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DEVELOPING A FRAMEWORK FOR IMPROVING THE QUALITY OF S U P P L Y CHAIN IN CONSTRUCTION INDUSTRY

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ABSTRACT

The recent issue of poor construction quality has drawn much attention of the public. This problem is not only due to poor quality control of the construction project team but also due to usage of inadequate construction materials in the project, that lead to poor quality assurance of supply chain in construction industry. The supply chain context is especially to monitor the quality assurance of construction projects as a contractor often the outsource the construction work to other members of the supply chain. Supply chain quality management practices, have the direct and indirect effects on the project quality performance. The purpose of this project is to examine the supply chain quality and develop a frame work to improve it. To execute this various literature are gone through and various factors affecting the supply chain quality is collected and the step carried out improving the quality of supply chain.

Keywords: six sigma, supply chain, Effective quality management, stakeholders.

INTRODUCTION

The construction industry involves multiple stages and a complex network of suppliers, contractors, and sub-contractors. Ensuring the quality of the supply chain in the construction industry is crucial to delivering a high-quality final product that meets or exceeds customer expectations.

Poor quality in the supply chain can result in delays, rework, and cost overruns, which can negatively impact the overall project schedule and budget. Quality issues can also result in safety hazards and potential legal liabilities for the construction company.

To ensure quality throughout the supply chain, construction companies need to establish and maintain quality management systems that cover all aspects of the supply chain. This includes supplier selection and management, material selection and management, process management, employee training and development, and continuous improvement. The quality of the supply chain in the construction industry is essential for maintaining customer satisfaction, reducing costs, and improving the competitiveness of the company in the marketplace. In this regard, construction companies must prioritize supply chain quality management to ensure that their final product meets or exceeds customer expectations.

The quality of the supply chain in the construction industry is critical to ensure that the final product meets or exceeds customer expectations. The construction industry involves multiple stages, including planning, design, procurement, construction, and maintenance, and each stage has its own unique challenges that can impact the quality of the final product.

To ensure quality throughout the supply chain, construction companies need to establish and maintain quality management systems that cover all aspects of the supply chain. This includes:

Supplier selection and management: Companies need to carefully select suppliers and ensure that they meet the required quality standards. Suppliers need to be regularly monitored and audited to ensure that they continue to meet the quality requirements.

Material selection and management: Companies need to ensure that the materials used in the construction process meet the required quality standards. This involves conducting regular testing of materials and establishing appropriate storage and handling procedures.

Process management: Companies need to establish appropriate processes for managing the construction process, including planning, scheduling, and monitoring. This involves establishing appropriate quality control measures and monitoring progress against these measures.

Employee training and development: Employees involved in the construction process need to be adequately trained and developed to ensure that they have the necessary skills and knowledge to maintain quality throughout the supply chain. Continuous improvement: Companies need to continually evaluate and improve their quality management systems to ensure that they remain effective and efficient.

SUPPLY CHAIN IN CONSTRUCTION INDUSTRY

The supply chain in the construction industry refers to the network of suppliers, manufacturers, distributors, contractors, sub-contractors, and other stakeholders involved in the construction process. The supply chain includes several stages, including planning, design, procurement, construction, and maintenance, and each stage can involve multiple parties. Effective supply chain management in the construction industry is critical for several reasons, including Cost

reduction: By optimizing the supply chain, construction companies can reduce costs associated with materials, transportation, and labour.

Improved efficiency: Effective supply chain management can help to streamline the construction process, reduce delays, and improve overall project efficiency. Quality control: Ensuring quality throughout the supply chain is critical to delivering a high-quality final product that meets or exceeds customer expectations. Risk management: By effectively managing the supply chain, construction companies can reduce risks associated with delays, quality issues, and other potential disruptions. To effectively manage the supply chain in the construction industry, companies must establish clear communication channels, establish appropriate quality control measures, work with reliable suppliers and contractors, and implement effective project management processes.

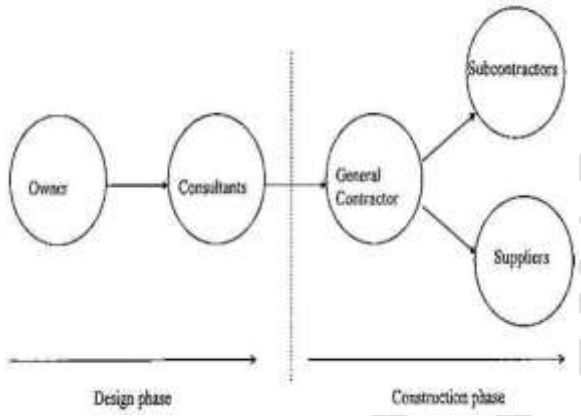

Fig 1.1: Supply chain of a construction project

EFFECT OF SUPPLY CHAIN CONSTRUCTION MATERIAL QUALITY

The supply chain can significantly impact the quality of construction materials. The construction industry involves several stages, including design, procurement, manufacturing, transportation, and installation, and each stage can have an impact on the quality of the final product. One of the most critical aspects of ensuring quality in construction materials is selecting reliable and reputable suppliers. Construction companies must work with suppliers that can provide high-quality materials that meet industry standards and are appropriate for the specific project requirements. Another critical aspect is the handling and transportation of construction materials.

Materials must be stored and transported in appropriate conditions to ensure that they do not become damaged or contaminated, which can impact their quality.

Additionally, the manufacturing process can have a significant impact on the quality of construction materials. Companies must work with manufacturers that have established quality control measures and processes to ensure that the materials meet industry standards and project requirements.

Finally, the installation process can also impact the quality of construction materials. Improper installation techniques or the use of incorrect materials can result in quality issues and potential safety hazards.

In summary, the supply chain can significantly impact the quality of construction materials. Construction companies must work with reliable suppliers, establish appropriate handling and transportation processes, work with reputable manufacturers, and ensure proper installation techniques to maintain the quality of construction materials throughout the construction process.

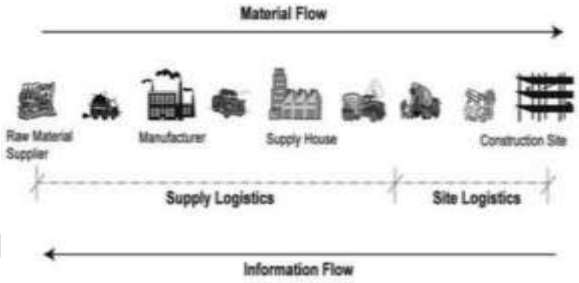

Fig 1.2: Material and information flow

SUPPLY CHAIN SCENARIO IN INDIA

The construction supply chain in India is complex and fragmented, with many small and medium-sized enterprises involved in the production and delivery of construction materials and services. The supply chain involves several stages, including the production of raw materials such as cement, steel, and bricks, the manufacturing of construction products, transportation and logistics, and construction site activities. One of the main challenges in the construction supply chain in India is the lack of standardization and quality control. Many small suppliers and manufacturers do not adhere to quality standards, leading to a high rate of defects and rework. Additionally, the lack of standardization makes it difficult for larger construction companies to manage their supply chains effectively, resulting in delays and cost overruns. Another challenge is the lack of infrastructure and transportation facilities, particularly in rural areas. This can lead to supply chain disruptions and delays, making it difficult to deliver materials and products to construction sites on time. The COVID-19 pandemic has also had a significant impact on the construction supply chain in India, with disruptions in global supply chains and reduced demand for construction materials and services. This has led to a slowdown in construction activities and increased pressure on construction companies to manage their supply chains effectively and reduce costs.

OBJECTIVES

- To analyze problems in supply chain of construction industry.
- Calculate the quality of supply chain using six sigma.
- To bring out new management strategy for improving supply chain.
- To check possibility using strategy in supply chain.

SCOPE

The scope of supply chain improvement in the construction industry includes optimizing material management, improving logistics and transportation, enhancing project management, mitigating risks, adopting sustainable practices, and leveraging new technologies to increase efficiency and improve collaboration. By focusing on these areas, construction companies can improve their bottom line, reduce waste, and create a more sustainable and socially responsible supply chain.

LITERATURE REVIEW

The literature review tells us about the supply chain quality management of different sectors from construction, military and industrial based. The research supports the premise that satisfying the customer can only take place when product quality, service, and value are coupled at every node of the chain. Linking quality at these nodes involves not only a commitment to quality also the intra-organizationally, but quality initiatives that extend beyond the firm to upstream and downstream channel participants. Although the global knowledge of the flow of information in construction is low, information flow remains vital to the material management during construction SCM. The complexity and fragment nature of the processes warrants an efficient information integration. Literature Review of Areas of Application of Supply Chain Management in Construction Industry. Another important aspect of SCQM is the selection and evaluation of suppliers. Al-Musawi et al. (2020) highlights the importance of considering both technical and non-technical factors when selecting suppliers. Technical factors such as quality standards and delivery times are important, but non- technical factors such as the supplier's reputation and financial stability can also impact SCQM. The authors recommend using a multi-criteria decision-making approach to evaluate and select suppliers.

Quality control and inspection are also crucial in SCQM. Wong et al. (2020) highlight the importance of using statistical process control (SPC) techniques to monitor and control the quality of construction materials and products. SPC techniques can help to identify and address quality issues before they become major problems, reducing the risk of defects and rework.

Wenjuan Zeng , Mike YK Tse and Minmin Tang /(2018),Supply chain quality management is crucial in the Chinese construction industry due to the complexity of the construction supply chain. However, there are several challenges to implementing effective supply chain quality management practices [1], including a lack of supplier evaluation mechanisms, inadequate communication and coordination among stakeholders, and inadequate training of personnel. Successful supply chain quality management can lead to improved project performance, increased customer satisfaction, and reduced costs. Future research should focus on the impact of digital technology on supply chain quality management practices and developing new strategies for enhancing supply chain quality management. Standardized quality management practices, increased collaboration among stakeholders, and government support are necessary for successful implementation

Georgios A. Papadopoulos*, Nadia Zamer, Sotiris P. Gayialis, Ilias P. Tatsiopoulos / 2016, Supply chain improvement is crucial in the construction industry to enhance efficiency, reduce costs, and improve quality outcomes. Strategies for improving the construction supply chain include supplier selection and evaluation, [2] standardization, collaboration, information sharing, digital technology, and lean construction. Implementing these strategies can lead to several benefits, including reduced project costs, improved quality outcomes, and increased customer satisfaction. Challenges to supply chain improvement in the construction industry include resistance to change, lack of standardization, and the complexity of the construction supply chain. Future research directions include investigating the impact of digital technology on supply chain improvement, developing new strategies for enhancing supply chain improvement, and evaluating the effectiveness of existing supply chain improvement practices.

Alfred Wong /1999, Total quality management (TQM) is a management philosophy that emphasizes continuous improvement and customer satisfaction in the construction industry in Hong Kong. TQM can be applied from a supply chain management perspective to improve quality outcomes and reduce costs. Key factors affecting the effectiveness of TQM include supplier selection and evaluation, communication and collaboration among stakeholders, and the use of

digital technology [3]. Successful implementation of TQM can lead to improved quality outcomes, reduced costs, and increased customer satisfaction. Challenges to TQM implementation in Hong Kong include the need for standardized quality management practices, increased collaboration among stakeholders, and government support. Future research should focus on the impact of digital technology on TQM implementation and developing new strategies for enhancing TQM from a supply chain management perspective

Carol J. Robinson, Manoj K. Malhotra/2005, Supply chain quality management refers to the management of quality across the entire supply chain, from suppliers to customers. It involves implementing processes and systems to ensure that products and services meet or exceed customer requirements and expectations, while also minimizing costs and risks. In academic practice, [4] SCQM is studied as a way to improve supply chain performance and competitiveness. Research in this area has focused on developing frameworks, models, and methods for managing supply chain quality, including supplier selection and evaluation, quality control and inspection, risk management, and continuous improvement. This research is important for understanding the best practices and strategies for managing SCQM in different industries and contexts.

In industrial practice, SCQM is essential for ensuring that products and services meet customer expectations and comply with quality standards and regulations. Effective SCQM can lead to improved customer satisfaction, reduced costs, and increased competitiveness in the market. Companies that fail to implement effective SCQM processes may face quality issues, delays, and other supply chain disruptions that can harm their reputation and bottom line.

Malik Khalfan1, Peter McDermott and Rachel Cooper/2004, Integrating the supply chain within the construction industry is essential [5] for improving efficiency, reducing costs, and enhancing quality. Effective supply chain integration involves collaboration and communication among stakeholders, supplier integration, lean construction principles, and technology integration. Collaboration and communication between designers, contractors, and suppliers ensure that everyone is working towards the same goal. Supplier integration involves selecting suppliers based on their ability to deliver quality products and services and integrating them into the construction process. Lean construction principles, such as just-in-time delivery, can help minimize waste, reduce costs, and improve efficiency. Technology, such as building information modelling and real-time tracking and monitoring systems, can streamline design and planning activities and provide visibility into the supply chain.

Erbiyik, H., & Saru, / 2015, Integrating supply chain management and quality management is crucial to meet or exceed customer expectations. A conceptual model proposal focuses on five key elements: customer focus, continuous improvement, employee involvement, process [6]management, and supplier relationships. This framework can help companies improve quality, reduce costs, and enhance customer satisfaction by ensuring that quality is maintained throughout the supply chain. Understanding and meeting customer needs, continuous improvement of processes and products, employee involvement, systematic process management, and building strong relationships with suppliers are essential for integrating supply chain management and quality management

Erfan Taghavi, Alireza fallahpour, kuan yew wong , seyed Amirali hoseilni /2021, Implementing green supply chain management (GSCM) in the construction industry is essential for reducing the environmental impact of construction activities and promoting sustainable development. To identify and prioritize effective factors for implementing GSCM in the construction industry, the following steps can be taken. Identify Stakeholders: The first step is to identify the stake holders who will be affected by GSCM implementation, including suppliers, contractors, clients, and regulators. Conduct a Gap Analysis: A gap analysis can be conducted to identify the current state of GSCM implementation in the construction industry and the gaps that need to be addressed. This analysis can help to identify areas where GSCM practices are lacking or could be improved. Prioritize Factors: Once the gaps have been identified, the next step is to prioritize the factors that are most important for implementing GSCM in the construction industry. This can be done using a variety of methods, such as stakeholder surveys, expert interviews, and multi- criteria decision-making techniques. Develop an Implementation Plan: Based on the prioritized factors, an implementation plan can be developed to guide the adoption of GSCM practices in the construction industry [7]. The plan should include specific actions, timelines, and responsibilities for each stakeholder group.

Husnain Arshad, Tarek Zayed /2022, Modular Integrated Construction (MIC) is a construction approach that involves prefabricating building components in a factory and assembling them on-site. Effective supplychain management is crucial for

the success of MIC projects. Key factors that influence supply chain management in MIC include supplier selection and management, logistics management, information and communication technology integration, design and engineering, quality management, and project management. By effectively managing these factors, companies can ensure timely delivery of high-quality building components and enhance the overall efficiency of the construction process [8].

Adel Azar,Reza Ahmadi Kahnali And Allahvirdi Taghavi/2010, There is a strong relationship between supply chain quality management practices and their effects on organizational performance. Organizations that implement effective supply chain quality management practices can achieve better performance outcomes, such as increased productivity, improved customer satisfaction, and enhanced financial performance. Key supply chain quality management practices that can lead to improved organizational performance include supplier selection and evaluation, quality control, continuous improvement, and collaboration among stakeholders. The impact of these practices on organizational performance can be measured through various performance indicators, such as cost savings, delivery performance, and defect rates. However, challenges exist, such as ensuring supplier compliance with quality standards, maintaining effective communication and collaboration, and managing supply chain risks. Future research directions include exploring the relationship between specific supply chain quality management practices and organizational performance outcomes [9], developing new strategies for enhancing supply chain quality management, and evaluating the impact of digital technology on supply chain quality management practices and performance outcomes.

Lin Lin1, Peter Gibson1/2010, Implementing supply chain quality management in a subcontracting system can help improve constructionquality by ensuring that all subcontractors meet quality standards. This can be achieved through various methods, such as developing a quality management plan, conducting supplier evaluations, and implementing quality control measures. By establishing a clear communication channel and collaboration among stakeholders, such as contractors, subcontractors, and suppliers, supply chain quality management can help reduce defects, increase efficiency, and enhance customer satisfaction. However, challenges include identifying and selecting appropriate suppliers, ensuring compliance with quality standards, and monitoring supplier performance.

Future research directions include developing new strategies for supply chain quality management, evaluating the effectiveness of existing practices, and exploring the impact of digital technology on supply chain quality management [10].

Katarzyna Antosz, Malgorzata jasiulew – Kaczmarek, Robert Wazkowski , Jose Machado / 2011, A manufacturing company implemented a Lean Six Sigma project to address frequent equipment breakdowns causing significant downtime and lost production. The team used the DMAIC methodology to identify the root cause, which was a lack of suitable maintenance procedures, and developed a solution that included a preventive maintenance program, training for maintenance technicians, and reorganization of spare parts storage. After implementation, the company observed a 50% reduction in equipment downtime, a 25% reduction in repair costs, and a 10% increase in production output [11]

Chitra Lekha Karmaker, Tazim Ahmed, Sayem Ahmed, Syed Mithun Ali Md. Abdul Moktadir, Golam Kabire /2021, Design for Six Sigma (DFSS) isa methodology that can be used to improve supply chain information sharing by designing an efficient, effective, and error-free process. The process involves defining the problem and critical-to-quality factors, measuring the current process's performance, analyzing the process to identify root causes of problems, designing a new process optimized for quality and reliability, and verifying and validating the new process to ensure it meets the desired outcomes. By following these steps, organizations can improve their supply chain information sharing and achieve operational efficiency and effectiveness [12].

Sabry, A. (2014) The successful implementation of Six Sigma quality programs in Lebanese hospitals can positively influence performance indicators such as reduced medical errors, improved patient satisfaction, increased operational efficiency, and enhanced financial outcomes. By focusing on these critical success factors, hospitals can achieve significant improvements in quality and patient care [13]

Rohini Titmarsh, Fadi Assad, Robert Harrison/ 2020, Lean Six Sigma is a quality management methodology that focuses on eliminating waste and defects in manufacturing processes, while Industry 4.0 refers to the integration of digital technologies into manufacturing processes. The combination of Lean Six Sigma and Industry 4.0 can optimize manufacturing processes, improve quality control, enable data analysis and support continuous improvement. By using Industry 4.0 technologies such as AI, machine learning and big data analytics, manufacturers can monitor and control their

manufacturing processes in real- time, identify defects early and analyze large amounts of data to identify areas for improvement. Overall, the integration of Lean Six Sigma and Industry 4.0 can bringsignificant benefits to the manufacturing industry [14].

Jason Matthews, Leah Pellew, Florence Phua and Steve Rowlinson / 2000, Building quality relationships among stakeholders in the construction supply chain is crucial for the successful delivery of a construction project. Effective communication, collaboration, transparency, accountability, and flexibility are key elements in building quality relationships. Clear communication, sharing of knowledge and resources, open sharing of project information, accountability, and flexibility can help establish trust, maintain progress, and ensure project success [15].

Hanbin Luo a,b, Ling Lin a,b Ke Chen, Maxwell Fordjour Antwi-Afari, Lijuan Chen /2021, Digital technology has been increasingly used in the construction industry to improve quality management. Tools like BIM,VR/AR, and IoT can reduce errors, improve communication and collaboration, and enhance monitoring and control. Challenges include standardization and interoperability of digital tools and the need for training. Future research directions include developing new digital tools, integrating them into the construction process, and evaluating their effectiveness [16]. Anne Vincent, Donnah Pocius, Yun Huang /2021, Six Sigma is a methodology that aims to improve the quality of processes by reducing defects and minimizing variability. In the context of point-of-care glucose measurement, Six Sigma can be used to evaluate the performance of quality indicators in the total testing process. This two-year review aims to assess the Six Sigma performance of quality indicators in the total testing process of point-of-care glucose measurement. The total testing process of point-of- care glucose measurement involves several steps, including sample collection, sample analysis, and reporting of results. Quality indicators that can be evaluated include accuracy, precision, and turnaround time. To assess the Six Sigma performance of quality indicators, data was collected over a two-year period from a hospital laboratory that performed point-of- care glucose testing. The results of the review showed that the accuracy of point-of-care glucose testing was within the acceptable range, with a Six Sigma value of 4.05. The precision of the testing was also within the acceptable range, with a Six Sigma value of 4.16. However, the turnaround time for reporting results was found to be outside the acceptable range, with a Six Sigma value of 3.36. This suggests that there was room for improvement in the turnaround time for reporting results [17].

Fernandes, A. C., Sampaio, P., Sameiro, M., & Truong, H. Q. (2017) The integration of supply chain management and quality management is crucial for improving operational efficiency and customer satisfaction. A conceptual model proposal suggests aligning goals, establishing quality metrics, selecting and developing suppliers, promoting communication and collaboration, and integrating quality management practices into supply chain processes. This integration enhances product quality, delivery performance, and customer satisfaction. By implementing this model, organizations can reduce costs, mitigate risks, and deliver superior value, resulting in improved competitiveness and customer satisfaction [18].

Fernandes, A. C., Sampaio, P., Sameiro, M., & Truong, H. Q. (2017) The article "Supply chain management and quality management integration: A conceptual model proposal" by Fernandes, Ana, Sampaio, Paulo, Sameiro, Maria, and Truong Quang, Huy proposes a conceptual model for integrating supply chain management and quality management. The model emphasizes the importance of aligning goals, establishing quality metrics, selecting and developing suppliers, promoting communication and collaboration, and integrating quality management practices into supply chain processes. Implementing this model is expected to improve supply chain performance, enhance product or service quality, reduce costs, mitigate risks, and deliver superior customer value [19]

Bharath, A. A., & Shankar, M. G. (2020). The article "Developing a framework for economically improving the quality of a construction processby Six Sigma" by Bharath, A. A., and Shankar, M. G. presents a framework for implementing Six Sigma methodology to enhance the quality of construction processes in an economically efficient manner. The frameworkinvolves steps such as identifying quality issues, analyzing data using Six Sigma tools, implementing process modifications, and considering economic implications. The study emphasizes the importance of improving construction process quality and discusses implementation challenges. By applying this framework, construction organizations can achieve quality improvements, reduce defects, and optimize their processes to deliver betterproject outcomes and enhance client satisfaction [20]

KL Lee, Y.Su research demonstrates the successful application of Six Sigma principles and tools in addressing a real-world problem in the construction

industry. By identifying and improving key input variables, the research has led to the development of a novel earthquake-proof construction method, potentially enhancing customer satisfaction and reducing repair costs in the case company [21].

Muraliraj, J., Zailani, S., Kuppusamy, S., & Santha, C. The purpose of this paper is to conduct a comprehensive literature review on Lean Six Sigma, aiming to enhance understanding by summarizing current trends, identifying gaps in existing research, and revealing opportunities for future studies. This review addresses published literature in the field, providing valuable insights for researchers and practitioners to advance the continuous improvement methodology. [22]

Nawanir, G., Lim, K.T. and Othman, S.N. The study conducted by Nawanir, Lim, and Othman in 2017 explores the implementation of Lean manufacturing practices in Indonesian manufacturing firms. The researchers aimed to investigate the extent of Lean adoption, its impact on operational performance, and the challenges faced by companies in implementing Lean principles. The study employed a mixed-methods approach, combining quantitative data from a survey of manufacturing firms and qualitative insights from interviews with industry experts. The survey collected information on the level of Lean adoption, the application of Lean tools and techniques, and the perceived impact of Lean on various performance metrics. The findings revealed that while many Indonesian manufacturing firms have embraced Lean principles, their level of implementation varies. Companies reported improvements in various operational areas, such as production lead time, inventory levels, and defect rates. However, the study also identified challenges, including resistance to change, lack of employee involvement, and difficulties in sustaining Lean initiatives [23].

Salah, S., Carretero, J. A., & Rahim, A. In today's competitive industries, meeting increasing demands for high-quality products at economic costs is a significant challenge. The success of an organization relies on the effective implementation of continuous improvement (CI) methodologies.

Total Quality Management (TQM) and Six Sigma are two crucial CI approaches used in manufacturing systems. Understanding these methodologies and their relationship can provide a competitive advantage to industries. While many industrial organizations utilize either TQM or Six Sigma as their core CI strategy, there is ongoing debate regarding their superiority, commonalities, differences, and how they relate to each other. Hence, this paper aims to investigate the relationship between TQM and SixSigma. The research begins by introducing TQM and Six Sigma and subsequently conducts a thorough comparison, exploring their similarities and differences. The study seeks to identify the points of convergence and divergence between these methodologies. Furthermore, the research delves into how TQM and Six Sigma can be integrated together to create a new structure that offers an improved approach to CI. This integration aims to leverage the strengths of both methodologies, providing a more comprehensive and effective approach to continuous improvement. [24].

Over the past two decades, the Kingdom of Saudi Arabia (KSA) has witnessed significant growth in construction projects. However, many of these projects have faced challenges such as time delays, cost overruns, and substantial waste generation. In response, lean construction principles have been introduced to the Saudi construction industry, though its implementation is still in its early stages. This study aims to assess the current state of lean construction adoption in the KSA construction industry. To achieve its objectives, the study conducted a structured questionnaire survey among 282 construction professionals. The survey sought to identify various aspects of lean construction implementation, including types of construction waste, the level of tool utilization supporting lean construction, stages of lean method application, and the benefits derived from lean construction practices. The analysis of the collected data, using mean score and Anuva tests, yielded significant insights. The most prevalent type of waste in the KSA construction industry is waiting, and Computer Aided

Design (CAD) is the predominant tool used to support lean construction. Additionally, lean construction is primarily applied during the construction stage of projects, and customer satisfaction emerges as the primary benefit obtained from implementing lean practices [25].

Negi, P. S., Mandaliya, A., Mahida, A., Patel, A., & Patyal, V. S The purpose of this study is to explore the role of Six Sigma (SS) implementation in the construction industry, with the ultimate goal of achieving zero defects and eliminating variations in business processes to drive significant business improvements. The researchers conducted a systematic review of published literature on SS from 2003 to 2016 using semantic search techniques. Out of the collected literature, a total of 39 relevant articles from reputable journals and proceedings were selected for analysis. The study revealed that there were more case studies on SS implementation in the construction industry compared to empirical and conceptual studies. However, empirical studies have gained

momentum over time, running in parallel with case studies.

The paper also identifies various application areas of SS in the construction industry. Quality tools such as cause and effect diagrams are commonly used in SS implementation, followed by Pareto charts, control and run charts, failure mode effects analysis (FMEA), histograms, and value stream mapping.

Based on the findings, the paper concludes that SS has significant potential for improving processes and outcomes in the construction industry. It highlights the importance of utilizing various quality tools to drive effective SS implementation in construction projects. Moreover, the study outlines future research directions to enhance the implementation of SS in the construction sector. These directions can help organizations to identify and address challenges and improve the overall effectiveness of SS in construction processes [26].

Six Sigma provides valuable tools for supply chain quality management in the construction industry. By applying Six Sigma principles, construction companies can enhance quality, reduce costs, improve time management, mitigate risks, and increase stakeholder satisfaction. Through defect and variation elimination, Six Sigma enables the delivery of high-quality products and services, leading to increased customer satisfaction and abetter industry reputation. Additionally, it minimizes waste, inefficiencies, and errors, resulting in cost reduction and improved profitability. Six Sigma streamlines processes, identifies bottlenecks, and reduces cycle times, ensuring timely project delivery. Furthermore, it promotes a customer- centric approach, enhancing stakeholder satisfaction and fostering long-term relationships with clients [27].

Implementing Six Sigma in the construction sector presents challenges due to the significant investment involved in each project. While Six Sigma is highly effective in manufacturing industries, the construction industry must address the direct relationship between project quality and cost. To overcome this challenge, a combination of Six Sigma and Cost Benefit Analysis is proposed. This approach allows for improving construction quality without exceeding the budgeted cost. By integrating these management tools, organizations can achieve successful, high-quality construction projects while ensuring adherence to budget constraints. The synergy between Six Sigma and Cost Benefit Analysis facilitates effective quality management without compromising cost efficiency [28]

This study aims to identify the causes of delays in construction projects and analyze the gaps between owners and contractors in successful and unsuccessful projects. By examining both successful and unsuccessful cases, the research seeks to understand the factors that lead to delays and develop effective mitigation strategies. The study will shed light on potential communication, coordination, and decision-making gaps between project stakeholders. The findings will provide valuable insights for

improving project management practices, fostering better collaboration, and reducing delays in construction projects. Ultimately, addressing these gaps can lead to more efficient and successful project outcomes in the construction industry. [29]

METHODOLOGY

The research identifies a list of constraints that affect supply chain quality through an in depth and comprehensive review of relevant literature and identified constraints. The data were collected by a structured questionnaire that includes two parts. The first section is dedicated to the personal and demographic information of the respondents. It includes respondent name, organization's name, years of experience, location of organization and current designation. The second part consists of questionnaire includes questions on constraints of supply chain quality. For each question the respondent should answer either "Yes or No".

FORMULATION OF PROBLEM

The construction industry faces significant challenges in maintaining supply chain quality due to the complex and dynamic nature of construction projects. One of the primary issues in supply chain quality in the construction industry is the lack of coordination and communication among the various stakeholders involved in the supply chain. This can lead to delays, rework, and cost overruns, which ultimately affect the quality of the final product. Additionally, the use of multiple suppliers and subcontractors can lead to variability in the quality of materials and workmanship, which can impact the overall quality of the project**.**

REVIEW OF LITERATURE

The purpose of a literature review is to provide a comprehensive analysis of the existing research on a particular topic or question, identify gaps or inconsistencies in the literature, and provide a foundation for a new research project or to inform policy and practice.

COLLECTING FACTORS AFFECTING THE SUPPLY CHAIN QUALITY

From the review of literatures regarding supply chain the factors affecting the supply chain are arrayed and they arranged according to the main factors and sub factors.

FORMATION OF QUESTIONNAIRE SURVEY

A questionnaire survey is a research method that involves collecting data from a sample of individuals through a set of structured questions. The purpose of a questionnaire survey is to gather information about opinions, attitudes, behaviors, or experiences of the targeted population. The survey questions can be administered through various methods such as paper-based questionnaires, online surveys, telephone interviews, or face-to-face interviews. This questioner is formed with the factors collected and circulated among the contractors.

COLLECTING RESPONSE

The questioner is allowed to flow in online form to all engineer and contractors. they have two respond the questions which are formed on base of factors collected. For each question the respondent should answer either"Yes or No".

CAUSE AND EFFECT DIAGRAM

A cause-and-effect diagram, also known as a fishbone diagram or Ishikawa diagram, is a graphical tool used to identify and analyze the potential causes of a problem or issue. It is often used in quality management and problem- solving methodologies to determine the root cause of a problem or to brainstorm potential causes and solutions. The diagram consists of a horizontal line representing the problem or issue being analyzed, with several "bones" branching off from the main line. Each branch represents a potential cause of the problem, with sub-branches representing further potential causes or contributing factors. The bones are labeled according to the categories of potential causes, such as people, process, equipment, materials, or environment.

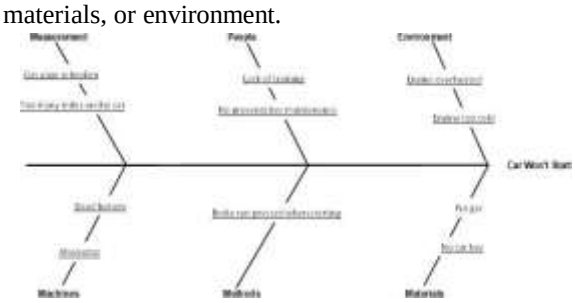

Fig 3.2 Example of fish bone diagram

PUGH MATRIX

A Pugh matrix, also known as a decision matrix or grid, is a tool used to evaluate and compare multiple options based on a set of criteria. It is often used in engineering, design, and product development to assess different design concepts and determine the most effective solution. The Pugh matrix is a useful tool for comparing and evaluating multiple options in a structured and systematic way. It helps to ensure that all criteria are taken into account and that decisions are made based on objective and consistent criteria.

Criteria	Optional Importance Weighting	Current Solution	Alternative #1	Alternative #2
Effectiveness	5	0	1	1
Availability of Resources	3	0	0	1
Support from Business	2	0	0	1
Long Term Benefit	2	0	1	0
Time to Implement	4	0	-1	0
Ease to Implement	1	0	0	0
Cost of Implement	5	0	-1	-1
	Totals	0	-2	5

Fig 3.3 Example of Pugh matrix

SIX SIGMA CALCULATIONS

Six Sigma is a methodology used in the construction industry to improve supply chain quality by reducing defects, enhancing efficiency, and achieving process excellence. By defining project objectives, measuring performance, analyzing data, implementing improvement strategies, and establishing control mechanisms, organizations can achieve benefits such as improved quality, reduced variability, enhanced efficiency, and increased customer satisfaction. Implementing Six Sigma in construction supply chains can lead to successful project outcomes and a competitive advantage in the market.

In general, a higher sigma value indicates a higher level of process capability and a lower defect rate. A sigma value of 6 is often considered the benchmark for Six Sigma, which corresponds to a defect rate of 3.4parts per million.

DEFECT PER MILLION OPPORTUNITY

Defects per Million Opportunities (DPMO) are a metric commonly used in Six Sigma to quantify the quality performance of a process. It represents the number of defects that occur in a process per one million opportunities for a defect to occur. The DPMO metric provides a standardized way to compare the performance of different processes or organizations.

- To calculate DPMO, the following steps are typically followed:

- Identify the number of defects: This involves counting the total number of defects or errors that occur in the process being evaluated.
- Determine the number of opportunities for a defect: An opportunity refers to a specific point in the process where a defect could occur. It could be a step, an action, or a feature that can be defective. The

number of opportunities should be carefully defined based on the process being analyzed.

- Calculate the DPMO: Once the number of defects and opportunities are known, the DPMO can be calculated using the formula:

DPMO = (Defects / Opportunities) x 1,000,000

The DPMO metric provides a standardized measure of quality performance, allowing organizations to compare processes, track improvement over time, and set quality targets. The goal in Six Sigma is typically to achieve a DPMO level of 3.4 or lower, which corresponds to a near-perfect defect rate of 99.99966%

CALCULATION OF DPMO AND SIX SIGMA VALUE

Assessment sheet is prepared with survey responses of experienced engineers' opinion. Rows filled with engineers and column with man factors and sub factors. When factor affects the supply chain quality the response is given as "YES". For YES, it is represented '1' if "NO" represent as '0'. Totally 80 responses are taken as sample. This consist of number of defects and opportunity and they help to know defects per million opportunities with this six-sigma value is calculated. By calculating the DPMO, you can assess the current performance of the supply chain in terms of defects and opportunities and identify areas for improvement. This information can help guide quality improvement efforts and enable you to set specific goals for achieving higher levels of quality in the supply chain

From the assessment sheet prepared, the number of respective defects that occurred in each supply chain quality. with this we get data for calculation for yield percentage and Defect per million opportunities.

Total number of defects =612

Total number of opportunities = 1870 Applying the value to formula

DPMO= ((total no of defect*1000000)/(total no of opportunities *no of input))*100

DPMO = **385026.7** defect per million opportunities

With help of six sigma table second shift (for long term) the dpmo value of assessment sheet is taken and interpolated the sigma value and yield % is found

sigma value = 1.793682 % of yield = 42.2106456% from this the quality of supply chain in construction industry is poor (since minimum sigma value in construction industry should 4)

RANKING OF FACTORS WITH PARETO CHART

The factors affecting the quality of supply chain most is ranked with help of the response where the most affected factor is ranked with help of Pareto chart. A Pareto chart is a visual tool used to prioritize and analyze the relative importance of different factors or categories based on their frequency or impact. It is named after Vilfredo Pareto, an Italian economist. The chart displays data in a bar graph format, with the bars arranged in descending order of frequency or magnitude. It helps identify the "vital few" factors that contribute to the majority of the observed effect, allowing teams to focus on addressing the most significant issues or opportunities for improvement. Utilizing a Pareto chart, you can identify and prioritize the most affected factors in the quality of a supply chain. This approach helps you allocate resources efficiently and effectively, leading to targeted improvements and better overall supply chain performance. From chart the 50% affecting response of the cause factors are taken. In this it is analyzed with help of the assessment the factors which more than 50% of responses points out the affecting factor is taken out to find out its causes and improve **the quality**

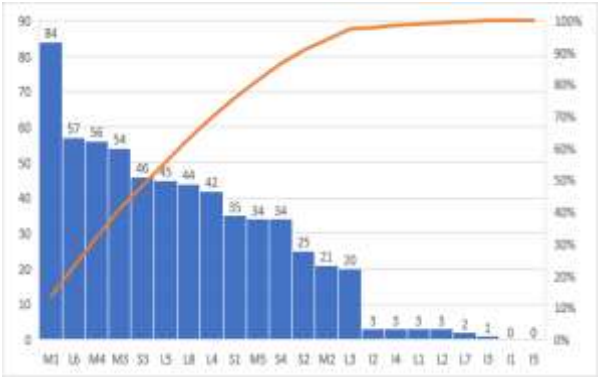

Fig 5.1 Ranking with pareto chart

From the pareto chart formed with the assessment sheet there are four factors affect the most which is pointed by the 50% of the respondent's they are

- Management strategies
- Cycle time.

- De centralization decision making.
- Planning and scheduling.

CAUSE AND EFFCT DIAGRAM AND MATRIX

The cause-and-effect diagram, also known as the Ishikawa or fishbone diagram, is a visual tool used to identify and organize potential causes of a specific problem or effect. It helps teams analyse and understand the various factors that contribute to an issue, enabling them to brainstorm solutions and take appropriate actions. The cause-and-effect diagram encourages a collaborative approach to problem-solving by involving cross- functional teams and stakeholders.

The cause-and-effect matrix, on the other hand, is a tool used to systematically analyse the relationship between causes and effects. It helps teams evaluate the impact of different causes on a specific effect or problem. The matrix assigns numerical values or weights to each cause based on its perceived importance or contribution to the effect. This allows teams to prioritize causes and focus on those that have the highest impact or likelihood of occurrence.

The cause-and-effect diagram and cause and effect matrix complement each other in the problem-solving process. The cause-and-effect diagram is useful for brainstorming and organizing potential causes, while the cause- and-effect matrix helps quantify and prioritize those causes. Together, these tools facilitate a systematic approach to problem-solving, enabling teams to identify root causes, develop targeted solutions, and make informed. Decisions

CAUSE AND EFFECT DIAGRAM

A cause-and-effect diagram, also known as an Ishikawa or fishbone diagram is a visual tool that helps identify and organize potential causes of a specific problem or effect. It consists of a central problem or effect, major categories representing different contributing factors, specific causes branching out from the categories, and sub-causes for more detailed insights. The completed diagram allows teams to analyse causes, brainstorm solutions, and take appropriate actions. This collaborative approach facilitates problem-solving by involving stakeholders and generates insights into the factors contributing to the problem. By addressing the identified causes, organizations can work towards resolving issues and improving processes or outcomes. The combined use of a Pareto graph and a fishbone diagram is a powerful approach in the construction industry to analyse the major factors impacting supply chain quality and identify their root causes. The Pareto graph helps identify the most significant factors contributing to quality issues, allowing construction professionals to prioritize their efforts effectively. The fishbone diagram, on the other hand, provides a visual representation of the causes and effects related to these factors. By connecting the major factors identified in the Pareto graph to different categories in the fishbone diagram, construction professionals can delve deeper into the underlying causes of supply chain defects and problems. This collaborative approach encourages stakeholders from various areas of the supply chain to contribute to the brainstorming process and gain a comprehensive understanding of the problem. By identifying the root causes through the fishbone diagram, construction professionals can develop targeted solutions and implement necessary improvements. These improvements may involve process optimization, enhanced communication and coordination among stakeholders, better supplier management, or the adoption of advanced technologies. By focusing on the significant issues and addressing their root causes, construction companies can enhance supply chain quality. The fish bone diagram for the factors is prepared with help of the literatures and the causes are made for the factors in the fish bone format and this will help to draw the diagram.

The management strategies have causes like lack of coordination, poor supplier management, and continues improvement.; The cycle time have causes like lead time, environmental impact, improper transportation; The de centralization decision making causes are lack of enterprise and knowledge, not considering accountability, limited over all scope; the planning and scheduling causes are allocation of resources, timely material availability, overlapping activity.

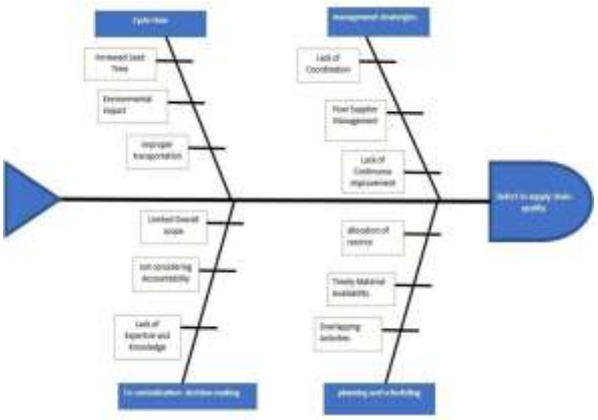

Fig6.1 Fishbone diagram

CAUSE AND EFFECT MATRIX

A Cause-and-Effect Matrix, also known as a C&E Matrix or a C&E Diagram, is a tool used to analyse the relationship between different causes and their effects on a particular problem or outcome. It helps identify the most critical causes that have the greatest impact on the desired outcome. Here is an explanation of how the Cause-and-Effect Matrix works:

Define the Problem or Outcome: Clearly articulate the problem or outcome that you want to address or achieve. This could be a quality issue, a customer complaint, a project delay, or any other problem that requires analysis.

Identify Potential Causes: Brainstorm and list all the potential causes that may contribute to the problem or outcome. These causes can be determined through team discussions, data analysis, previous experiences, or any other relevant sources.

Determine Impact and Likelihood: Assess the impact and likelihood of each potential cause on the problem or outcome.

REMEDIAL AND SUGGESION

The impact refers to the degree to which a cause affects the problem, and the likelihood refers to the probability or frequency of the cause occurring.

Assign Ratings or Weights: Assign ratings or weights to each cause based on their impact and likelihood. These ratings can be numerical or qualitative, depending on the specific requirements of the analysis. The ratings help in quantifying the significance of each cause.

Create the Matrix: Construct a matrix with the potential causes listed vertically and horizontally. The matrix will have cells where the impact and likelihood ratings intersect for each cause. This visually represents the relationship between causes and their effects on the problem or outcome.

Analyse the Matrix: Analyse the Cause-and-Effect Matrix to identify the most critical causes. Focus on the causes that have high impact ratings and high likelihood ratings. Take Action: Based on the analysis, prioritize the critical causes and develop appropriate action plans to address them. This may involve further investigation, root cause analysis, process improvements, training, or other corrective and preventive measures.
Utilizing insights from a literature review, construction industry professionals can implement remedial measures to enhance supply chain quality. These measures include process standardization, supplier development and collaboration, technology adoption, continuous improvement and learning, risk management and resilience, collaboration and integration of stakeholders, and continuous monitoring and evaluation. By implementing these strategies, construction companies can improve efficiency, collaboration, risk management, and overall project outcomes, leading to increased stakeholder satisfaction. Then it is implemented in Pugh matrix.

PUGH MATRIX

The Pugh Matrix, also known as the Pugh Method or Decision Matrix, is a tool used to evaluate and compare multiple alternatives against a set of criteria. It helps in making informed decisions by systematically assessing and comparing the strengths and weaknesses of various options.

Here's an explanation of how the Pugh Matrix works:

Define Criteria: Identify the criteria that are important for evaluating the alternatives. These criteria can be specific requirements, performance metrics, or any other factors that are relevant to the decision-making process. The criteria should be clear, measurable, and aligned with the objectives of the decision.

Select a Baseline: Choose one of the alternatives as a baseline or reference point against which other options will be compared. The baseline is typically an existing solution or the current state of affairs.

Evaluate Alternatives: Assess each alternative against the defined criteria and compare them to the baseline. Use a scoring system, such as a numerical scale or a Likert scale, to assign ratings to each alternative for each criterion. Positive scores indicate advantages over the baseline, while negative scores indicate disadvantages.

Weight the Criteria: Assign weights to each criterion based on their relative importance or priority. The weights reflect the significance of each criterion in the decision-making process. The sum of the weights should equal 100% to maintain consistency.

Calculate Total Scores: Multiply the ratings of each alternative by the corresponding criterion weights and calculate the total scores for each alternative. The total score represents the overall performance or desirability of each alternative. Analyse Results: Compare the total scores of the alternatives to determine which option performs best overall. The alternative with the highest total score indicates the most favorable choice based on the defined criteria.

Make a Decision: Consider the results of the analysis, taking into account other factors such as feasibility, cost, and strategic objectives. Use the insights gained from the Pugh

Matrix as a valuable input in the decision- making process. The Pugh Matrix provides a structured and systematic approach for comparing and evaluating alternatives. It helps in making objective decisions by considering multiple criteria and their relative importance. The matrix promotes transparency, consistency, and rationality in the decision- making process.

RESULT AND DISCUSSION

In the construction industry, the effective implementation of Six Sigma principles and various tools can lead to significant improvements in supply chain quality. One such tool that can be utilized is the Cause-and-Effect Matrix, also known as the Fishbone Diagram or Ishikawa Diagram. This tool helps identify the potential causes of problems or defects in the supply chain and is instrumental in guiding improvement efforts.

By employing the Cause-and-Effect Matrix, construction companies can systematically brainstorm and categorize potential factors contributing to supply chain issues. These factors may include material quality, communication breakdowns, process inefficiencies, and supplier performance, among others. By visualizing the interrelationships between these causes and their potential impact on the supply chain, companies can prioritize areas for improvement and target their efforts accordingly. Additionally, the Pugh Matrix can be utilized to evaluate and compare alternative solutions for supply chain improvement. This matrix enables the systematic evaluation of different options based on predefined criteria, providing a structured approach to decision-making. By weighing the pros and cons of each alternative, construction companies can identify the most effective solutions to enhance supply chain quality.

The suggested measures for improving supply chain quality in the construction industry encompass various aspects of operations and collaboration. Aligning supplier processes with quality objectives is essential for fostering a shared commitment to delivering high-quality products and services. Providing detailed requirements to suppliers sets clear expectations and ensures consistency in product quality. Collecting relevant data and metrics is crucial for assessing supplier performance and identifying improvement opportunities. Key performance indicators such as on-time delivery, defect rates, and lead times provide valuable insights into supplier capabilities and overall supply chain performance. Regularly tracking and analyzing these metrics allow construction companies to identify trends, spot potential issues, and drive continuous improvement efforts. A systematic approach to root cause analysis is vital when quality issues arise. By identifying the underlying causes of problems rather than just treating the symptoms, construction companies can implement sustainable solutions that prevent recurrence.

Effective communication channels among all stakeholders in the supply chain are paramount for smooth operations. Transparent and efficient communication promotes collaboration, enables prompt issue resolution, and ensures everyone is aligned with quality objectives.

Furthermore, conducting regular supplier performance reviews allows construction companies to assess supplier adherence to quality standards and overall performance. These reviews facilitate constructive feedback and help build strong supplier relationships, contributing to a more reliable and efficient supply chain.

By integrating these measures into the framework of Six Sigma principles, construction companies can enhance their supply chain quality significantly. Improved efficiency, collaboration, risk management, and overall project outcomes result from these collective efforts. Ultimately, these improvements lead to increased stakeholder satisfaction and strengthen the construction industry's position in the market. Construction companies that embrace Six Sigma and its associated tools for supply chain quality improvement are better equipped to respond to challenges, optimize operations, and achieve success in today's competitive business environment.

CONCLUSION

The project's primary objective is to tackle the issue of poor construction quality in the construction industry by focusing on supply chain quality and proposing a robust framework for improvement. The project recognizes that the problem stems from inadequate quality control practices within the construction project team and the use of substandard construction materials due to weak quality assurance in the supply chain. To comprehensively address this issue, the project conducts an extensive literature review to identify key factors impacting supply chain quality in the construction industry. These factors encompass challenges related to standardization, communication, coordination, and personnel training. To counteract these challenges, the project explores various strategies that hold promise as potential solutions.

The methodology involves gathering data through a questionnaire survey administered to engineers, subcontractors, and contractors actively engaged in the construction supply chain. The collected data are analyzed using effective techniques such as the Pareto chart and cause-and-effect diagram to pinpoint the

most influential factors affecting supply chain quality. Key areas of focus identified in the analysis include management strategies, cycle time, decentralization decision making, and planning and scheduling.

The culmination of this research aims to present a comprehensive framework for enhancing supply chain quality. This framework encompasses measures like careful supplier selection and management, stringent quality testing and proper storage of construction materials, efficient process management, continuous employee training. By implementing the proposed strategies and adhering to the comprehensive framework, construction companies can significantly elevate their overall project performance.

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