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Optimization of Time Efficiency in the CAPEX Purchasing Chain: A Simulation Study in the Mining Industry Using the Just-Time Method

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Abstract

This research aims to optimize the CAPEX purchasing process in a large polymetallic mining company, evaluating the problems and bottlenecks present in this process. The methodology presented focuses on the exhaustive collection of quantitative and qualitative data, as well as on the implementation of strategies based on Lean methodologies such as Just in Time and Muda. As a result, there is a significant reduction in delivery times for purchase orders, as well as an improvement in efficiency and overall process performance, validated by statistical analysis and simulations in ARENA software. The conclusion is that the implementation of the Just in Time and Muda strategies has proven to be effective in optimizing the CAPEX purchasing process, with positive impacts on operational efficiency and reduction of times with a 95% confidence level. It is recommended to continue exploring the potential of the Just in Time methodology in international environments and to monitor the improvements implemented in the long term.

Keywords
Purchasing Process, CAPEX, Efficiency, Optimization, Just in Time.

1. Introduction
Mining in Peru plays a crucial role in its economic dynamics, being an important engine of growth. In recent years, its contribution to the Gross Domestic Product (GDP) has reached 10% of the national total, showing exponential growth (Simon et al., 2023). This is not surprising considering that Peru is one of the main producers of minerals in the world. In addition, in 2023, mining accounted for 62% of the country's exports (Coayla et al., 2024). This is due to the diversity of minerals extracted in the country, such as gold, silver, copper, zinc and others. These minerals are not only fundamental to the national economy, but also play a crucial role in the global commodity market (Rodríguez & Álvarez, 2023).

In this context, the Ministry of Energy and Mines of Peru plays a fundamental role in promoting mining investment projects known as CAPEX (Capital Expenditure), which are vital for the sustained growth of the mining industry and of the national economy. These projects are coordinated through a consensus between the authorities, the population and the private sector, with the aim of ensuring a balanced and sustainable development (Yearbook 2022, s. f.).

The importance of CAPEX projects lies in their ability to boost the production of minerals and metals, which are not only essential to the national economy, but also have a significant impact on the global commodity market. In 2023 the General Directorate of Promotion and Sustainability presented the CAPEX portfolio of mining investment projects, which consists of 47 projects from different mining companies with a total investment of US$ 53,715 million (MINEM 2023, s. f.).

That is why CAPEX projects, since they represent a high degree of investment, must be carried out with a high level of effectiveness, since an error would cause significant economic problems in companies. Therefore, the management of the CAPEX project procurement supply chain is closely linked to the effort, since the timely delivery of Purchase Orders directly influences the execution as planned (Wang et al., 2021).

Therefore, the search for processes that improve the efficiency of purchasing processes within the mining industry is crucial to ensure profitability and competitiveness in an increasingly demanding market with a high degree of investment (Kolmakova & Lysenko, 2023). This study focuses on the CAPEX purchasing chain, a vital component of mining industry operations.

1.1. Objectives

Despite their crucial importance, CAPEX procurement processes often encounter problems of time inefficiency, from the creation of the SOLPED requirement to the issuance of the Purchase Order. These delays can have significant effects, such as exorbitant costs, production delays and loss of essential business opportunities (Er et al., 2017).

To address this issue in a technical and strategic way, we suggest the implementation of the Just-Time method, a production management strategy that focuses on operational efficiency and waste reduction in procedures (Zeng et al., 2022). Through a comprehensive simulation study, we analyze how this method could be incorporated into the CAPEX procurement chain and the potential benefits it could bring.

The primary purpose of this research is to improve time efficiency within the CAPEX procurement chain, specifically within the mining industry. Our approach includes the precise identification of areas of inefficiency, the structured application of the Just-Time method and the careful assessment of the results achieved, with the aim of substantially improving CAPEX purchasing management with respect to active time, wait, total and bidding, evaluating its effects on the production and total profitability of the company.

As for the CAPEX investment, it is noted that the company approved a total of 308 million USD for Peru and Brazil in 2023, with a projected to reach 381 million USD for the following year, which evidences a high demand index of purchasing requirements in the analyzed time horizon. These data reveal the complexity and volume of operations the company faces in terms of acquisitions, highlighting the need to implement significant improvements in the purchasing process to optimize efficiency and reduce delivery times.

2. Literature Review

The literature reviewed in the mining sector emphasizes an obvious need for improvement in procurement practices for CAPEX projects. Globally, there is a growing understanding of the fourth industrial revolution and its goal of transforming services in the mining supply chain. This situation has motivated a considerable interest in increasing operational efficiency, especially in essential areas such as the management of processed orders, monitoring of delivery times and service quality, with research showing levels of discontent among internal customers due to these failures (Lv & Shang, 2023) (Merdin & Ersoz, 2019).

At the local level, specifically in Peru, there is a growing drive to improve purchasing procedures in CAPEX mining projects. Companies face challenges ranging from price fluctuation to the intrinsic complexity of the supply chain in the mining industry. Given this situation, optimization models are being implemented using engineering techniques to increase efficiency and effectiveness in the procurement of inputs and services needed for these projects, suggesting the application of strategies such as Just in Time/Lean as effective tactics to increase competitiveness and efficiency in the mining sector, both locally and globally (Produção et al., 2022).

2.1. Supply Chain

The supply chain process is an essential component of our study, as it plays a critical role in the global economy. It consists of the complete process that includes the manufacture and distribution of products, from the purchase of basic inputs to the delivery of the final good to the customer. Our study focuses on how to perfect this process to increase efficiency, reduce costs and enhance customer gratification by improving the process and optimizing times. At the global level, an effective supply chain can provide companies with a competitive advantage, enabling them to act more effectively and react promptly to market fluctuations (Khachaturyan, 2023). However, it also brings challenges, such as managing suppliers in different nations, adhering to local regulations and minimizing the dangers associated with foreign trade.

2.2. Mining Purchasing Process

The CAPEX acquisition phase in the mining sector is vital to our study, as it allows us to examine how international mining corporations expand their operations and guarantee the resources required to sustain their production. This procedure, which extends from the generation of the order request (SOLPED) to the issuance of the Purchase Order, usually encounters difficulties of inefficiency in relation to time, which can lead to exorbitant costs, production delays and loss of crucial business opportunities. In an international context, these obstacles can be even more complicated due to differences in government regulations, fluctuations in the world economy and logistical and environmental problems (Mucha et al., 2023). To address these drawbacks, we propose the implementation of the Just-Time approach, a production management tactic that focuses on operational efficiency and waste minimization. Through a detailed simulation study, we explored how this approach could be integrated into the CAPEX procurement chain and the potential benefits it could provide.

2.3. Just in Time/Lean

Just in Time (JIT) and Lean are two production management approaches that focus on efficiency, waste reduction and continuous improvement. Both have significant applications in our research, especially in the context of an international environment. JIT, which focuses on demand-driven production, can help businesses respond more effectively to global market fluctuations while minimizing excess inventory and associated costs. On the other hand, Lean focuses on maximizing customer value by eliminating unnecessary or inefficient activities in the production process. In an international environment, Lean can help businesses stay competitive by enabling them to deliver high quality products faster and more cost-effectively (Alarcon et al., 2023).

3. Methodology

The research focuses on optimizing the CAPEX purchasing process of a large polymetallic mining company in the sector, with a daily production of more than 5000 tons. To this end, a thorough analysis of the problems and bottlenecks present in this process is carried out, from the creation of the SOLPED requirement to the publication of the Purchase Order, with interviews with key administrative personnel with experience in mining purchases. The 80/20 (Pareto) principle is used as a guide to identify critical areas that have the greatest impact on process efficiency and time.

It is considered the process map for the CAPEX purchasing process of the mining company AS-IS, detailing each stage from the creation of the requirement to the creation of the purchase order. In addition, the 80/20 principle is used to focus efforts on solving the most significant problems, identifying 20% of the volume of time of the purchasing process that represents 80% of the problems in order to a TO-BE analysis. These actions are primarily aimed at improving efficiency and reducing procurement time, which will help optimize the mining company's supply chain. Figure 1 shows the research process map.

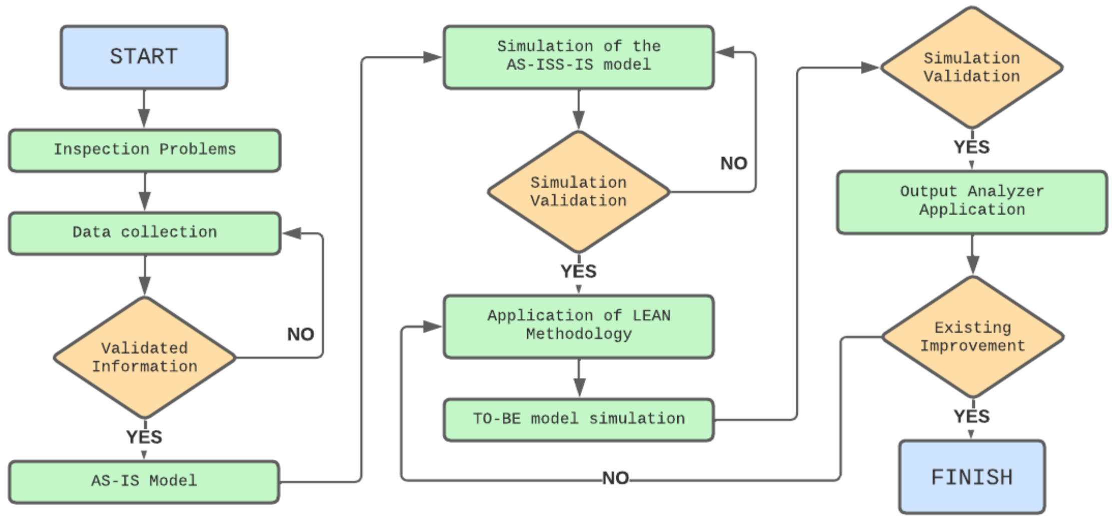

Figure 1. Map of the research process

The methodology begins with a thorough inspection of the problems and bottlenecks of the CAPEX purchasing process at the mining company. It looks carefully from the generation of the SOLPED requirement to the issuance of the Purchase Order, and interviews are conducted with key staff such as the Purchasing Manager, Chief of Supply and Senior Procurement Analyst, who contribute their experience of more than 10 years in the mining purchasing sector, generating a greater validity and reliability of the information collected.

After identifying the problems, we proceed to collect comprehensive data related to the CAPEX purchases of the evaluated company, which works with an ERP system that allows the planning and control of business resources. Therefore, within the SAP ERP platform of the mining company, information is collected on the demand for requirements, the number of projects in progress, the approved and planned investment, among other relevant aspects for the analysis. This stage is crucial for understanding the magnitude of procurement operations and establishing a quantitative basis for evaluating and improving the process to be improved.
An in-depth analysis of the current model of the purchasing process (AS-IS) is performed that allows us to visually evaluate the operation of the process by identifying problems or situations proposing improvements in the future, This model is based on the experience of the administrative staff and the information collected from the SAP ERP managed by the company (Orłowska, 2023). It describes current threads, interactions and workflows, identifying critical areas and opportunities for improvement. This phase lays the foundations for the subsequent simulation and design of the future model.

Through the ARENA program an advanced tool for simulation, allows us the virtual representation of the AS-IS model. This allows simulating times, identifying bottlenecks, evaluating process efficiency and proposing improvements based on concrete data. The simulation is executed with multiple monthly replicas to capture the variability and dynamics of the process over time (Ahmed & Tuan, 2023).

Once the critical points to be improved within the simulations have been identified, Just in Time and Muda methodologies are applied to optimize the purchasing process. Just in Time focuses on reducing waiting times and waste that are presented within the purchasing process, while Muda focuses on eliminating activities that do not add value. In addition, a detailed workflow analysis is performed to identify unnecessary activities, redundancies and downtime.

With the improvements proposed and implemented, the future model of the purchasing process (TO-BE) is designed. This model incorporates the improvements identified in the previous phase, optimizing workflows, reducing time and costs, and improving overall process efficiency. The simulation is performed in the ARENA software again to quantify the changes and compare the performance of the TO-BE model with the AS-IS with the application of the Just in Time and Muda methodologies.

Finally, the impacts of the improvements implemented in terms of costs, time and operational efficiency are evaluated. Statistical and comparative analysis tools, such as Input and Output Analyser in ARENA, are used to make a detailed and quantitative evaluation of the results obtained. This phase provides a complete overview of how improvements affect the overall performance of the procurement process, allowing final adjustments and recommendations for long-term implementation.

4. Data Collection

The data collection required for research involves a comprehensive approach encompassing both quantitative and qualitative information. At this stage, quantitative information is collected through the analysis of internal and external databases, such as the mining company's SAP ERP platform and external sources of data related to the mining and purchasing sector. This information includes data on the demand for purchasing requirements, planned investments, processing times, among other key indicators to understand the magnitude and dynamics of the CAPEX purchasing process.

On the other hand, interviews and work sessions are held with key staff in the purchasing area, including the Purchasing Manager, Head of Supplies and Senior Procurement Analyst, with the aim of obtaining qualitative information on internal processes, operational challenges, current practices and stakeholder perceptions. This combination of quantitative and qualitative data allows a complete understanding of the problems and opportunities in the purchasing process, laying the foundation for analysis and further improvement.

5. Results

5.1. Modeled Results

To improve efficiency and reduce time for CAPEX procurement processes, the research implemented strategies based on Lean methodologies such as Just in Time and Muda. The detailed analysis of the times of each phase of the process was taken into account, identifying the critical areas that required intervention to optimize purchasing management and reduce delivery times of purchase orders.

After thorough inspection and detailed interviews with key procurement staff, the procurement problem tree was obtained as shown in Figure 2. This tree allowed a detailed classification of the effects, the main problem, the direct causes and indirect causes of the delay in issuing purchase orders, thus providing a full understanding of the interrelationships between the different elements contributing to delays in the CAPEX procurement process. This classification, by clearly identifying root causes and associated factors, laid the groundwork for developing effective strategies to optimize workflow and significantly reduce lead times for purchase orders at the mining company.

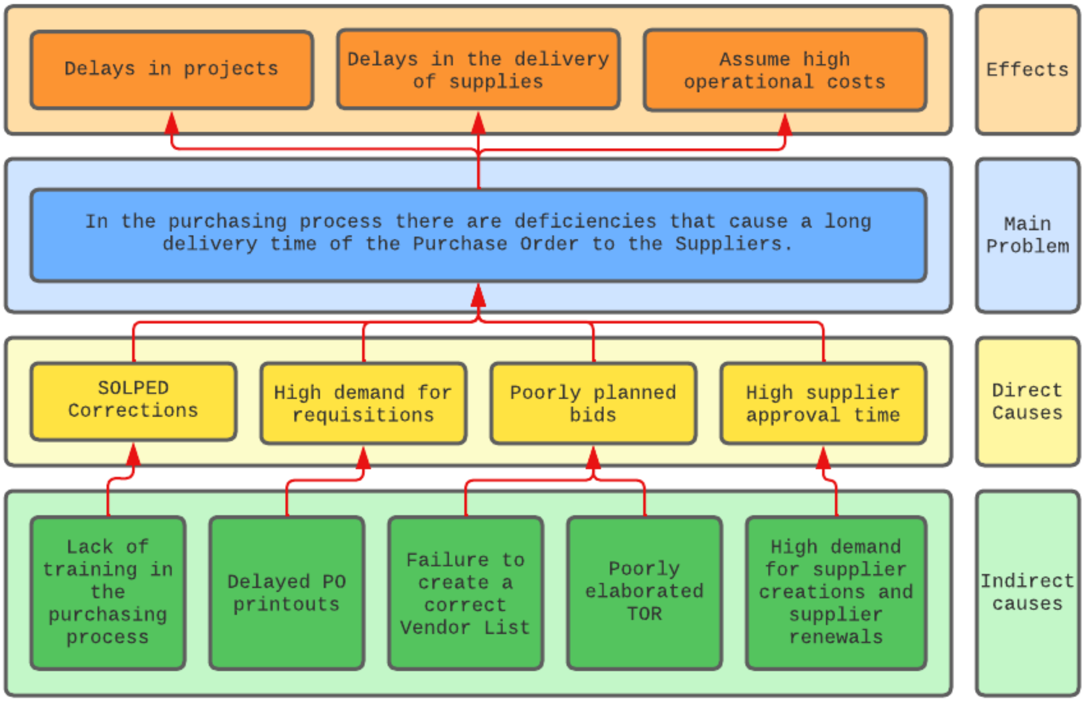

Figure 2. Problem tree of purchases

After identifying the problems, the research has allowed us to collect a significant amount of data related to the mining company's CAPEX purchases. According to information obtained from the SAP platform, a total demand of 1,317.6 procurement requirements between materials and services is registered during the period from January to September 2023 in Peru. This translates into a daily average of 4.88 purchasing requirements. In addition, 356 budgeting requirements are identified for future projects of mining units and refinery in the country.

The analysis of SAP ERP data and the tree of identified problems, together with the times evaluated in the mining company's purchasing process, contributes to a comprehensive understanding of the challenges and opportunities for improvement in the company's purchasing system. The simulation was performed using a total of 12 replicates, equivalent to one replicate per month, taking into account a total of 25 working days per replicate to obtain a quantifiable observation of procurement processes over time.

After carrying out the simulation in the ARENA program, a diagrammable simulation model is obtained that accurately represents the processes, resources and distribution in the purchasing system as shown in Figure 3.

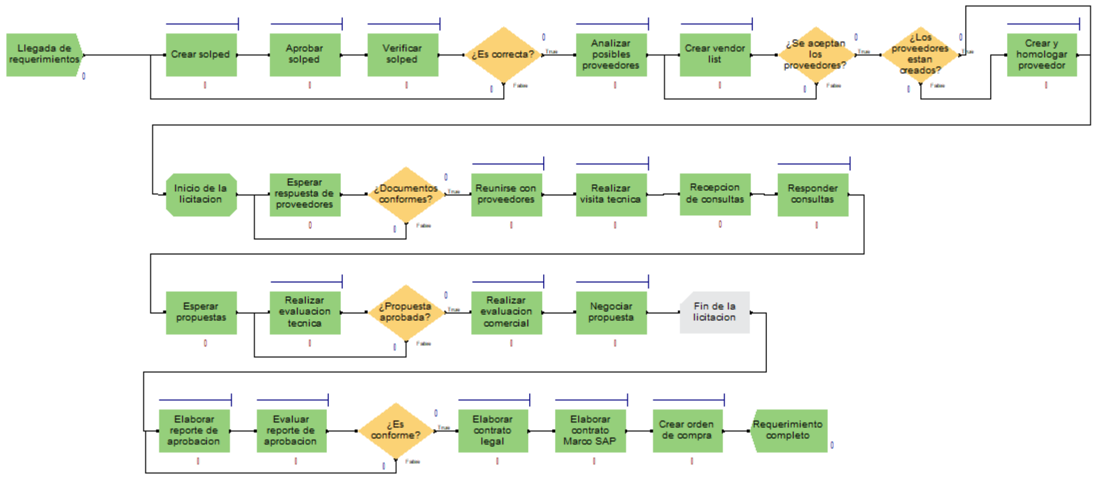

Figure 3. Simulation model of the purchasing process AS-IS – ARENA

The results of simulation and unstructured staff interviews include key metrics such as processes, resources, minimum value, most probable value and maximum value which is evidenced in **Table 1**. These indicators are fundamental to evaluate the current performance of time-based purchasing simulation as shown in **Table 2**, in addition, to identify specific areas that require improvements with the aim of optimizing efficiency and productivity in the mining company.

Table 1. AS-IS process evaluation.

Process number	Process	Resources	Minimum value	Most probable value	Maximum value
1	Create SOLPED	Technical user (1)	0.45	0.5	0.55
2	Solped Approval	User's boss (1)	6.75	7.5	8.25
3	Verificar solped	Buyer (1)	0.45	0.5	0.55
4	Analyze potential suppliers	Buyer (1)	4.05	4.5	4.95
5	Create vendor list	Buyer (1)	0.45	0.5	0.55
6	Create and approve vendor	Supplier creator (1)	33.75	37.5	41.25
7	Wait for supplier response		0.5	1	1.5
8	Meet with suppliers	Buyer (1)	2	4	6
9	Schedule technical visit	Buyer (1)	6.75	7.5	8.25
10	Receive inquiries		11.25	22.5	33.75
11	Answering inquiries	Technical user (1)	11.25	22.5	33.75
12	Wait for proposals		26.25	52.5	78.75
13	Conduct technical evaluation	Technical user (1)	11.25	22.5	33.75
14	Conduct commercial evaluation	Buyer (1)	6.75	7.5	8.25
15	Negotiate proposal	Buyer (1)	5	10	15
16	Prepare approval report	Buyer (1)	2.7	3	3.3
17	Evaluate approval report	Purchasing Manager (1)	6.75	7.5	8.25
18	Draw up legal contract	Legal Area (1)	33.75	37.5	41.25
19	Draw up SAP master agreement	Buyer (1)	0.45	0.5	0.55
20	Create purchase order	Buyer (1)	0.45	0.5	0.55

Table 2. AS-IS Time Indicators

Indicator	Average	Mean amplitude	Standard deviation	Minimum average	Maximum average
Active time	122.77	1.53	2.41	119.96	126.51
Standby time	264.29	5.87	9.23	241.1	275.55
Total time	387.06	6.01	9.46	367.12	400.51
Bidding time	316.84	5.5	8.66	304.21	331.09

By understanding the AS-IS model graphically and numerically with statistical data, it is possible to identify the gaps and areas of opportunity to design the TO-BE model realistically, which allows to effectively model the processes through which a purchase order passes, from the creation of the requirement to the issuance of the purchase order, ensuring an accurate representation of business operations and a solid basis for the implementation of improvements.

The application of the Just in Time methodology (JIT) and waste disposal (MUDA) are revealed as essential components to optimize the CAPEX purchasing process. JIT focuses on simplifying and streamlining the existing manufacturing process, thus reducing waste and improving efficiency. MUDA, as part of the LEAN methodology, focuses on eliminating waste and generating high quality services with lower production costs.

In summary, the Just in Time methodology is based on several key principles. The first is to tackle fundamental problems using the Pareto principle, which allows for the rapid identification of minorities of vital characteristics requiring more attention. Second, it seeks to eliminate waste using the 7 waste approach (MUDA), identifying and eliminating unnecessary activities that do not add value to the process. Third, simplicity is sought to avoid bureaucracy and streamline workflow. And finally, effective systems are established to identify problems and make informed decisions based on concrete data.

Table 3 shows the three key phases of the procurement management process identified in the Just in Time process, each focused on addressing specific aspects of the procurement process to improve efficiency and reduce waste, also describes the period of time that each task demands. Where the Pareto diagram is made for the three phases of the total process, which is evidenced as a tool to identify and prioritize the problems that have the greatest impact on the purchasing process, thus allowing a focused and effective improvement.

Table 3. Process Evaluation Phases Total

Phase	Task	Hours
First Phase	Create solped	0.5
	Approve solped	7.5
	Verify request	0.5
	Assign request	
	Analyze potential suppliers	4.5
	Create vendor list	0.5
	Evaluate vendor list	
	Create and approve supplier	37.5
Second Phase	Send invitation to suppliers	
	Wait for response from suppliers	1
	Meet with suppliers	4
	Schedule technical visit	7.5
	Receive inquiries	22.5
	Respond to inquiries	22.5
	Wait for proposals	52.5
	Conduct technical evaluation	22.5

	Conduct commercial evaluation	7.5
	Award supplier	
	Negotiate proposal	10
Third Stage	Prepare approval report	3
	Evaluate approval report	7.5
	Draw up legal contract	37.5
	Draw up SAP master agreement	0.5
	Create purchase order	0.5
	Releases	

From Table 3, which shows the phases identified in the Just in Time process, a graph has been generated that reveals significant data. Figure 4 highlights that the second phase (MUDA) represents the major phase with a cumulative 64.1% in terms of impact on the purchasing process. In addition, it is noted that this phase has a frequency of 177.5 hours, indicating the time spent on activities that could be considered waste. These data suggest that the second phase is crucial and needs to be thoroughly evaluated in the Just in Time process to achieve significant improvements in efficiency and reduction of waste in the procurement workflow.

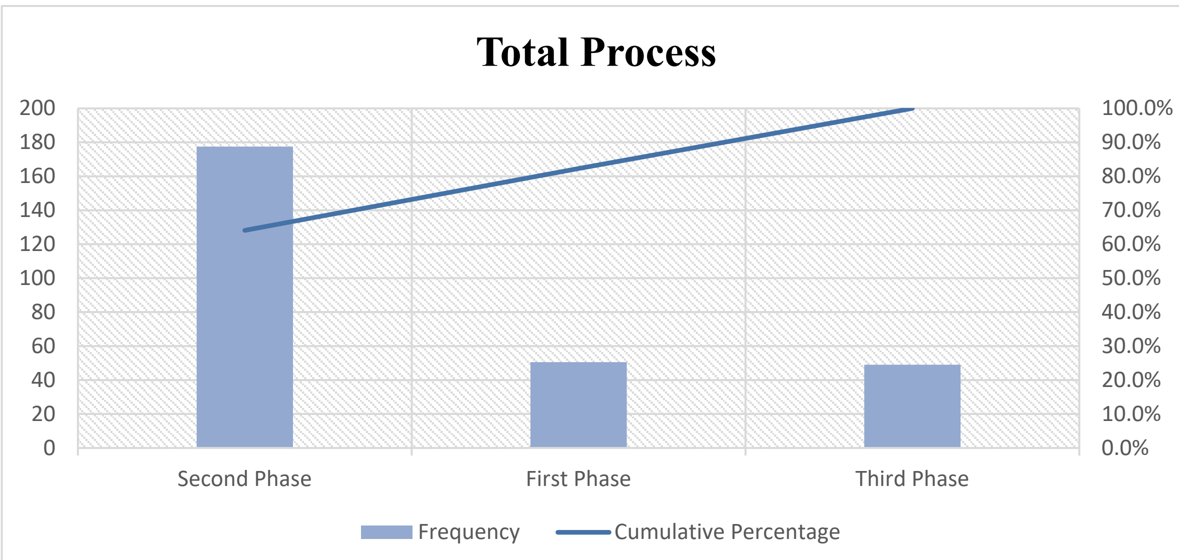

Figure 4. Pareto Diagram Processes Phases Total

After a detailed analysis of the graph and the related table, it is proposed to focus the approach on phase two of the process (MUDA), as a critical point to optimize the Just in Time process in the context of purchases. **Table 4** provides specific information about each activity within this phase, including the frequency of occurrence, the percentage accumulated and the total time accumulated that each activity demands. This detailed data allows a deep understanding of how activities are distributed and how they contribute to the total time spent in the second phase.

Table 4. Process Evaluation Second Phase

Phase	**Task**	**Frequency**	**Cumulative Percentage**	**Cumulative Sum**
Second Phase	Waiting for proposals	52.5	35.0%	52.5
	Receiving inquiries	22.5	50.0%	75
	Answer queries	22.5	65.0%	97.5

Conduct technical evaluation	22.5	80.0%	120
Negotiate proposal	10	86.7%	130
Schedule technical visit	7.5	91.7%	137.5
Conduct commercial evaluation	7.5	96.7%	145
Meet with suppliers	4	99.3%	149
Wait for response from suppliers	1	100.0%	150

After analyzing the table, we proceed to perform a Pareto analysis graphically to identify the most critical phases that require priority attention in terms of time of the second phase. The four phases that represent 80% of the accumulated percentage frequency are "Waiting for proposals," "Receiving inquiries," "Answer queries," and "Conduct technical evaluation," with time frequencies of 52.5, 22.5, 22.5, and 22.5 respectively as evidenced in **Figure 5**. These phases stand out as the most significant in terms of time demand, which indicates that they must be carefully evaluated to improve the efficiency of the purchasing process and reduce waiting times.

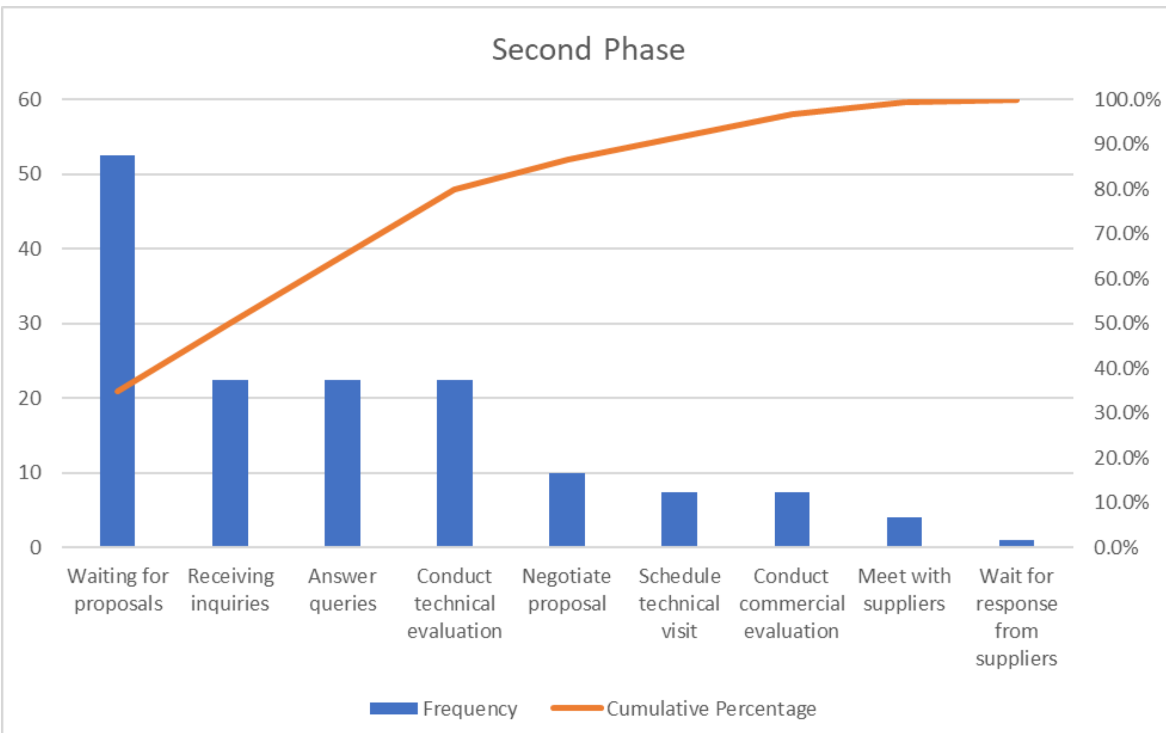

Figure 5. Pareto Diagram Second Phase Processes

According to the above analysis of the identified Pareto graphs and activities, the process of improvement is presented in **Table 5**. This table focuses on the evaluated phases of the process identified in the Pareto diagram, where strategies are proposed to address key problems, proposed solutions, waste disposal and additional comments. Each improvement process focuses on the four fundamental stages of Just In Time, from Pareto analysis to the establishment of systems to identify problems, with the aim of optimizing the efficiency of the purchasing process and reducing waiting times effectively.

Table 5. Improvement Proposal and Just-in-Time Analysis

JUST-TIME Process	1. Attacking the fundamental problems: Pareto	Waste	Solution	Comments

1. PARETO	Wait for proposals: Implements a system to identify and prioritize the most viable and strategic bidding opportunities. This through the analysis of historical data and a scoring system.	Delay in analyzing proposals	Develop a prioritization matrix based on cost, impact and scope.	Cannot be simulated
	Reception of queries: Implement a Wechat platform in a time between ranges.	Delay in answering each query	Wechat so that everyone can leave their queries and everyone can observe them.	25% reduction in repeat queries
	Answering queries: Through a live virtual platform, all queries will be answered.	Respond one by one in private	Hold a meet and greet meeting to answer all queries within a set time frame.	Reduction of 35% of answering queries
	Conduct technical evaluation: Establish deadlines and rigorous follow-up, define clear and realistic deadlines for the technical evaluation of proposals.	Bottleneck in proposing several solutions and determining the most important one.	Set a deadline so they can focus on what is most important.	Decrease of standard deviation in the module of performing technical evaluation
2. MUDA	Overproduction	Focusing only on purchasing requirements that have been previously approved or that the project is in the approval process.	Cannot be simulated	Cannot be simulated
	Waiting time	Delays in waiting times for approvals and digitization of signatures on contracts.	Eliminate bottlenecks in management approvals	Remove approval report module
	Transportation	Technical visits should only be used when necessary, as it extends the PO execution time.	Eliminate technical visits by 25%	Add a desgin module before technical visit
	Excess processing	Unnecessary reprocessing in purchases under USD 20,000.00	Make automatic POs with purchases under 20,000.00 USD with the respective support.	Add a design before bidding (10%)
	Inventory	High rate of supply of equipment that is stocked in units	Perform POs that are immediately installed in the unit.	Cannot be simulated
	Movement		Eliminate homologations	Cannot simulate

	Defects	High percentage of poorly created requisitions	Increase monthly training to end users.	Decrease solped creation time, decrease solped verification time and decrease percentage of poorly created solpeds
3. Search for Simplicity	3. Search for simplicity : Avoiding bureaucracy	Delays in senior management approvals	Schedule meetings or specific times for approvals.	Modify the distribution of the module to create solped and elaborate the approval report (Max: 5 days and Min: 1).
4. Establish systems to identify problems	4. Establish systems to identify problems	Various systems searching for problems that are normally insignificant	Implement ASANA for the entire process so that the status of the process can be seen in a transparent and live manner.	Cannot be simulated

5.2. Proposed Improvements

Within the framework of the Just in Time evaluation, an improvement analysis is proposed using points of improvement management based on the Lean philosophies mentioned in the TO-BE diagram shown in Figure 6, which represents the future definition of the service and seeks to generate an improved version of the process that leads to the desired objectives. With these improvement points identified in the TO-BE diagram, a simulation is carried out in the ARENA program under the same conditions as the first simulation, which consists of 12 monthly replicas. This approach allows you to quantify changes in the purchasing process in terms of time optimization, thus providing a clear view of how the proposed improvements can positively impact the efficiency and overall performance of the process.

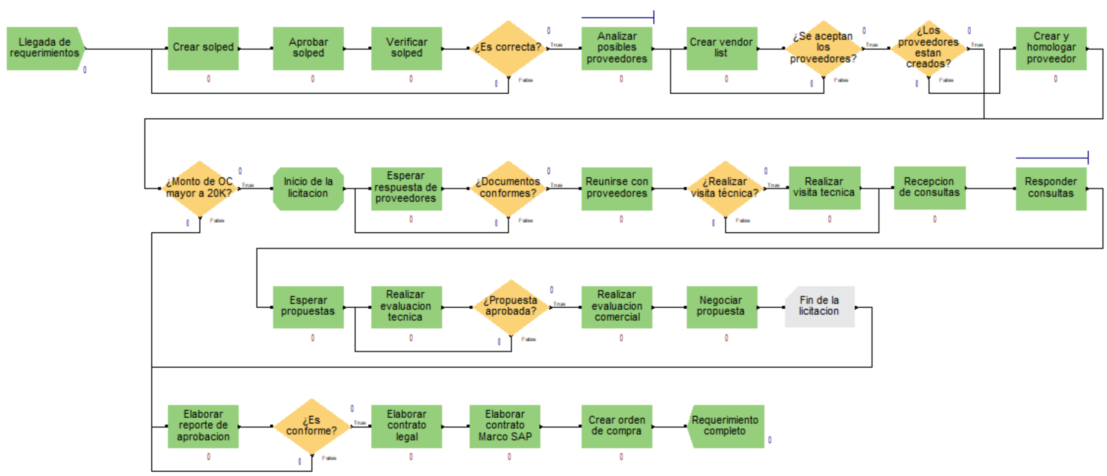

Figure 6. Simulation model of the purchasing process TO-BE – ARENA

The results of the simulation shown in **Table 6** include key metrics such as processes, resources, minimum value, most probable value and maximum value, implementing the improvements in the TO-BE model. These improvements were carried out through the implementation of Just in Time process improvement strategies, which ensured effective optimization of resources and process times in the TO-BE model of purchases.

Table 6. TO-BE process evaluation

Process number	Process	Resources	Minimum value	Most probable value	Maximum value
1	Create solped	Technical user (1)	0.225	0.25	0.275
2	Approve solped	User's boss (1)	6.75	7.5	8.25
3	Verify solped	Buyer (1)	0.225	0.25	0.275
4	Analyze potential suppliers	Buyer (1)	4.05	4.5	4.95
5	Create vendor list	Buyer (1)	0.45	0.5	0.55
6	Create and approve vendor	Supplier creator (1)	33.75	37.5	41.25
7	Wait for supplier response		0.5	1	1.5
8	Meet with suppliers	Buyer (1)	2	4	6
9	Schedule technical visit	Buyer (1)	6.75	7.5	8.25
10	Receive inquiries		8.438	16.875	25.313
11	Answer inquiries	Technical user (1)	7.313	14.625	21.938
12	Wait for proposals		26.25	52.5	78.75
13	Conduct technical evaluation	Technical user (1)	11.25	22.5	33.75
14	Conduct commercial evaluation	Buyer (1)	6.75	7.5	8.25
15	Negotiate proposal	Buyer (1)	5	10	15
16	Evaluate approval report	Purchasing Manager (1)	6.75	7.5	8.25
17	Draw up legal contract	Legal Area (1)	33.75	37.5	41.25
18	Develop SAP master agreement	Buyer (1)	0.45	0.5	0.55
19	Create purchase order	Buyer (1)	0.45	0.5	0.55

5.3. Validation

To validate the impact of the improvements, four key indicators are established to measure the performance of the current purchasing process (AS IS) compared to the proposed process (TO BE). These indicators are: active time, waiting time, total time and bidding time. Active time refers to the period in which an "order request" entity is being used in one of the Seize Delay Release modules. Timeout is the time when the entity is not associated with any resource and is waiting for a module to be released. The total time spans from the start to the end of the simulation process, while the bidding time refers to the process that goes from the call to suppliers to the negotiation of the proposal.

Subsequently, the Output Analyzer program is used to compile all replications of both models and compare them using a Two-Sample-T test, with a confidence level of 95%, in order to determine whether the difference between the two models in each of the indicators is significant or not. Figures 7, 8, 9 and 10 present the comparison of these indicators between the two models.

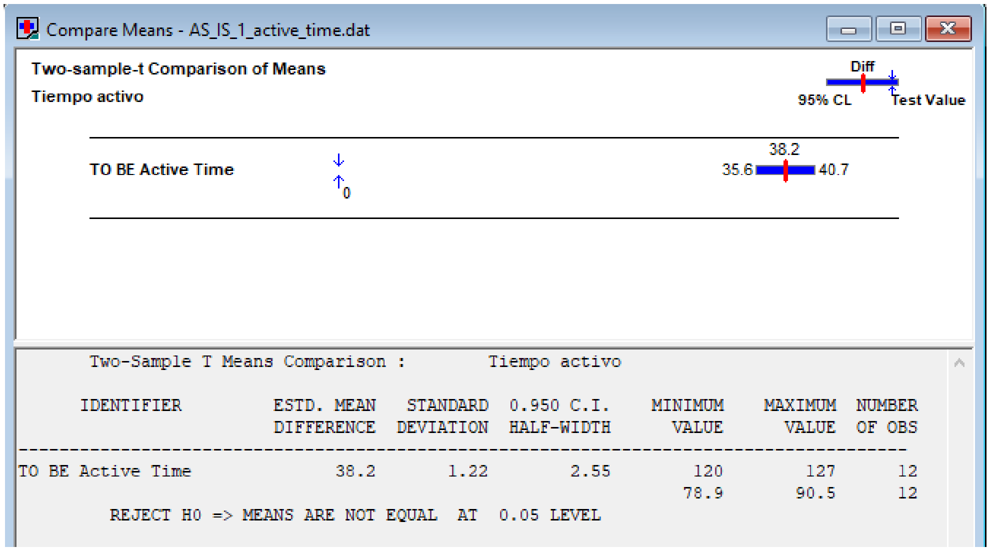

Figure 7. Comparison of active time between both models

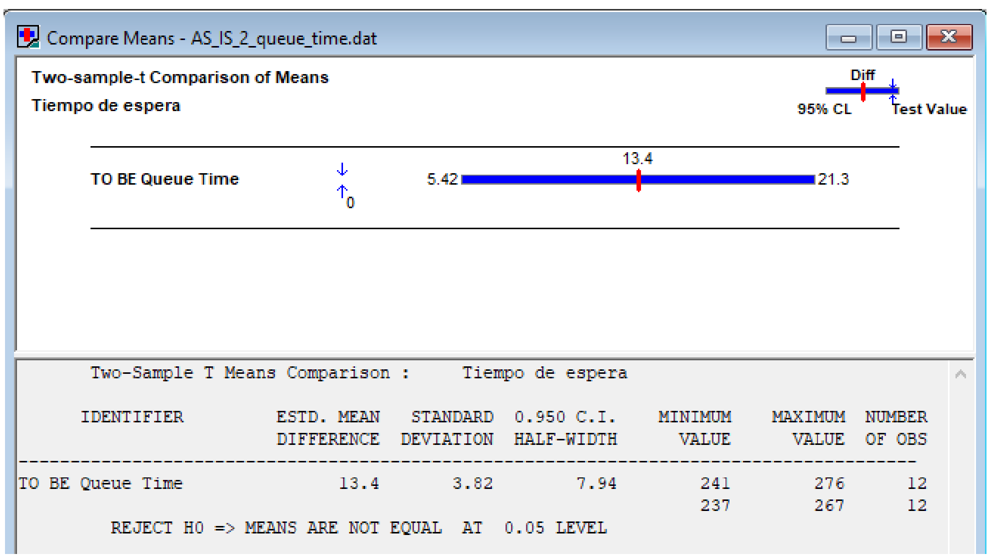

Figure 8. Comparison of waiting time between both models

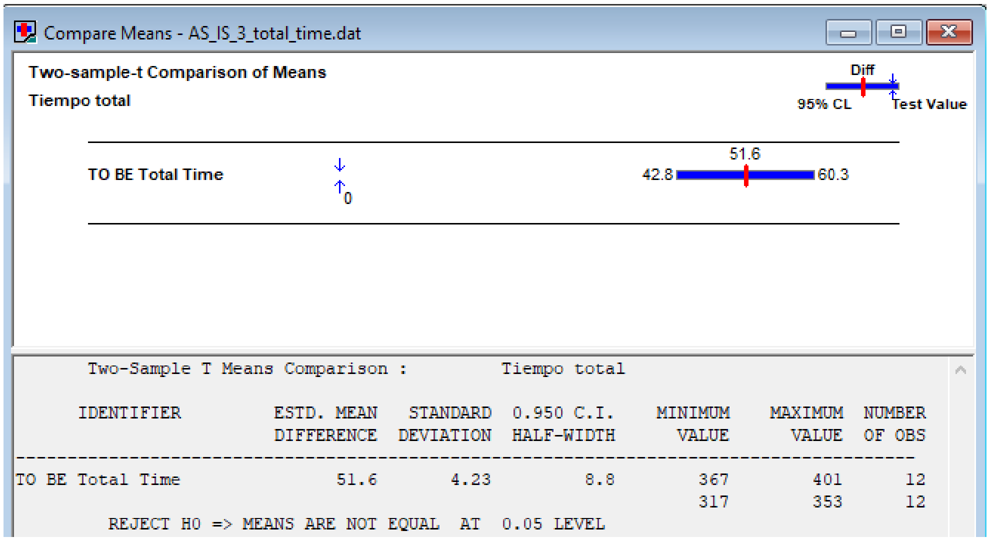

Figure 9. Comparison of total time between both models

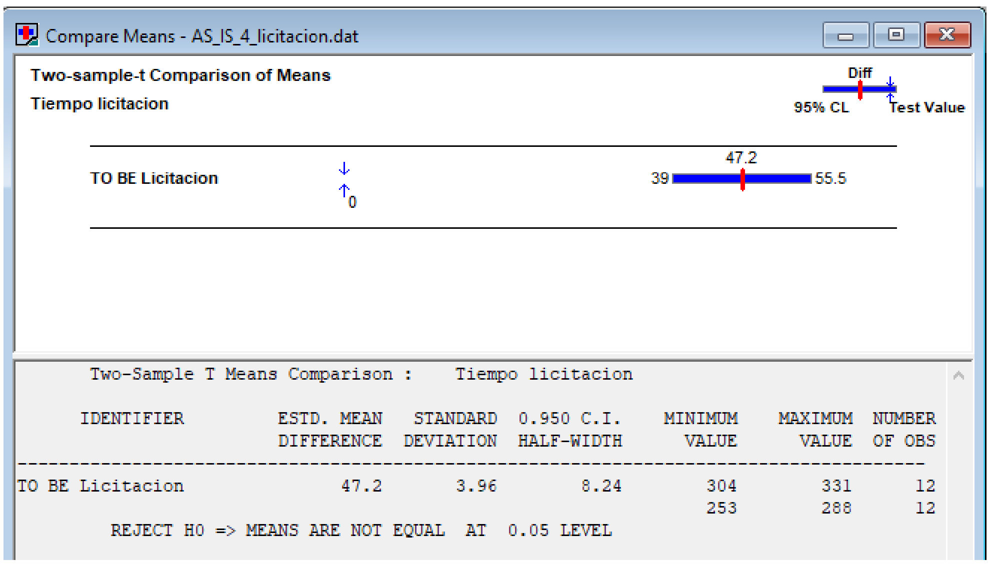

Figure 10. Comparison of bidding time between both models

When analyzing the above figures, it is observed that the difference between the indicators of the new purchasing process and the original model is different from zero. That is, the active time, waiting time, total time and bidding time show lower values in all replications compared to the original model. Based on the confidence tests carried out on these results, it is concluded with 95% confidence that the proposed purchasing model presents significant and effective changes in terms of optimizing time and resources.

6. Conclusions

From the results obtained, it was concluded that the implementation of strategies based on Lean methodologies, such as Just in Time and Muda, has proven effective in optimizing the CAPEX purchasing process in the mining company. A significant reduction in purchase order delivery times was achieved, as well as an improvement in efficiency and overall process performance validated by the Output Analyzer and compared to a Two-Sample-T test with a 95% confidence level.

Therefore, a clear validation was obtained of the positive impact of the proposed improvements of the active, waiting, total and bidding time, both in terms of time optimization and in the operational efficiency of the purchasing process. Simulation results and statistical analysis support the effectiveness of the implementation of Just in Time and Muda strategies in optimizing workflow and reducing procurement time.

Future research recommends continuing to explore the potential of the Just in Time methodology for optimizing the procurement process, especially in international environments and in sectors with large operations. In addition, it is suggested to monitor the implementation of the proposed improvements over the long term in order to assess their continued impact and make additional adjustments if necessary.

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