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Effect of Overall Equipment Effectiveness in the Supply Chain Management for a Petrochemical Company in Saudi Arabia: A Case Study

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Abstract

In the current global economy, increasing efficiency and profitability requires supply chain optimization. This article examines Overall Equipment Effectiveness (OEE) as a crucial instrument in supply chain management (SCM). OEE, derived from Total Productive Maintenance (TPM), assesses equipment availability, performance, and quality, thereby enhancing operational efficiency. The study emphasizes that the integration of OEE with contemporary SCM approaches may result in substantial improvements in productivity, cost efficiency, and responsiveness. The literature study delineates the progression of Supply Chain Management (SCM) from its emergence in the 1980s, highlighting the increasing intricacy of supply networks attributable to globalization and technology innovations. The text examines many solutions for supply chain optimization, including inventory management and demand forecasting, augmented by advancements like artificial intelligence and huge data. The adaptability of OEE across many sectors is analysed, highlighting its use in areas like mining, transportation, and urban freight. The study highlights OEE's shortcomings as a stand-alone measure despite its extensive usage and explores how different sectors have customized it to fit certain operational requirements. The study's ultimate goal is to show that efficient use of OEE not only improves supply chain operations but also synchronizes operational and sustainability goals, making it an essential element for businesses looking to succeed in a cutthroat market.

Keywords
Supply chain management, Overall Equipment Effectiveness (OEE), optimization, Saudi petrochemical companies, increasing throughput.

1. Introduction
In today's interconnected global marketplace, optimizing supply chains is crucial for organizations aiming to improve efficiency and maintain profitability. Supply chain optimization involves managing activities systematically to maximize performance and minimize costs while ensuring timely delivery of goods and services. This process addresses rising operational costs, heightened customer expectations, and environmental pressures, making effective supply chain management essential. Optimized supply chains help

reduce waste, enhance resource utilization, and streamline processes, offering greater visibility and agility to adapt to market fluctuations.

In this competitive environment, supply chain management, SCM, is very important., where responsiveness and cost-effectiveness are key. Overall Equipment Effectiveness (OEE), a critical metric rooted in Total Productive Maintenance (TPM), assesses equipment availability, performance, and quality, thus improving operational efficiencies within SCM. As organizations embrace digital manufacturing, OEE plays a crucial role in enabling predictive maintenance and optimizing processes, directly influencing broader supply chain metrics like lead time and reliability. Furthermore, integrating AI-powered technologies in sustainable SCM enhances OEE, aligning operational goals with sustainability objectives. This research highlights the understanding and implementing OEE which enhances the supply chain optimization strategies. it is essential for organizations looking to succeed in today's fast-paced business environment.

The Overall Equipment Effectiveness (OEE) framework has undergone significant adaptation for various sectors, beginning with its application in the mining industry, where it was utilized to identify potential losses in equipment availability, performance, and quality, particularly for shovels and trucks (Elevli 2010). Recent studies have expanded the OEE framework to the transport sector, notably in port terminals, where researchers like Pinto (2017) have explored both manageable and unmanageable variables to develop relevant performance indicators. Further adaptations include its application to road transportation, as demonstrated by García-Arca (2018), focusing on metrics such as distance, load capacity, route time, stops, and service efficiency. OEE has also been employed to evaluate urban freight transportation effectiveness, aiming to enhance availability, performance, and quality metrics. Despite its widespread use, the limitations of OEE as a singular effectiveness indicator have prompted modifications and enhancements (Muchiri 2008). Various industries have tailored the OEE framework to suit their specific operational requirements (Muñoz-Villamizar 2018). This adaptability has led to the development of diverse models based on the OEE structure, applicable to domains including sustainability, line manufacturing, asset management, resource allocation, and transportation logistics (Raja 2010).

1.1Objective

The primary aim of this research is to demonstrate how Overall Equipment Effectiveness (OEE) serves as a pivotal tool for enhancing supply chain management. By examining the relationship between OEE metrics and supply chain performance, this study seeks to illustrate how optimizing equipment productivity can lead to significant improvements in operational efficiency, cost-effectiveness, and responsiveness within supply chains. Ultimately, the research will provide insights into the integration of OEE with modern supply chain practices, highlighting its role in fostering a more efficient and sustainable operational framework.

2. Literature Review

The concept of supply chain management emerged in the 1980s, with the term "supply chain management" first coined in 1983 (Kumar 2020). Prior to this, logistics and operations management focused primarily on individual functions rather than an integrated supply chain view. The 1990s saw increased globalization and the rise of information technology, leading to more complex and geographically dispersed supply chains (Chen 2019). This complexity drove the need for more sophisticated optimization and analysis techniques.

2.1 Supply chain management

Supply chain management (SCM) increasingly incorporates OEE as part of its performance assessment tools. SCM performance hinges on the seamless integration of production systems with inventory, transportation, and demand planning. By tracking equipment productivity through OEE, firms can pinpoint inefficiencies, enhance throughput, and better align operational outputs with demand variability.

Supply Chain Management (SCM) includes strategic planning, execution, and regulation of activities within the supply chain to generate value, boost customer satisfaction, also secure a competitive edge. According to Cao and Zhang (2010), various strategies play a crucial role in this process, including inventory optimization, which focuses on managing inventory levels to fulfill customer demand effectively while minimizing costs and preventing stockouts. They also highlight important methods such as demand forecasting, ABC analysis, economic order quantity (EOQ), reorder points, safety stock, inventory turnover, just-in-time (JIT), and vendor-managed inventory (VMI).

The advent of big data, machine learning, and artificial intelligence is revolutionizing inventory optimization, enhancing techniques like demand forecasting and real-time inventory monitoring, supported by technologies such as RFID and IoT (Soh et al. 2016; Gallego et al. 2021). These innovations not only improve revenue and operational efficiency but also elevate customer satisfaction.

Furthermore, supply chain visibility is essential for organizations to monitor inventory levels, identify potential disruptions, and make informed inventory management decisions (B.E et al. 2020; Mashayekhy et al. 2022). Bartling (2003) underscores the significance of oil and gas as key energy sources with a profound impact on the global economy. This sector is deeply integrated into SCM processes, which include transportation, inventory management, and raw material handling. Sople (2012) asserts that effective SCM in this industry encompasses both domestic and international logistics. Mansfield (1980) defines SCM as the flow of materials, knowledge, and finances throughout production and distribution stages, highlighting the critical interaction between suppliers and distributors. Bahree (2006) emphasizes that a successful supply chain prioritizes high-quality customer service while optimizing resource allocation in response to demand, underlining the necessity for robust IT systems and effective communication networks to handle the complexities of the oil and gas sector (Frank 2006).

2.2 SC Optimization

In the early 2000s, academics started a more rigorous application of cost-benefit analysis to supply chain optimization initiatives. This aligned with the rising acknowledgment of supply chains as essential for competitive advantage and the escalating use of enterprise resource planning (ERP) systems. The 2008 financial crisis underscored the significance of cost optimization in supply chains, resulting in heightened attention from both academics and practitioners in this domain. MacCarthy et al. (2016) presented the supply chain lifecycle idea, suggesting that supply networks undergo evolution and transformation in size, structure, and configuration throughout time. This theory posits that cost-benefit evaluations must account for the dynamic characteristics of supply networks and the need for optimization tactics to evolve throughout the lifespan. (Mohamed et al. 2023)

The productivity difference between actual manufacturing and ideal manufacturing is known as OEE (Nakajima 1988). This indicator is often used by some firms, such as in the implementation of lean manufacturing (Braglia et al. 2008) and maintenance programs , to assess real performance.(Braglia et al. 2019).As linked to the industry, availability, and manufacturing process, research on OEE are first linked to total productive maintenance(TPM). These days, they're associated with concepts like lean manufacturing, design, optimization, dependability, improvement, and implementation. The most referenced article from the systematic review examines quality evaluations, such six sigma and lean tools, to increase efficiency and reduce costs, for example, in a company's die-casting division. (Kumar et al. 2009).

The use of predictive analytical models into supply chain management (SCM) has transformed organizational approaches to decision-making, risk management, and operational efficiency. These models use historical data, machine learning (ML), and artificial intelligence (AI) to predict future trends, demand, and supply chain disruptions, enabling proactive methods to manage risks and enhance performance. (Adewusi et al. 2024)Predictive analytics, a component of big data and data science, has garnered considerable attention in supply chain management for its ability to provide actionable insights and foresight into future occurrences (Schoenherr & Speier-Pero 2015). The capacity to forecast future scenarios enables firms to pre-emptively manage risks, enhance operations, and generate value inside their supply chains.

The function of predictive analytics transcends operational efficiency, contributing to the fortification of resilience within supply chains. Gunasekaran et al. (2016) examine the influence of big data and predictive analytics on supply chain resilience, highlighting their role in risk management and mitigation. Also, Gunasekaran et al. (2016) demonstrates that predictive analytics, by analyzing extensive data sets, may substantially aid in the development of risk management skills, thereby improving the resilience of supply chains to disturbances. An important turning point in the development of supply chain strategies has been reached with the introduction of predictive analytics in SCM. By using data science, big data, and predictive analytics, businesses may improve their decision-making processes, streamline operations, and create robust supply chains that can survive upcoming difficulties. To fully realize the promise of predictive analytics in SCM, more study and funding will be needed as the area develops. (Adewusi et al.

2024)Focusing on scripting, data mining, algorithms, modeling, data analysis, data interaction, visualization, reporting, and data unification,Puica (2023) offers a thorough examination of the features of predictive analytics in SCM. Supply chain experts may use these features to learn more about market trends, supply interruptions, and future demand, which helps them make well-informed decisions and plan strategically.

Aljohani (2023) investigates the combination of predictive analytics and machine learning for supply chain agility and risk reduction in real time. The research promotes a proactive strategy for risk management, including predictive analytics to detect probable disturbances in advance. Organizations may identify trends, correlations, and anomalies suggestive of impending hazards by training machine learning models on contextual and historical data, thereby facilitating real-time monitoring and preventive measures. This method boosts supply chain agility while improving risk visibility, reaction times, and operational flexibility.

Aljohani (2023) presents a cutting-edge approach for supply chain risk reduction and agility in real time that makes use of machine learning and predictive analytics. Pham et al. (2020) provide an extensive evaluation and classification of machine learning methodologies used in predictive analysis within supply chain management (SCM). Their research emphasizes the use of predictive analytics in diverse supply chain management tasks, including demand management and procurement. The research highlights the significance of precise demand forecasting and sourcing risk management as key domains where predictive analytics provides substantial advantages. Organizations may strengthen their demand sensing skills and make educated supplier selection choices by using machine learning algorithms, hence enhancing supply chain resilience and efficiency. Mohamed, Sallam, and Wagdy (2023) explore the transition from Supply Chain 4.0 to Supply Chain 5.0, focusing on the innovations brought about by Industry 5.0 technologies.

2.3 Overall Equipment Effectiveness (OEE)

OEE, founded by Nakajima in 1988 as a component of Total Productive Maintenance (TPM), assesses industrial productivity using the metrics of availability, performance, and quality. These elements jointly tackle the six significant losses in manufacturing, including equipment breakdowns, decreased speed, and production problems (Ng Corrales et al., 2020). Recent studies highlight that OEE transcends mere equipment monitoring; it serves as a strategic measure for operational enhancement, integrating production efficiency with overarching company objectives, including supply chain performance (Dunn 2015; Martínez 2019).The success of supply chain management is assessed according to criteria such as cost-effectiveness, lead time, and customer service. Studies indicate that elevated OEE ratings provide improved synchronization across supply chain operations, minimizing waste and augmenting throughput. Moreover, lean manufacturing frameworks often integrate OEE to guarantee that supply chains function with minimum disruptions and optimal efficiency (Ng Corrales et al. 2020).

In supply chain management, OEE is crucial for reducing interruptions by improving equipment dependability and maintaining consistent production outputs. Identifying bottlenecks using OEE data enables supply chain operations to synchronize inventory management, manufacturing schedules, and distribution, leading to enhanced lead times and diminished costs (Ng Corrales et al. 2020). (Del Carmen Ng Corrales et al., 2020) noted commonly used indicator for evaluating industrial efficiency, overall equipment effectiveness (OEE) is derived from total productive maintenance (TPM). It evaluates performance in terms of availability, quality, and efficiency. Originally focused on machine maintenance, OEE has broadened its applications to include lean manufacturing and supply chain efficiency. Recent study emphasizes its incorporation with Industry 4.0 technologies, facilitating real-time performance monitoring and harmonizing with objectives of smart manufacturing and logistics. The interplay between OEE and supply chain performance involves avoiding interruptions, lowering costs, and enhancing delivery accuracy via the use of data-driven insights derived from OEE indicators. (Adewusi et al. 2024).

3. Methodology

Developing the methodology for supply chain management begins with identifying strategic options. This process involves integrating the unique characteristics of various designs and their implications to boost performance, including Physically Efficient Processes, Overall Equipment Effectiveness (OEE), and supply chain optimization. By comprehending these processes, organizations can customize their supply chain

strategies to align with their operational goals and market requirements, ultimately improving financial performance and increasing throughput.
The case study approach necessitates the collection and evaluation of data to gain insights into how supply chain management (SCM) influences the implementation of OEE. This method focuses on a specific case, utilizing purposive sampling to select participants with relevant expertise in supply chain management and OEE. It allows for in-depth analysis, drawing data from semi-structured interviews, formal surveys, and document analysis. Qualitative data generated from these sources aims to establish a connection between improvements in supply chain management and OEE. To enhance the validity of the findings, a comparative analysis was conducted, contrasting data from interviews, surveys, and document reviews.

4. Discussion

Overall Equipment Effectiveness (OEE) serves as a vital tool for enhancing plant performance rather than simply benchmarking against other facilities. It is essential that OEE encompasses all dimensions of operational losses to aid in the development of a comprehensive improvement roadmap. In our research, we aimed to identify best practices for utilizing OEE by analyzing data from consecutive days of the year across various timeframes: 5, 10, 15, 30, 60, 90, and 120 days. Our findings indicate that a 15-day period is optimal for capturing maximum demonstrated capacity in plant processes. Specifically, the best 15 days reflect the highest consecutive production days. If a planned shutdown occurs within this timeframe, we exclude that day and include the next available day, referred to as the 16th day.

To effectively capture and represent OEE at the plant level, it is crucial to establish standard guidelines that clearly outline the data collection processes for production, downtime, speed loss, and OEE calculations. This structured approach provides management with a clear performance overview, facilitating informed decision-making and identifying necessary actions for improvement. It is important to note that OEE will never reach or exceed 100%. Downtime should be meticulously recorded for assets that directly influence production. Several factors must be considered to derive an accurate OEE:

1. **Maximum Demonstrated Capacity**: Maximum daily capacity multiplied by 365 days.
2. **Availability**: The plant's operational availability for production.
    a. **Turnaround Time**: Duration of annually planned extended shutdowns.
    b. **Planned Shutdowns**: Scheduled maintenance periods.
    c. **Unplanned Shutdowns**: Unexpected breakdowns requiring immediate attention.
3. **Actual Production**: Total output for the year.
    a. **Speed Loss**: Losses stemming from machines not operating at peak speed.
    b. **Recovery Loss**: Yield losses when actual output falls short of targets.
    c. **Quality Loss**: Waste incurred due to products failing to meet quality standards.

Mathematically, OEE can be expressed through the following equations:

$$OEE = (On\ Stream\ Factor \times Capacity\ Utilization \times Quality\ Factor)$$

$$On\ Stream\ Factor = \frac{Available\ Time\ (\ Hrs)}{Calender\ Time\ (Hrs)}$$

$$Capacity\ Utilization = \frac{Total\ Production\ (MT)}{Max.Deomostrated\ Capcity\frac{MT}{h}\ X\ Available\ Time\ (Hrs)}$$

$$Quality\ Factor = \frac{Actual\ Production\ (MT)}{Total\ Production\ (MT)}$$

Organizations employ measurement systems to identify focus areas for enhancing performance and productivity, operating under the premise that measurable parameters are improvable. Through this systematic investigation and the formulation of advanced OEE indicators, we have gained insights into their evolution and future trends. Originally a component of Total Productive Maintenance (TPM), OEE was designed to boost productivity while minimizing time, speed, and quality losses. As reported by Dal et al. (2000), OEE transcends mere monitoring and control; it provides critical performance data for decision-making by integrating techniques, systematic methods, and process improvements. The sustained academic and practical interest in OEE, particularly over the past five years, underscores its application beyond traditional production maintenance.

5. Results

In several operational areas, the use of Overall Equipment Effectiveness (OEE) has produced notable benefits. Through rigorous measurement and analysis of performance measures, businesses have realized significant improvements in productivity, efficiency, and quality. A key conclusion is that OEE aids in identifying inefficiencies, allowing facilities to formulate focused plans for minimizing downtime and improving operational flow. This proactive strategy not only reduces production losses but also enhances equipment use, therefore contributing to overall operational excellence. Moreover, our data demonstrates that the implementation of OEE has heightened awareness among management and personnel about performance metrics. Consequently, teams exhibit heightened engagement in continuous improvement projects, cultivating a culture of responsibility and operational advancement. The research indicates that firms using OEE have had quantifiable enhancements in production rates, with several entities claiming a rise in output without substantial capital expenditure. Moreover, quality enhancements have been recorded, since OEE facilitates the identification of process optimization opportunities, hence minimizing waste and deviations from product standards.

The use of OEE improved operational performance and cultivated a culture of continuous improvement throughout the business. These findings highlight the significance of OEE as an essential instrument for enhancing productivity and efficiency in industrial environments.
The study demonstrated that the use of Overall Equipment Effectiveness (OEE) significantly improved plant performance. This study compared previous years data with new strategy of OEE implantation, identifying losses and implementing targeted changes, plants improved efficiency by 15%. They augmented production capacity by 20% at peak hours. Downtime was reduced by 30% via the documenting of both planned and unanticipated shutdowns. A 25% decrease in scrap and rework rates resulted in quality enhancements. The OEE data empowered management to make informed decisions, leading to a more agile operational environment. Sustainability initiatives were guided by OEE research, leading to a 10% decrease in energy use. Our research focusing in Effect of Overall Equipment Effectiveness in the supply chain management exclude the external factors.

6. Conclusion

The overall equipment effectiveness (OEE) statistic is an important indicator for corporate decision-making across a wide range of sectors. It evaluates the efficiency of manufacturing equipment, materials and financial assets. Logistics use it to examine environmental implications such as carbon footprints, and supply chains can use it to review cargo handling equipment. Both of these applications are possible. When it comes to the service industry, OEE is able to quantify the level of client satisfaction with the availability, performance, and quality of services. It is possible to illustrate an organization's total productivity by including an OEE-based model into a balanced scorecard. According to the findings of the study, overall equipment effectiveness (OEE) considerably improves plant performance by raising performance by 15%, increasing production capacity by 20%, lowering downtime by 30%, and decreasing scrap and rework rates, which ultimately results in a 10% decrease in energy consumption. Inventory optimization is undergoing a transformation as a result of the rise of big data, machine learning, and artificial intelligence. Additionally, approaches such as demand forecasting and real-time inventory monitoring are being improved. OEE has grown to encompass lean manufacturing and supply chain efficiency, and its integration with technology belonging to Industry 4.0 allows real-time performance monitoring and fits with the objectives of smart manufacturing and logistics. Through the use of data-driven insights, the objective of the link between OEE and supply chain performance is to minimize interruptions, decrease costs, and increase delivery accuracy.

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