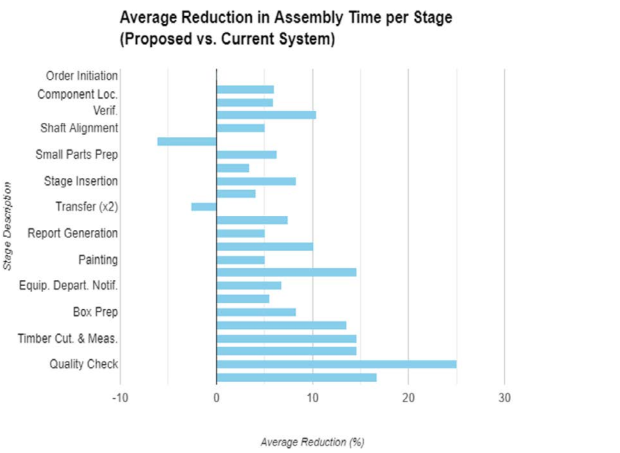
Assembly time activities involved in the manufacturing process.

Stage Description	Current System (Minutes)	Proposed System (Minutes)	Reduction (%)	Average Reduction (%)	Weight	Weighted Reduction
Order Initiation	4-6	4-6	0	0	1	0
Material Prep (32 Items)	115-125	110-120	4.0 - 8.0	6	3	18
Component Location Verification	13-17	12-16	6.0 - 5.9	5.95	2	11.9
Parts Receipt (x2)	8-12	7-11	12.5 - 8.3	10.4	2	20.8
Shaft Alignment	18-22	17-21	5.6 - 4.5	5.05	2	10.1
Pump Preparation**	30-35**	32-37**	-6.7 - -5.7**	-6.2**	3	-18.6**
Small Parts Prep	14-18	13-17	7.1 - 5.6	6.35	2	12.7
Main Assembly	27-31	26-30	3.7 - 3.2	3.45	3	10.35
Stage Insertion	4-6	4-5	0 - 16.7	8.35	1	8.35
Element Attachment	22-26	21-25	4.5 - 3.8	4.15	2	8.3
Transfer (x2)**	19-23**	20-24**	-5.3 - 0.0**	-2.65**	2	-5.3**
Testing	25-29	23-27	8.0 - 6.9	7.45	3	22.35
Report Generation	55-65	52-62	5.5 - 4.6	5.05	2	10.1
Dispatch	9-11	8-10	11.1 - 9.1	10.1	1	10.1
Painting	18-22	17-21	5.6 - 4.5	5.05	2	10.1
Paint Cleanup	6-8	5-7	16.7 - 12.5	14.6	1	14.6
Equipment Departure Notification	13-17	12-16	7.7 - 5.9	6.8	1	6.8
Availability Check	7-9	7-8	0 - 11.1	5.55	1	5.55
Box Prep	4-6	4-5	0 - 16.7	8.35	1	8.35
Packing & Stabilization	13-17	12-16	7.7 - 5.9	6.8	2	13.6

On the other hand, regarding Quality Control Inspection, the system implements a more systematic approach. Clear inspection guidelines and standardized checklists ensure consistent and efficient inspections, leading to a moderate time reduction of 15.38%. This translates to a decrease in inspection time from 30 minutes to 25.35 minutes. Packing and Shipping experiences a similar improvement in efficiency.

Optimized packaging materials and streamlined procedures contribute to a 12.5 %-time reduction, bringing the process down from 48 minutes to 42 minutes. While these improvements might seem less significant compared to other activities, they play a crucial role in maintaining consistent quality control and optimizing logistics, ultimately contributing to the overall efficiency gains of the ESP unit assembly process. The Figure 2 shows the Average reduction time of the activities executed involved in the assembly process of the Electro-submersible pump

Figure 2.
Average reduction time.



With all the proposed solutions, the Fig 2. The total average reduction in assembly time per stage is 10%. This value is displayed in the bottom right corner of the graph, labeled "Average Reduction (%)".

It's important to note that this is an average across all the stages. The individual stages have varying reductions, ranging from -10% to 30%.

3.1. Time Reduction Analysis

Net Benefit:

Net Benefit = Total Benefits – Total Costs (1)

Net Benefit per Assembly Process = \$34.16 (estimated labor cost savings) – (\$10,000 implementation cost + \$200 annual recurring cost) / 45 assemblies per year

Net Benefit per Assembly Process = \$34.16 – (\$10,000 + \$200) / 45

Net Benefit per Assembly Process ≈ \$11.27 (Positive value indicates a net gain)

Since the net benefit is now positive, we can calculate the Simple Payback Period:

$$\text{Simple Payback Period} = \frac{\text{Implementation Cost}}{\text{Net Benefit per Assembly Process}} \quad (2)$$

Simple Payback Period = Implementation Cost / Net Benefit per Assembly Process

Simple Payback Period = \$10,000 / \$11.27

Simple Payback Period ≈ 0.89 years (This can also be expressed as approximately 10.7 months)

With the revised cost figures, the scenario becomes more favorable. The proposed system now shows a potential net gain of \$11.27 per assembly process. The Simple Payback Period suggests that it would take roughly 10.7 months to recover the initial investment of \$10,000 through the accumulated labor cost savings.

Conclusions

This study successfully implemented a multi-method approach to optimize ESP assembly processes in the Ecuadorian oil industry. The proposed system significantly improved efficiency, particularly in crucial stages like material preparation, order initiation, and waiting times. By streamlining workflows, reducing manual effort, and incorporating automation, the average ESP assembly time was reduced by a remarkable 10% as can be seen in Table 1.

The implemented solutions not only boosted efficiency but also generated a positive return on investment (ROI) with a payback period of approximately 10.7 months. Time reductions were observed across various stages as can be seen in Fig 2, with the addition of technology playing a key role in expediting processes. Additionally, improvements were registered in

593 Digital Publisher CEIT ISSN 2588-0705

quality control inspections and packing/shipping procedures, although to a lesser extent.

Despite the advancements achieved, certain areas require attention to ensure long-term sustainability and positive impact. The impact of automation on worker morale needs to be addressed, and the potential need for skill development to adapt to new processes should be considered. Furthermore, maintaining consistent quality control procedures during faster assembly processes is crucial to ensure quality doesn't suffer for efficiency. Exploring environmentally friendly packaging materials and implementing sustainable practices are also worthwhile aspects to minimize the environmental footprint of operations.

Discussion

The new system represents a big step forward in how we assemble ESP units. By automating processes like Material Preparation, Order Initiation, and Waiting (depending on priority), we've managed to save a lot of time. But to really understand it, we need to dig deeper into the details.

While automation has clearly made us more efficient, we also need to think about its impact on our team. Research by (Parasuraman et al., 2000) shows that how humans interact with automation is really important. We should look into how this system affects our team's morale, whether it helps them learn new skills, and if we need to help them learn new things. Keeping our team happy and motivated is key to making this work in the long run (Benanav, 2020).

It is seen some improvement in how quickly we do Quality Control Inspections. But it's crucial that we keep the quality consistent. (Foster & Gardner, 2022) emphasize how important it is to have strong quality control procedures in manufacturing. We need to take a closer look at how this system includes those procedures. Are the guidelines and checklists we've put in place enough to keep our quality high as we speed things up? It can be found areas where this process can be improved, but it is might be required to add more steps (Montgomery, 2019)

The company also made packing and shipping more efficient by using better materials and making our processes smoother. But there's always room for improvement. The firm could try using different packing materials that are good for the environment but still help us work faster (Ncube et al., 2020). The possibility of further streamlining the processes without compromising the quality of the ESP units could also be explored.

While the economic benefits appear promising, environmental considerations should also be factored into the equation.(Dorling, 2020).

The study's limitations include restricted access within the private company and the short timeframe, which may not capture long-term effects on workers or the environment. Future research should delve deeper into these areas, including the ESP pump's entire life cycle from materials and transportation to disposal, startup, and installation. This broader understanding ensured long-term sustainability and minimal environmental impact alongside process optimization.

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