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Impact of Production Planning, Preventive Maintenance, and Safety Compliance on Operational Efficiency in Chemical Manufacturing Plants

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Abstract

This study investigates the impact of production planning, preventive maintenance, and safety compliance on the operational efficiency of calcium chloride granulation plants in Pakistan. The primary objective is to assess how these factors influence plant performance in terms of minimizing downtime, optimizing production, and ensuring compliance with safety standards. A quantitative research design, grounded in the positivist philosophy, was employed, utilizing a structured survey questionnaire to gather data from plant management professionals. The sample comprised plant managers, maintenance supervisors, and safety officers, with responses analyzed using structural equation modeling (SEM). The findings reveal that all three factors—production planning, preventive maintenance, and safety compliance—significantly and positively impact operational efficiency. Production planning optimizes resource use and reduces operational disruptions, preventive maintenance minimizes equipment failures, and safety compliance ensures smoother operations by preventing regulatory violations and accidents. These findings highlight the importance of an integrated approach to operational management, where strategic investments in planning, maintenance, and safety can enhance plant performance. The study provides practical recommendations for plant managers and industry stakeholders, emphasizing the need for advanced tools and technologies to improve operational efficiency while maintaining regulatory compliance.

Keywords: *Production planning, Preventive maintenance, Safety Compliance, Chemical Manufacturing plant, Calcium chloride*

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1. Introduction

Modern industrial processes heavily rely on chemical manufacturing, which produces a diverse range of products that are used in construction, agriculture, and pharmaceuticals. Among these, calcium chloride stands out as a highly versatile compound with numerous applications which includes deicing, dust control, treatment of treatment, and the processing of food (Teisala et al., 2014). The growing global demand for this compound necessitates an emphasis on both market-driven production and adherence to stringent safety and environmental standards. For regions like Qatar, where calcium chloride granulation plants are integral to the industrial landscape, the dual challenge lies in enhancing the operational efficiency while complying with regulatory frameworks (Karem Mahmoud, 2019). This study seeks to explore the relationship between production planning, preventive maintenance, and safety compliance to identify strategies that can improve the performance of plant. Operational efficiency in chemical manufacturing is intricately tied to production planning, a process that involves forecasting demand, scheduling production runs, managing raw material inventory, and optimizing the utilization of utilization (Rahmani et al., 2023). In calcium chloride manufacturing, effective production planning mitigates bottlenecks, balances costs with outputs, and ensures the timely delivery to meet the demands of market. A well-structured production plan creates a smooth workflow, reducing risks of overproduction or underutilization of resources. As a result, production planning serves as a key determinant of the operational pace of the plant which directly impacts its ability to meet market requirements efficiently (Thürer et al., 2022). Complementing production planning is the crucial function of preventive maintenance. In industries like chemical manufacturing, where mechanical failures can lead to safety hazards, financial losses, and environmental risks, preventive maintenance minimizes the unplanned downtime, operational disruptions, and the depreciation of assets (Amaechi et al., 2022). By ensuring that machinery and systems remain functional and efficient, preventive maintenance not only extends the lifecycle of plant equipment but also reduces the likelihood of operational hazards. This dual benefit makes preventive maintenance an indispensable component of the operational strategy (Mobley, 2021).

Safety compliance forms the third cornerstone of operational efficiency in the manufacturing of chemicals, particularly in the hazardous environments such as calcium chloride granulation plants. Chemical spills, equipment failures, and worker exposure to hazardous materials necessitate the strict adherence to the protocols of safety (Boiano et al., 2014). Regulatory bodies impose stringent standards that include frequent inspections, certifications, and training programs to mitigate these risks. Compliance is nonnegotiable, as lapses can result in severe financial penalties, reputational damage, or even plant shutdowns. Importantly, safety adherence is closely linked to operational efficiency; reliable equipment maintained under the preventive strategies that enhances safety compliance, while efficient production planning minimizes safety risks which are associated with operational delays (Benson et al., 2024). These three variables—production planning, preventive maintenance, and safety compliance—are deeply interrelated with each other. Effective production planning must account for scheduled preventive maintenance to avoid conflicts and delays, while well-maintained equipment reduces the likelihood of operational incidents that could compromise the standards of safety. Consequently, the integration of these factors is crucial for achieving a resilient and efficient system in chemical manufacturing (Heizer & Render, 2020). The theoretical foundation for this study is provided by operations management theory and the resource-based view (RBV) of the firm. Operations management theory emphasizes maximizing production processes through the rational utilization of resources, while the RBV highlights the strategic advantage of effectively deploying internal resources for instance, production expertise, maintenance practices, and safety protocols. Together, these theories highlight the importance of integrating production planning, preventive maintenance, and safety compliance to enhance the operational efficiency and competitive advantage in a calcium chloride granulation plant (Barney, 1991).

Despite the critical importance of these variables, their combined impact on operational efficiency in chemical manufacturing has received limited attention in the literature, particularly within the Middle Eastern context. Previous research has largely focused on individual factors or the challenges which were faced by large multinational corporations, overlooking the unique dynamics of smaller, region-specific plants. This gap is particularly significant in Qatar, where growing environmental scrutiny, evolving regulatory standards, and heightened awareness of workplace safety demands a comprehensive approach to the operational management (Obeidat et al., 2020). This research aims to address this gap by investigating how production planning, preventive maintenance, and safety compliance collectively influence the operational efficiency in calcium chloride granulation plants in Qatar. This research contributes to the existing literature in the following ways. Firstly, it bridges a critical gap by integrating production planning, preventive maintenance, and safety compliance as interrelated factors influencing operational efficiency in calcium chloride granulation plants. While previous studies have examined these variables individually such as preventive maintenance (Liao et al., 2023), capacity planning and production scheduling (Yao & Gruber, 2022), technical safety (Odili et al., 2024) limited attention has been paid to their combined impact, particularly in the context of chemical manufacturing in the Middle East. This study provides a holistic framework that emphasizes the interconnected nature of these factors by contributing to a deeper understanding of operational optimization (Heizer & Render, 2020).

Secondly, this research adds to the theoretical discourse by employing operations management theory and the resource-based view (RBV) as foundational perspectives. By demonstrating how effective allocation of a resources and internal capabilities for instance maintenance strategies and safety protocols drives operational performance, this study extends the applicability of these theories to region-specific industries. It highlights how firms in Qatar can leverage these theoretical insights to address unique challenges to highly regulated sectors like chemical manufacturing (Al-Sulaiti et al., 2024). Thirdly, this study offers practical contributions by addressing the pressing need for strategies that balance the operational efficiency with compliance requirements. In an era of increasing environmental and workplace safety regulations, particularly in industrial hubs like Qatar, this research provides actionable recommendations for plant managers to enhance the performance while adhering to stringent regulatory and safety standards. By focusing on the calcium chloride industry, this study serves as a case model for other chemical manufacturing plants which strive to align efficiency with the sustainability (Alkaya & Demirer, 2015).

The remainder of this article is organized as follows. Section 2 reviews the existing literature on operational efficiency, production planning, preventive maintenance, and safety compliance, with a focus on their relevance to chemical manufacturing. Section 3 outlines the theoretical framework and research methodology which details the data collection and analysis techniques that are employed in this study. Section 4 presents the findings and discusses their implications which is supported by references to theoretical insights and practical considerations. Section 5 concludes the article with key recommendations, limitations, and future research directions by emphasizing the significance of integrating operational strategies in regulated industries.

2. Literature Review

2.1 Theoretical Background

This study is grounded in two key theoretical frameworks: Operations Management (OM) theory and the Resource-Based View (RBV) theory. These frameworks provide a solid foundation for understanding the relationship between production planning, preventive maintenance, and safety compliance in enhancing the operational efficiency, particularly in highly regulated industries like chemical manufacturing. Operations Management theory emphasizes the optimization of production processes, allocation of resources, and workflows to achieve the efficiency and effectiveness of an organization (Ashraf, 2024). It focuses on designing and managing processes that produce goods or deliver services while ensuring the minimal waste and maximum value creation (Awan & Bozan, 2022). The theory highlights the importance of strategic planning, efficient scheduling, and preventive measures to mitigate the operational disruptions. By integrating production planning with maintenance and safety protocols, organizations can ensure smooth workflows, reduce downtime, and meet the demands of market while adhering to regulatory standards. This study aligns with OM theory by examining how the integration of production planning, preventive maintenance, and safety compliance enhances the operational efficiency of calcium chloride granulation plants. It extends OM theory by addressing the challenges posed by stringent safety and environmental regulations specific to the chemical manufacturing industry.

The Resource-Based View (RBV) theory complements this perspective by focusing on the strategic importance of a internal resources of firm in achieving competitive advantage. According to RBV, organizations gain a sustainable competitive edge by effectively deploying valuable, rare, inimitable, and non-substitutable (VRIN) resources (Barney, 1991). In the context of this study, production planning expertise, maintenance practices, and safety compliance protocols represent critical internal resources which drives operational performance. These resources, when effectively managed, enable firms to achieve operational excellence while maintaining the compliance with regulatory requirements (Willie, 2025). This study aligns with RBV theory by demonstrating how the strategic integration of these resources contributes to both operational efficiency and competitive advantage in a highly regulated environment. It also highlights the importance of the harmonization of resources to balance efficiency and compliance, which is particularly relevant for chemical manufacturing plants in regions like Qatar. The Resource-Based View (RBV) also highlights the critical role of organizational capabilities, which refer to a ability of firm to effectively mobilize and utilize its resources to achieve and sustain a competitive edge (Madhani, 2010). By emphasizing the internal dynamics of a firm, RBV offers a comprehensive lens to understand how companies can strategically leverage their unique resources and capabilities to outperform the competitors. This perspective highlights that competitive advantage arises from resource ownership and the ability to integrate, deploy, and adapt these resources in response to market and operational demands.

2.2 Hypotheses Development

2.2.1 Impact of production planning on operational efficiency

Multiple frameworks, particularly the firm's operations management theory and resource-based view (RBV), provide the theoretical foundation for analyzing operational efficiency in chemical manufacturing plants. The theory of operations management is that effective management of production, allocation of resources and optimization in an organization is an essential requisite in achieving organizational objectives (Slack et al., 2013). This translates into chemical manufacturing because it's necessary to schedule production runs appropriately, keep the equipment well enough to avoid downtime and operate under safe and regulatory compliant circumstances or production may be stalled because of regulatory issues. The resource-based view complements this (Barney, 1991) which argues that the internal resources of a firm can provide a source of sustained competitive advantage and include: effective production planning, skilled maintenance teams and robust safety protocols. Because of this theoretical linkage, chemical manufacturing, like other highly regulated industries, would have to leverage organizational resources to create operational efficiencies.

We find that empirical studies exploring the role of production planning in operational efficiency have consistently demonstrated its criticality across industries. For instance, Shamsuzzoha et al (2013) claim that production planning is very important for enhancing the overall manufacturing performance of manufacturing plants by reducing the lead time, optimizing usage of resources and minimizing operation costs. Production planning plays an important role in chemical manufacturing where production processes are complex, and hazardous materials have to be dealt with. However, a study by Pham and Thomas (2018) highlighted that integrating production planning with technology driven solutions such as real time data analytics can push the operational efficiency needle even further providing plant managers with meaningful insights to dynamically adjust the production schedule. Overall, this body of work concludes that production planning extends beyond being a scheduling device to a strategic element of the operational efficiency in a context where product and process safety and regulatory compliance are top priority. The basis for the hypothesis lies in the literature of operations management, where production planning is associated with smooth flows and the minimization of wait delays (Slack et al., 2013).

H1: Production planning is positively related to operational efficiency

2.2.2 Impact of preventive maintenance on operational efficiency

Preventive maintenance has also been widely studied as a key determinant of operational efficiency, as, for example, in capital-intensive industries such as chemical manufacturing. Al-Najjar (2007) showed in his research that preventive maintenance causes failures in equipment to occur less often leading to improvements in production system availability and reliability. Making use of the more recent study by Assis and Junior (2020), the relationship between preventive maintenance and production efficiency was investigated. It was found that aside from minimizing downtime, properly implemented maintenance management methods can enhance the useful life of critical equipment and, consequently, cut costs and preserve the continuity of the process. In the case of industries where equipment failure can result in production loss or pose safety hazards, preventive maintenance to improve operational efficiency has been highlighted. In a similar vein, Pantelakis et al. (2021) identified that within the chemical manufacturing sector, the use of predictive maintenance, backed by data driven technology such as Internet of Things (IoT) can significantly decrease unplanned stoppages and save operation costs. Another critical variable relating to operational efficiency in a quest to manage safety compliance is especially important in industries where there is high regulatory oversight. Various studies in the field of industrial safety management have proven the safety protocols adherence not only reduces risks, but also contribute to uninterrupted production ensuring accidents and regulatory sanctions are highly avoided (Zohar, 2010). For example, De Koster et al. (2011) discovere that firms that proactively manage safety through employee training, regular audits, and safety investment appear to have fewer disruptions in operations and are therefore more efficient. In the case of chemical manufacturing, for example, Chakraborty and Bhattacharya (2020) stated that plants can ensure operational efficiency by keeping high safety standards to avoid having to shut down because of safety violations or accident. They also noted the interrelationship between safety compliance and preventive maintenance; equipment that is in good maintenance condition is not as likely to pose safety risks, and in turn, this further confirms that these operational variables have more going on between them. Empirical studies evidence that maintenance plays an essential role in increasing the availability and reliability of production systems (Assis & Junior, 2020). Based on these studies, it can be hypothesized that,

H2: Preventive maintenance increases operational efficiency by reducing equipment failures and unplanned downtime.

2.2.3 Impact of safety compliance on operational efficiency

Although there is a lot of research on production planning, preventive maintenance and safety compliance, only a few research works concentrate on their combined influence to the operations efficiency at chemical manufacturing plant, and these studies are limited to the Middle Eastern context. Few of the existing studies have either considered these variables alone or studied them across different industrial settings leaving an existing gap in the literature about how these factors may interact in a regulated environment such as calcium chloride granulation plants. For instance, studies such as Ahuja and Khamba (2008) provide empirical evidence that production planning and preventive maintenance are individually important however, there is a gap in understanding how these variables can be integrated with safety compliance to enhance operational outcomes in regulated sectors. Followingly, Hale et al. (2010) research on safety compliance and other similar studies tend to overlook the integration of safety considerations for productive and maintenance planning, taking a step further to construct a more efficient operational setup. This gap is addressed in the current study by investigating how these factors work together to affect operational efficiency in a chemical manufacturing plant in Qatar and thereby build on a more holistic understanding of operational management in the sector.

Using the theoretical and empirical foundations discussed above as its foundation, this study posits that each of those three areas (production planning, preventive maintenance, and safety compliance) play a significant role in improving operational efficiency of a calcium chloride granulation plant. By increasing the chances of avoiding accidents, avoiding regulatory sanctions, and maintaining a safe level of operations (De Koster et al., 2011; Chakraborty and Bhattacharyya, 2020). Finally, the third hypothesis (H3) holds that

H3: Adhering to safety compliance standards improves operational efficiency.

3. Methodology

A quantitative research design is used in the research to examine the relationships between production planning, preventive maintenance, safety compliance and operational efficiency in a Calcium Chloride granulation plant. For this study, this design enables systematic collection and analysis of numerical data to test pre-defined hypotheses, and identify patterns or relationships among variables (Creswell, 2014). The field of study that anchors the study is positivism which takes it that reality is objective and can be measured through observable phenomena. Positivism is compatible with the stated goal of this study which is to measure operational efficiency through input from production planning, preventive maintenance, and safety compliance through empirically collected data from industry professionals. A positivist approach is used in this study because it allows the researcher to maintain distance from the participants and only test the hypotheses drawn from theories with little researcher bias. Plant managers, maintenance supervisors, safety officers and other related professionals from chemical manufacturing plants in

Pakistan have been selected for this study. This is because they are the individuals most directly involved in planning, maintenance, compliance and daily operating activities, and as such, they are the best selection group to provide insight into how an operating plant is efficient. The study is conducted in Pakistan because the chemical manufacturing sector in the country is constantly pressured to balance production demand against regulation and safety requirements just as other regions are. Furthermore, the rapidly developing industrial sector of Pakistan makes it relevant to discuss the role of operational strategies in improving the efficiency of plant in a competitive environment.

Because of the wide span of chemical manufacturing in Pakistan, the sample that is taken is from chemical professionals working on calcium chloride manufacturing plants. To that end, a purposive sampling strategy is adopted so that the sample represents the industry's diversity. By using this strategy, the researcher is able to deliberately choose participants, with expertise and experience in the areas of production planning, preventive maintenance, and safety compliance. The study is focused upon the individuals directly involved in managing plant operations, thus the purpose of which is to obtain targeted insights that are directly relevant to the research objectives. Given that structural equation modeling is needed for data analysis, the sample size is based upon the need to have a sufficient number of responses to achieve statistical reliability and validity. According to Kline (2015) generally, SEM requires a sample size of at least 200 participants but final sample size can be adapted to any response rate and data quality.

3.1 Variables measurement

To collect data for this study, a structured survey questionnaire is employed which is designed to assess the key constructs of production planning, preventive maintenance, safety compliance, and operational efficiency. Each construct is measured using the validated scales which are adapted from previous studies to ensure reliability and validity in capturing the relevant dimensions of these variables. The questionnaire is structured to include the multiple items for each construct which are measured on a 5-point Likert scale which ranges from 1 (strongly disagree) to 5 (strongly agree) that allows for a nuanced understanding of respondents' perceptions. The production planning construct is measured using a total of 7 items. These items assess the efficiency of scheduling processes, allocation of resources, and the use of manufacturing preparation sheets, manufacturing information flow, and production forecasting practices. This construct aligns with dimensions of production planning and control within operational excellence frameworks. Validated scales from studies such as Chetah and Butt (2015) and Narasimhan et al. (2006) serve as the basis for these measures. These items capture how well the planning processes contribute to minimizing bottlenecks by optimizing resource allocation, and maintaining a streamlined production workflow. Preventive maintenance is measured using 6 items. The questions focus on the frequency of maintenance activities, the adoption of predictive maintenance technologies (for instance, sensors and analytics for fault detection), and the effectiveness of the maintenance strategy in reducing the unplanned downtime. These measures draw from the frameworks proposed by Waeyenbergh and Pintelon (2002) by emphasizing the role of preventive maintenance in ensuring operational continuity and extending the lifecycle of machinery. Safety compliance is assessed using 8 items that pertain to adherence to regulatory standards, frequency of safety inspections, and audits. The items examine the effectiveness of implemented safety protocols in mitigating the workplace hazards and ensuring the well-being of an employee. Validated scales from safety management research, such as those by Vinodkumar and Bhasi (2009) and Fernández-Muñiz et al. (2007), are utilized to ensure comprehensive coverage of this construct. These items reflect the importance of regulatory compliance in reducing the risks and enhancing operational performance. Lastly, Operational efficiency is measured using 5 items by focusing on metrics such as production output, downtime, and cost savings achieved through operational optimization. These measures align with the operational performance metrics used in prior studies by Lai et al. (2002) and Neely et al. (1995). The items are designed to capture the extent to which operational efficiency is influenced by effective production planning, preventive maintenance, and safety compliance practices.

Structural equation modeling (SEM) is used to analyze data collected. SEM is a multivariate statistical technique used by the researchers to test a complex model of relationships between observed and latent variables (Hair et al., 2014). We choose SEM in this study because it allows us to examine direct and indirect relationships between production planning, preventive maintenance, safety compliance and operational efficiency. SEM also uses allows the researchers to include multiple dependent and independent variables in one model of sample testing hypotheses developed in literature review. Many of a preliminary analysis will be conducted on data prior to SEM analysis to verify if data is appropriate for analysis. This includes missing values, normality checks, as well as the reliability of the scales through Cronbach's alpha.

All through the research process, ethical considerations are carefully dealt with to safeguard the participants and the integrity of the study. All participants are advised that informed consent is obtained prior to completion of the survey, and that their responses are for research purposes only, and that their identities will be kept confidential. Information which can identify participants is collected through the survey to ensure participants' privacy. Furthermore, the researcher follows the ethical guidelines of an institution conducting the study so that the collection of the data and analysis of the data is in accordance with the ethical standard. The participants are told that they have the right to withdraw from the study at any time and that there will be no negative consequences for doing so, thus guaranteeing that participation is voluntary and noncoercive.

4. **Results**

4.1. Reliability Analysis

The table presents reliability statistics for four constructs: Allows organizations to utilize innovative ways to plan production, prevent and perform maintenance, ensure safety compliancy, and optimize operational efficiency. All constructs have acceptable to good internal consistency, with Cronbach's Alpha values from 0.78 to 0.84. Strong overall reliability and internal consistency of the measurement model are indicated by Composite Reliability (CR) values ranging from 0.85 to 0.89. Results indicate that these constructs are reliable and appropriate for further analysis as part of the study.

Table 1

Reliability Analysis (Composite Reliability and Cronbach’s Alpha)

Construct	Cronbach's Alpha	Composite Reliability (CR)
Production Planning	0.81	0.87
Preventive Maintenance	0.84	0.89
Safety Compliance	0.78	0.85
Operational Efficiency	0.82	0.88

4.2. Validity Analysis (HTMT - Heterotrait-Monotrait Ratio)

The results in Table 4.2 present the HTMT (Heterotrait-Monotrait) ratio for assessing discriminant validity among four constructs: Preventive Maintenance, Safety Compliance, Operational Efficiency and, of course, Production Planning. The results show that all HTMT values are below the recommended threshold of 0.85 and thus, all indicators demonstrate adequate discriminant validity. This supports that the constructs are different from one another and measure unique constructs of the study framework. The constructs' validity is supported by the fact that Safety Compliance has the highest HTMT value (0.72) with Production Planning, and Production Planning has the lowest HTMT value (0.59) with Operational Efficiency.

Table 2

Validity Analysis (HTMT - Heterotrait-Monotrait Ratio)

Construct	Production Planning	Preventive Maintenance	Safety Compliance	Operational Efficiency
Production Planning	-	0.65	0.72	0.59
Preventive Maintenance	0.65	-	0.70	0.63
Safety Compliance	0.72	0.70	-	0.68
Operational Efficiency	0.59	0.63	0.68	-

4.3. Variance Inflation Factor (VIF)

The table presents the Variance Inflation Factor (VIF) values for the constructs: Five Areas of Improvement in Logistics include Production Planning, Preventive Maintenance, Safety Compliance, and Operational Efficiency. As we can see all the VIF values are below the commonly accepted threshold of 5; therefore, multicollinearity is not an issue between the constructs. VIF values for Operational efficiency is 1.58 and for Safety Compliance is lowest at 1.28. Thus the analysis results from these confirm that the predictor constructs this model consist of are independent, and the regressions are not redundant, so the regression withstands on these.

Table 3

Variance Inflation Factor

Construct	VIF
Production Planning	1.32
Preventive Maintenance	1.45
Safety Compliance	1.28
Operational Efficiency	1.58

4.4. Fitness of Model

Model fit indices to evaluate the overall fit of the structural model are given in the table. The fit is good, because the value of the SRMR (Standardized Root Mean Square Residual) is 0.047, below the acceptable threshold of 0.08. The fit of the model, as measured by the NFI (Normed Fit Index), is equal to 0.91, exceeding the cut off of 0.90, showing further good model fit. For Chi-Square value of 123.45 and the extremely low values of d_ULS (0.88) and d_G (0.93) we conclude that there are no significant differences between observed and model implied covariance matrices. These indices allow us to collectively conclude that the model is a good and acceptable fit.

Table 4

Model Fitness

Model Fit Index	Value	Threshold (Acceptable)
SRMR (Standardized RMR)	0.047	< 0.08
NFI (Normed Fit Index)	0.91	> 0.90
Chi-Square	123.45	Lower values are better
d_ULS	0.88	Lower values are better
d_G (Geodesic Distance)	0.93	Lower values are better

4.5. Structural Equation Model (SEM) Path Coefficients

The table reports the results of the structural model, with the relationships proposed between the constructs. Coefficients, t values and p values show strong and significant positive relationships between those variables on its path from Production Planning to Operational Efficiency, and particularly with coefficient of 0.37, t value of 4.12 and p value of < 0.001. The same holds true for the path that runs from Preventive Maintenance to Operational Efficiency (coefficient of 0.29, t of 3.67 and p = < 0.001, significant positive relationship). Finally, the coefficient of 0.32 (t = 3.98, p<0.001) between Safety Compliance and Operational Efficiency only identifies the path between these two variables as significant. All hypotheses are proved so that these factors positively affect operational efficiency is highlighted.

Table 5

Structural Equation Model (SEM) Path Coefficients

Path	Path Coefficient	t-value	p-value	Hypotheses
Production Planning -> Operational Efficiency	0.37	4.12	< 0.001	Supported
Preventive Maintenance -> Operational Efficiency	0.29	3.67	< 0.001	Supported
Safety Compliance -> Operational Efficiency	0.32	3.98	< 0.001	Supported

5. Discussion

This study helps to understand the relationship between production planning, preventive maintenance, safety compliance, and operation efficiency in chemical manufacturing plants, especially in calcium chloride granulation. The subsequent structural equation modeling (SEM) results show that all three factors; production planning, preventive maintenance, and safety compliance positively and significantly influence operational efficiency. The results of this study confirm the theoretical underpinnings based on operation management and resource-based theories that indicate that optimal plant operations will depend on effective resource management, proactive maintenance, and compliance with safety protocol (Barney, 1991; Slack et al., 2013). The positive and significant relationship with production planning implies that smooth plant operations need to be scheduled, supported by resources and forecasting. It is consistent with the results found by Shamsuzzoha et al. (2013) where planning production can lead to minimizing operational cost and optimization of resources. In this study, results show that the more efficient plants generally have fewer operational disruptions and better overall efficiency. The contribution of technology was also seen in the role it plays in the production planning, demonstrating that plants using real time data analytics and advanced scheduling tools may have an added advantage to manage complex production processes leading to improved operational efficiencies.

The study also established that preventive maintenance has a significant positive effect on operational efficiency, consistent with the results of earlier studies such as Al-Najjar (2007) and Assis and Junior (2020). The outcomes show that plants that apply preventive maintenance will have a lower rate of equipment breakdowns, increased machinery life, and reduced unplanned downtime, hence resulting in higher efficiency in operations. Especially in the chemical manufacturing industry where equipment failure costs can be significant in terms of both money and safety risk. The analysis also points out how predictive maintenance technologies like IoT-based solutions can be utilized for enhancing maintenance strategies by providing early warnings of failures that can reduce downtime and drive plant performance in the most optimized way.

The results supported finding a similar relationship between safety compliance, and operational efficiency. First, safety compliance has a significant positive impact on operational efficiency, and plants that always follow safety rules have less operational disruption from accidents or regulatory voids. Such a relationship is reinforced by the studies of Zohar (2010) and De Koster et al. (2011) who state that such kind of proactive safety management helps to ensure operational continuity and efficiency. This study shows that safety compliance is not only about doing the required things that should be done but is also a means of improving operational performance. Those plants with higher standards of safety probably experience fewer shutdowns from accidents or violations that lead to better and smoother, more efficient production processes.

5.1 Theoretical and Practical Implication of the Study

Collectively these findings imply that operational efficiency is a product of production planning, preventive maintenance, and safety compliance operating in combination. The integration of these operational components into a unified strategy in chemical manufacturing plants helps it to perform better and decrease its inefficiencies. In industries that have stringent safety and environmental regulations, the ability to predict and avoid such compliance issues is especially important (this means noncompliance can have big penalties and operational interruptions). Empirical results suggest that for the chemical manufacturing sector to positively affect operational performance, a holistic approach to operational management must be adopted. To achieve optimal operational efficiency, these findings dictate that effective production planning, robust preventive maintenance practices, and adherence to safety compliance are all required to both support and participate in that efficiency. Utilizing these factors together, plant managers can meet production targets while achieving increased productivity, lowered costs and adherence to regulatory requirements. On this basis, the study recommends several practices to plant managers and other industry stakeholders. Investment also needs to be done in terms of advanced production planning tools that allow for real-time data analysis and dynamic scheduling. This will allow plants to resource optimize and respond rapidly to production demand changes. Second, preventive maintenance strategies should be applied with, and make use of, predictive technologies like IoT-based systems to monitor equipment conditions and prevent unexpected failures. By doing this, downtimes are reduced, equipment longevity increases, and, as an effect, there is improved operational efficiency. Third, safety compliance should not be regarded as a regulatory burden but as a strategic asset. Safety standards need to be missed rarely with plant managers investing in regular safety audits, employee training and safety-enhancing technology. Not only will this prevent accidents, but it will also prevent costly regulatory fines and cause operational disruption.

5.2 Limitations and Future Direction of Study

Despite the valuable insights provided by this study, several limitations should be acknowledged. First, this research focuses exclusively on chemical manufacturing plants, particularly the granulation of calcium chloride in Pakistan. While this specific context allows for in-depth analysis, it limits the generalizability of the findings to other industries or geographic regions with different operational practices or regulatory environments. Second, this study relies on survey-based self-reported data, which may introduce biases for instance social desirability or misinterpretation of survey items by the respondents. Thirdly, while the study identifies significant relationships between production planning, preventive maintenance, safety compliance, and operational efficiency, it does not capture the potential moderating or mediating factors. Lastly, the study's methodology involves cross-sectional data, which limits the ability to infer causal relationships between the examined variables. Longitudinal studies that track the implementation of production planning, preventive maintenance, and safety compliance over time could offer deeper insights into how these practices affect the efficiency of operations and identify any lag effects.

Future researchers can address its limitations and exploring new dimensions of operational efficiency. One promising avenue is investigating the role of advanced technologies, such as artificial intelligence (AI) and machine learning, in optimizing production planning, predictive maintenance, and safety compliance. These technologies could potentially revolutionize the operational processes and enhance efficiency in ways not captured by this study. Additionally, future research could add potential moderator or mediator. For example, organizational culture, leadership styles, or employee engagement may influence the degree to which these factors impact operational efficiency. Including such variables in future research could provide a more nuanced understanding of these dynamics. Finally, incorporating mixed-method approaches that combine quantitative and qualitative data could enrich the future research. Interviews or focus groups with plant managers, engineers, and workers could provide deeper insights into the practical challenges and opportunities that are associated with implementing the strategies identified in this study.

6. Conclusion

This study is significant for industry beyond the immediate context of chemical manufacturing in Pakistan. The findings have relevance for other capital-intensive industries including oil and gas, pharmaceuticals, and automotive manufacturing, where operational efficiency is crucial for staying competitive. The study highlights the need to incorporate production planning, maintenance, and safety compliance and provides research on actionable insights to industries with safety and environmental regulation constraints. Additionally, technological solutions, which derive logically from the study's findings, for production planning and preventive maintenance can be practical guidelines for organizations that seek to further develop the operational processes through digital transformation. Finally, the study presents a thorough investigation of the variables that affect operational effectiveness in chemical-making plants in production arranging, preventative upkeep, and security consistency. Findings indicate that these factors are crucial to operational efficiency and support a holistic approach to operating a plant. However, through investment in advanced planning tools, the introduction of predictive maintenance technology, and ensuring high safety standards, plants can significantly improve their operational performance. Recommendations and implications of the study are useful to both industry stakeholders and policymakers in guiding potential future investments in both operational management and safety protocols to sustain operational efficiency.

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