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# Integrating Traditional and Industry 4.0 Approaches in Quality Management the Case of Wärtsilä Marine and Energy Systems

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## Abstract

This research explores the integration of traditional Quality Management (QM) techniques such as TQM, Lean Manufacturing, Six Sigma, and ISO 9001 with Fourth Industrial Revolution technologies like IoT, AI, and Digital Twins. Focusing on Wärtsilä, a multinational company in marine and energy solutions, the study examines how it addresses sustainability, efficiency, and customer value challenges in advanced manufacturing. Through a descriptive case study, including participatory observation, interviews with quality control managers and engineers, and employee questionnaires, the research highlights the positive impact of combining traditional QM practices with Industry 4.0 technologies. Key benefits include improved product quality, operational efficiency, and environmental conservation, achieved through digital twins and predictive maintenance, allowing for real-time monitoring and reduction of defects and downtime. The study also discusses how Wärtsilä proactively manages training and infrastructure costs with strategic investments in human capital. It offers recommendations for industries aiming to adopt similar integrations to stay competitive in the global market.

**Keywords:** Total quality management, Industry 4.0, Lean production, Industrial IoT.

## 1 | Introduction

QM has been known for quite some time as being integral and important to the manufacturing industry, especially for increasing the quality of the products, the efficiency at which the work is being delivered and the satisfaction of the end users.

In the last few decades, there have been many effective methodologies of QM developed, among which are TQM, Lean Manufacturing, Six Sigma, and ISO standards that have been of help in increasing organizational

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effectiveness in industrial organizations [1], [2]. Nevertheless, using Industry 4.0 technologies, there was observed an interest in how these traditional practices can be better linked with new digital technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and Big Data analytics for the additional improvement of the product quality as identified by [3]. While both components can be discussed indisputably, there is a lack of research studies that focus on the integration of the best and new traditional manufacturing paradigm and Industry 4.0 tools. This paper closes this gap by concentrating on Wärtsilä, a premier marine and energy original equipment manufacturer and solutions provider, to examine how it embraces both QM traditional philosophies and modern digitization applications. Through the following, the study seeks to reveal the dynamic nature of QM in a contemporary technological environment to demonstrate how its integration fuels sustainability, effectiveness and customer satisfaction in worldwide manufacturing contexts.

It is no longer news that quality has, over the years, been recognized by everyone as one of the key issues facing every manufacturing organization. While in the last two decades or so, numerous quality management philosophies, methodologies, practices and tools have been conceived, formulated and implemented, details concerning the measure and form of their impact have emerged only recently. Some of the outlined works had the major purpose of identifying and quantifying a number of the QM elements. Operating measures were also defined by Saraph et al. [4] to estimate key factors of quality management. Flynn et al. [5] followed it while giving a step by step method of reliability and validity analysis of the developed measures.

The data necessary to distinguish Black and Porter's [6] lookup of QM critical constituents were obtained using the Malcolm Baldrige Award criteria. Benson et al. [7] quantified QM in terms of an ideal versus an actual system structural model of the QM perception of the managers. Ahire et al. [8] addressed questions related to the system-wide as compared to a component-wise implementation of these components, while Anderson et al. [9] suggested a causal model to examine the practice of input QM components and the corresponding organizational and operational outcomes. To this end, Sitkin et al. [10] pointed to shortcomings in how TQM has been executed hitherto. They pointed out that the universal application of quality management models is simplistic and that a more researchable approach to assess and visualize the complex interactions involved in applying quality management to specific areas is through a contingency-based application approach. We consider project management as a special and rather prospective sphere of applying quality management experience and methods. According to the project management institute (1996) in its Guide to the Project Management Body of Knowledge, a project is defined as a temporary endeavor undertaken to create a unique product or service.

## 2 | Literature Review

QM has passed through an enormous transformation process from traditional practices like TQM Lean manufacturing to Six Sigma for the enhancement of industrial performance. TQM was introduced by Deming [1] and centers on increasing organizational effectiveness through constantly improving standards, together with focusing on customer needs and engaging employees to do the same, which has been found to lead to further improvements in product quality and process performance. Lean manufacturing, a concept derived from the Toyota Production System (TPS) [11], aims at minimizing waste and optimizing processes in the delivery of complete, accurate value to the customer. Further, Six Sigma, developed by Motorola and General Electric, involves a statistical approach to minimizing the number of defects and variations in the production processes [2]. ISO 9001 requirements have been in place as a basic foundation for implementing the international framework of quality and quality management and for guaranteeing that organizations follow set benchmarks for quality throughout their various industries [12]. However, as for the consequence of competition in delivering new values and satisfying the new and newly emerging customers' requirements, Industry 4.0 technologies are playing ever more significant roles. ERP and IoT, AI and digital twins allow brands and manufacturers to track processes in real-time, anticipate that something is going to go wrong and prevent that from happening, as well as manage production cycles with preposterous efficiency that wasn't possible before. The combination of these digital innovations with the conventional QM methods is a

paradigm shift in manufacturing as the benefits of both systems can be availed by manufacturing companies such as Wärtsilä. According to Kagermann et al. [3], there is evidence that Industry 4.0 technologies are proactively driving efficiency in energy consumption and efficient waste management. The emergence of these technologies has a close association with the industries, resulting in the need to develop a holistic approach to QM that borrows from both conventional and advanced sense-making tools.

Quality management or QM, as embraced by many manufacturing firms, is of paramount importance for consistency and effectiveness of products, processes as well as customer satisfaction. In recent years, many techniques like Total Quality Management (TQM), Lean Manufacturing, Six Sigma and Implementation of Organizational Standards of ISO have been implemented by many industries to improve the quality of production. This review seeks to look at some of the core concepts under quality management and the observation of their application within the manufacturing sector carrying emphasis on Wärtsilä Marine and Energy Company.

Wärtsilä serves in a highly competitive and innovation-sensitive industry where it is essential to ensure high product quality and commitment to regulatory requirements. The role that this company has embraced in quality management is extensively important to guarantee the adequacy and reliability of the products & services such as ship engines to energy solutions. For its global manufacturing and service business activities, Wärtsilä employs both conventional and novel QM practices.TQM takes on the general principle of carrying out continual improvement, understanding the customer's notion and overseeing employees drive the process of improving the product quality and process architecture [1].

Research evidence suggested that TQM influenced the manufacturing industry by having a positive relation with product quality and operational efficiency. For instance, Yusuf et al. [13] noted that the astonishing benefits of TQM are improvement in the organizational processes, reduction in product defect rates, and enhanced customer satisfaction. In supporting this system, Wärtsilä Quality Management Systems is implemented in the firm to conform to ISO 9001 standards besides promoting a culture of quality improvement among the various departments of the firm. According to various TQM principles, Wärtsilä incorporates the feedback of consumers into product design since its main aim is to increase satisfaction among customers as well as promote product development. But, as pointed out by Sila and Ebrahimpour [14], one of the problems of TQM is the coupling of the implementation of TQM with the strategic direction of the organization. Wärtsilä manages this problem through communicative quality targets put as a part of a corporate strategy that makes it possible for the company to coordinate the firm's overall development, define all business processes in compliance with a chosen quality, and adapt all the spheres of the organization's work to targets set.

Lean manufacturing is the lean version of manufacturing, which was developed based on the TPS and the purpose of the lean approach is to reduce waste and increase value for customers. Thus, Lean practices have been implemented in Wärtsilä, mostly in manufacturing processes, including engines and energy solutions. Shah and Ward [11] reveal that Lean practices like Just-In-Time (JIT) and Kaizen help in decreasing the lead time and wastage in manufacturing operations. Lean thinking is employed at Wärtsilä to keep costs as low as possible while at the same time not reducing the quality of products and services being delivered. In Wärtsilä, the implementation of the lean has also enhanced supply chain management. The processes used here also include Lean practices to ensure that the company works hand in hand with suppliers, especially to ensure the delivery of key components. Similarly, Simpson et al. [15] opine that Lean integration in the supply chain brings improvement in supplier quality, and this forms part and parcel of the woes facing Wärtsilä. However, according to Hines et al. [16] it is not easy to continuously maintain Lean practice over time, particularly in lean organizations.

Six Sigma is a statistically based method to eliminate process waste and improve the quality and consistency of the product by utilizing the DMAIC structure (define, measure, analyze, improve and control) [2]. Six Sigma is especially useful in manufacturing environments where the levels of precision, for example, engine and energy system manufacturing, need to be optimized. Currently, for improved process control and

minimized production of forms or defects in the production line, Wärtsilä has employed the use of Six Sigma. For instance, Six Sigma tools are implemented to improve the performance of the engines, and guarantee that all parts correspond to the required quality prior to the integration of the final product. According to Antony [17], Six Sigma is effective in industries that have high demands for quality with fewer defects in areas of operation, such as Wärtsilä's energy solutions division.

However, Wärtsilä has utilized Six Sigma in various aspects of its organization where process improvement is necessary today in its after sales services, which is very important due to the impact of downtime and reliability of spare parts in its operations. Six Sigma has helped Wärtsilä minimize the number of equipment breakdowns, respond to customers more quickly, and satisfy customers–particularly in marine services. ISO 9000 is one of the bestselling quality assurance standards in manufacturing organizations, with guidelines on how to develop a quality management system, ISO, 2015. ISO 9001 helps Wärtsilä to guarantee that its products and services fulfill the needs of customers and applicable standards. The mentioned works, including Naveh and Marcus [18], reveal that the introduction of ISO 9000 has led to the standardization of processes, better product quality, and higher operational effectiveness. This is well illustrated in the following particulars of the Wärtsilä quality control mechanism: Implementation of ISO 9001 standards, audits, risk evaluations, and correctives. Apart from ensuring high internal quality, this certification also has a positive impact on the global market to Wärtsilä. Another applied drawback highlighted by Boiral [12] is that some organizations engaging in the process of receiving confirmation of the requirements of ISO 26000 do not essentially value this document, meaning that the fulfillment of requirements of this document is valuable for them. Nonetheless, Wärtsilä has incorporated ISO 9001 into its working environment to show that quality management is not a one-shot deal but a continuous procedure.

New Industry 4.0 technologies, including IoT, big data, and AI, are introducing changes in quality management in manufacturing. These technologies help in live observation or monitoring, projection of further use and utilization, and an elevated degree of optimization of processual routines (as cited by Kagermann et al. [3]). From the experience of one of the key players in the industry, namely Wärtsilä, it remains at the initial stage of implementing digital trends to improve production and services. This approach of practicing quality management in advance minimizes more time wastage and guarantees that the company's product meets standard quality. Zhong et al. [19] opine that smart manufacturing systems improve the flow rate of processes and offer improved means of quality management in complex settings.

Another prominent application of technology promotes a more efficient approach to product quality in the design and manufacturing phases: digital twins or replicas of real-life systems. These technologies make it possible for Wärtsilä to trial possible outcomes in engine and energy systems production and be confident that they meet performance standards before being taken to the market. It is therefore necessary to provide additional qualitative assessments obtained from the questionnaires that quantify customer perceptions regarding satisfaction, the employees' perceptions of the entire processes of quality and the successes achieved by the quality management initiatives. Basic questionnaires give stakeholders an opportunity to speak out on the performance of products, project management and areas of concern.

Another aspect of Wärtsilä company's approach to improvement of quality is the involvement of the employees in the process. From the questionnaires, employees give qualitative results on the effectiveness of quality management practices and recommend changes that may be needed. This feedback loop makes deeper sense in relation to the TQM view that embraces all workers in quality activities [1]. Employee-generated insights are most useful in Lean and Six Sigma climates since process improvement is a constant activity. Conducted questionnaires are also used in evaluating individual projects, bearing in mind the quality results obtained, time used as well as resources used. Such a qualitative input helps Wärtsilä enhance the quality management approaches to suit the problems that may occur in various projects. For instance, obtaining feedback from the project managers, engineers, and suppliers can identify the SC-specific sources of waste, and consequently, the pinpointed areas can be targeted for Lean or Six Sigma initiatives.

However, there are several challenges despite the following quality management practices in Wärtsilä organization: According to McAdam and Lafferty [20], it is not easy to match up the quality management practices with the organizational initiatives, especially when the company is giant and spread across the globe. To overcome this problem, Wärtsilä incorporates quality goals in the company's strategic plan and makes all its personnel members, including the top officers, shop floor operators, and technicians, work towards improving the quality of the products that the company delivers.

Moreover, the application of emergent technologies like, Industry 4.0 in current systems of manufacturing inspires major investments in training and infrastructure. Mittal et al. [21] believe that implementing smart quality management systems has two factors, namely workforce preparedness and the needed digitization infrastructure. To overcome this, Wärtsilä has embarked on the training of its employees and creating a digital platform to support its fourth industrial revolution projects. In the literature on quality management within the manufacturing industry, key success factors include constant pressures for improvement, customer orientation, and optimization processes. This paper is an elaboration of Wärtsilä's approach, where TQM, Lean Manufacturing, Six Sigma, ISO 9001, and Industry 4.0 technologies are applied to boost quality management and where traditional and modern quality management practices have been shown to work hand in hand.

# 3|Description of Case Company and Methodology

The procurement specialists highlighted some shared benefits of effective suppliers whereby audits and workshops maintained the quality of incoming supplies, thereby minimizing disruptions. Lecturers and engineers reported that the integration of TQM with emerging technologies, including the IoT and digital twins, coordinative integration, thereby enhancing the overall standards of the product and its production process.

Wärtsilä is a Finland-based corporation involved in the business of designing, manufacturing and servicing marine and energy solutions. The products and services offered by this company, such as ship engines and energy storage systems, among others, are developed with a greater focus on sustainable production, cost control and environmentally friendly production. The quality management at Wärtsilä potentials various methodologies, including TQM, Lean, and Six Sigma, together with IoT, AI, and digital twins that secure top-of-the-line quality across diverse global markets. This research focuses on how quality management has been integrated with technological advancement by the Wärtsilä organization, with special attention given to the reduction of carbon emissions and enhancement of energy production, making the organization most suitable for this advocacy. This paper also employs a descriptive research method entailing a case study with participative observation interviews and questionnaires in order to acquire ample information about Wärtsilä's practices in detail in relation to its QM system. Participative observation enables an assessment of the internal organizational structure of the company, and interviews with the quality control managers and engineers help to understand how these various QM tools are used in practice. Also, questions administered to employees from various divisions of the organization provide insights into the efficiency of Wärtsilä's quality policies and procedures. By using both quantitative and qualitative research, the author is able to provide a clear and detailed analysis of how Wärtsilä has effectively implemented both traditional and Industry 4.0 quality management approaches and the overall performance of the firm.

Wärtsilä is a provider of innovative products, solutions and services for the marine and energy industries with an emphasis on reducing carbon emissions. For this business area, Wärtsilä provides products for producing energy, flexible power plants, and energy storage solutions as well as optimization technologies; its engines implemented today are ready to be operated with low-emission and sustainable fuels of the future. Wärtsilä specializes in the marine business, delivering engines, propulsion solutions, hybrid, and lifecycle services to increase efficiency, safety and environmental impact reduction. Portfolio Business is one of them that focuses on several units that contain individual efficiency driving mechanisms based on strategies.

Sustainability principles are fully embraced at Wärtsilä as they preserve economic, environmental as well as social sustainability. The goal of the company is to provide the ever-increasing demand for energy more efficiently, environmentally friendly ways that will make good business sense and application of best business practices. Moreover, this paper underlines how Wärtsilä has extremely developed quality management processes as a means to guarantee the delivery of high-quality, reliable, and environmentally friendly products and services for both the marine and energymarkets. The article is based on a single case study of a quality strategy formation process over time. The empirical data have been collected through participative observation in the Wartsila quality control manager. According to (Merriam & Tisdell, 2016), Other types of quantitative data collection methods include individual interviews, group interviews, case studies, ethnography, and participating observation.

According to Cohen et al. [22], Empirical research uses facts that can be directly or indirectly observed, and experiments are used in the process. This data is used as a framework for making conclusions, hypothesis testing as well as developing theories. These approaches enable researchers to capture detailed information from the participant's questionaries' that are actively involved regarding quality management tools and the process used in the Wartsila renewable energy system. The case study focuses on the formation of a distribution strategy. Participative observation has been chosen for the data collection and analysis process. Data was collected from the overall view of the renewable energy system and its detail. The company and, indeed, most employees are highly focused on quality management and ensuring the best for end users, sales subsidies and global client satisfaction. Here, each order line is translated directly into a production order following the quality tools that are used in Wartsila.

# 4 | Analyze and Results

An examination of Wärtsilä's QMS shows how 'digitalization' in the form of Industry 4.0 instruments has been incorporated into 'classic' QM applications to serve as the backbone of the company's improvement efforts in relation to product quality, effectiveness and compliance with international norms. At Wärtsilä, Six Sigma Dane is in use, especially the DMAIC model, to reduce defect occurrence in manufacturing procedures in its energy systems divisions [2]. Some of the specific business processes that have been pointed out are Lean Manufacturing, JIT and Kaizen for enhancing production with an invariably positive impact in increasing organizational efficiency and cutting costs [11]. That has been propped up with modern touch applied to traditional practices from Industries 4.0 technology applications like digital twin, simulative real-time rendition of product performances, IoT sensors for predictive maintenance and AI analytics for supply chain efficiency [3]. One example of a digital twin in action is Wärtsilä's, which lets the company virtually test the functionality of marine engines and power systems ahead of their physical implementation, with the goal of foreseeing early signs of FAIL and fine-tuning its product for efficacy and longevity. Currently, IoT sensors can come to the aid of predictive maintenance–identifying equipment anomalies reduces downtime and increases the lifespan of the entire machinery [19]. These innovations have not only given a way to decrease the defect rate but also to increase customer satisfaction due to the fact that products are more durable and have better quality. Still, the integration of these technologies has not been very smooth sailing. One of the challenges that the firm experienced was how to train its personnel to incorporate technological tools as well as another challenge was how to deal with the high fixed costs required to acquire such technological tools. However, with ambitious goals laid down in the learning and development activities of Wärtsilä employees, these challenges have been effectively addressed in favor of guaranteeing the long-term success of the systems of quality management.

Wärtsilä also focuses on customers' needs and expectations regarding the product, as well as quality criteria in the early stages of product planning. A formal system such as Quality Function Deployment (QFD) is employed at the organization to ensure that the voice of customer requirements is translated into technical requirements. Such feedback, as received from marine and energy customer segments, is useful in improving managerial product architectures. Wärtsilä's culture of innovation in the development of its products also guarantees that solutions meet high standards of other regulatory standards like ISO, IMO regulations and

the like, and environmental standards. The company has ensured that the processes of design and development match the quality standards of customers across the globe and that durability, reliability and sustainability are incorporated into the product.

The company functions internationally with factories in several areas; however, it controls its manufacturing processes using quality management systems, including ISO 9001. This standardization helps to maintain the quality of products offered across various places or regions it is taken to. Every facility uses globally integrated processes, and these are the identification of trends, audits and compliance with the best practices in manufacturing. These standards are highly related to the quality objectives of Wärtsilä, which include Operating effectiveness, low level of defects and conformance to specified performance standards to enable the products used in harsh conditions in which Wärtsilä products are applied.

Absolutely, that is how Wärtsilä has designed the testing and validation procedures, to cover any possible condition that a product may have to face, perhaps through rough seas or high energy requirements. Engines, power systems and marine solutions are tested in Wärtsilä research and development facilities for a range of load circumstances, including temperature and corrosive conditions. To prevent consequent field issues, these tests are accompanied by FMEA, as well as LCA. Consequently, many Wärtsilä products are today designed to operate and withstand the specific conditions they are likely to encounter to guarantee efficiency and longevity.

Currently, at Wärtsilä, the company enjoys a well-developed supplier quality management system. It means that all incoming materials are assessed before they get to production in the company to ensure they are of high quality. Approved sub suppliers, receiving inspection procedures and material certification requirements help Wärtsilä to ensure that raw materials and components required for manufacturing its products meet its standards. Furthermore, Wärtsilä collaborates with suppliers through partnerships to be sure that it has the right quality expectations and that these are achieved. This minimizes the likelihood that defective parts are delivered into their supply chain and guarantees the company's quality of materials utilized in creating their products, Wärtsilä.

Wärtsilä then solves the issue of financial limitations by identifying strategic priorities to invest in a select group of projects that seem to fit its vision and mission most appropriately. The organization uses techniques like digital twinning and advanced prediction to improve reliability without much capital expenditure. Supplier and partner collaboration means cost sharing; risk management means the concentration of effort in areas of greatest vulnerability. Likewise, Wärtsilä also presses on the lifecycle support solutions and services, including the aspects of predictive overhauls, to create the customer value of continuous revenue and to reduce customer costs. Due to a culture of steady progression supported by safety and legal requirements, costs are minimized without compromising on quality or safety.

To determine the effectiveness of the various products in the field, Wärtsilä employs field monitoring, predictive analysis, digital models and feedback from their clients. The company uses condition-based as well as predictive maintenance, which includes schedules, failure reporting analysis for condition and outcome summary, FRACAS and root cause analysis to curb any resulting downtimes. Information gathered from institutes, service agreements, field trials and or lifecycle management is provided to Wärtsilä quality management system according to the ISO 9001 regulations in order to enhance product development, new manufacturing processes and efficiency. This feedback loop guarantees continuous improvement in product quality, reliability and compliance with the customers' needs and demands, all the time minimizing risks and costs.

To monitor the performance of products, Wärtsilä makes use of remote monitoring and analytics, condition-based maintenance, digital copies of actual assets, feedback from customers and failure reporting systems. Substantial big data is acquired from sensors and IoT devices for constant monitoring and analysis, determining when failures are likely to occur and for making correct maintenance decisions in time. The experimental module evaluates the product's performance and limitations using digital twins, while combined customer experience and field service insights reveal areas of poor quality. FRACAS is the examination of the

use of Failure Reporting and Analysis and its feedback on product design and manufacturing. Field trials and lifecycle collection of information on design, material, and processes make iterative enhancements in the reliability and quality of products that conform to high-quality standards.

This company follows and incorporates international and house quality standards across its projects to achieve coherence, stability, and legal and customer conformity. Organizational standards such as ISO 9001 and ISO 14001 are implemented from the design phases so that the organization's products meet the international standards as it is adopted. The developed company's standards correspond to company values and targets in the field of sustainability and innovation as well as improve according to Wärtsilä internal indicators and customers' feedback. Implementation of strict documented procedures with tracking systems and automated quality checks is a way to maintain compliance from the initial manufacturing process to the end product. Regular control and verification, complemented by data analysis in real-time and by using the method of predicting the need for maintenance, helps identify deviations from the previously established standards, domestic and international, throughout the product life cycle.

Quality and reliability-based training programs are provided to the staff of Wärtsilä so that everyone at every level can fully champion the relevant standards. These are basic courses on international standards, the application of industry standards in renewable energy as well as practitioner's exposure through practical exposure/gold standard model comprising of on-the-job training and virtual scenarios. The workers are provided with digital knowledge of such things as predictive maintenance, the use of digital twin technology to monitor the performance of the product as well as observing certain signs of failure. Skills are also augmented through training and refresher courses that are repeated periodically or when a new post is taken; these are fitted for different personnel, quality control teams and managers with a chance to sit for Six Sigma and ISO.

To ensure adequate product quality and reliability of manufactured products, Wärtsilä continues to collect data and adopt IoT technology. Monitoring by sensors yields real-time data on essential parameters, including temperatures, pressures and vibration, hence the ability to identify changes and faults in products quickly. Predictive maintenance uses big data to make some presumption on the conditions of the operation and the failure that might be in the future and then reduce the time which is out of service. Machines with offices for AI perform inspections and contribute to statistical process control for improved accuracy and help with finding the source of errors. By connecting information for the entire architecture of the product, from creation to use, Wärtsilä ensures that production decisions are associated with future dependability while also promoting an ongoing cycle of learning for quality enhancements. Data collection at Wärtsilä is systematic to ensure that the firm receives feedback from the customer on the quality and reliability of the products after they have been put in the field. SHOP sphere contains satisfaction surveys, observation and feedback gathering, while routine services real-time performance monitoring as a source of information about reliability and field performance.

According to the engineers, following the Five Step DMAIC approach of Six Sigma, there was a tremendous improvement in product quality as there was a huge decline in defects due to the properilosntion of workflows that included rework cycles. Likewise, the implementation of Lean Manufacturing Methods, including Just Time Delivery and Kaizen, reduced raw materials and also improved production efficiency as per some of the production crew. The IoT sensors have altered maintenance through predictive maintenance with technicians preserved on making bi-corrective detection and repair of equipment breakdowns, thereby reducing downtime and increasing equipment longevity.

# 5 | Conclusion

Various studies with customers indicated improved satisfaction arising from the dependability and longevity of Wärtsilä's products embracing marine engines and energy solutions coupled with foresighted maintenance activities. Feedback obtained was that the training programs prepared the employees for Industry 4.0 and also saw an enhanced employees' confidence and cooperation in the creation of a culture that encourages

innovation and adaptability. Quality managers also highlighted that digital twins and real-time analytics had enhanced the product design and energy-efficient systems, meeting Wärtsilä sustainability objectives as well as work for global competitiveness.

From this research work, it becomes clear that incorporating the concept of quality management in the context of Industry 4.0 will help organizations improve operation efficiency and sustainability and better serve their customers. It was further highlighted that defining Wärtsilä's core competencies includes the integration of TQM, Lean Manufacturing, and Six Sigma reliability with the disruptive power of the IoT, AI, and Digital Twins to make the company a guiding light in the Marine and Energy Sectors. The implication here is that other industries can emulate Wärtsilä's success in the use of two approaches to quality management, the conventional and the technological, to address current requirements. With the further development of the manufacturing industry and the deepening of manufacturing upstream and downstream links, the combination of Industry 4.0 technology with QM will gradually become more important in promoting competitiveness and achieving the goal of delivering quality products. Future research could examine other industries besides manufacturing to understand further how these integrated QM practices are being implemented and whether the rapidly increasing field of emerging technology, specifically quantum computing, could influence the development and ongoing management of future quality management systems.

The paradigm shift of a new generation of quality management is already transforming industries, organizations and businesses by embracing innovative technologies in order to improve the company's efficiency and customer satisfaction as well as product quality. The incorporation of sophisticated technologies like AI, IoT, big data and data analysis automation helps companies manage quality in real time. Measures are taken during the production process, where examinations and tracking of performance are done through smart sensors and connected devices, where any problem is detected immediately, hence minimizing the possibility of a defect. Thus, new technologies like automation technology, robotics technology, and predictive analytics are making the process even more efficient while reducing human errors in the outcomes acquired, along with enhancing product quality. Also, practices like Six Sigma, lean manufacturing and TQM are further evolving through the use of digital tools for their ongoing enhancement of, control of wastes, and process enhancements. These improvements not only help enhance productivity but also lead businesses to be compatible with international standards like ISO 9001, 14001, and ISO 26000, which would create a more competitive environment internationally. With these innovations, industries are not only obtaining efficiency in their organization but they are also increasing the level of confidence customers have in their industries.

In Wärtsilä's quality management structure, a set of traditional and new-age principles have been incorporated according to the advanced demands of the modern world. Having adopted and incorporated management practices such as TQM, Lean, Value, and Six Sigma and implemented novel additional trends like IoT, AI and the use of real-time data, the company has found itself at the cutting edge of Industry 4.0. This digital transformation does not only improve its functionality more so the quality and reliability of its products and services. SkyLight is an example of the actual use of real-time data by Wärtsilä; the company's unique intellectual solution has positively impacted on efficiency of operations, fuel consumption, and customer satisfaction within the marine and energy industries. In addition, Wärtsilä's focus on putting people at the center of change makes certain that technology implementation and leveraging involve and develop employees. In this way, social media management and human-centric design apply tension toward the future, which is critical for maintaining a strategic vision that is crucial for ongoing viability.

Since the energy business is gradually shifting towards more flexible and renewable platforms, Wärtsilä is in a vantage point to navigate the change. Innovative investment in flexible power systems and energy storage implies a vision towards a fully renewable energy society. Thus, based on the systematic and effective technological approach to quality improvement, Wärtsilä has implemented sustainable measures, which make it possible to provide the customer with high-quality and reliable technological solutions in manufacturing and energy of the future.

To conclude, factors influencing Quality Management consider that it is very important for any organization operating across national borders because it guarantee constant quality, reliability and customer satisfaction in different global markets. It implies that there is a quality of products and services being practiced by manufacturers and service providers in order to ensure that their products and services match the required standards of customers across the globe. Quality management enhances displaying conformity to International regulations and standards, thus minimizing the chances of law violations and barriers to the market. It also makes operations more efficient, and reduces wastage and costs of production, thus helping organizations to continue to compete in a global market. Lastly, effective management of quality systems is very important to guarantee the long run success of any business as well as catering to ever-rising customer demands in the global market. Collectively, these observations demonstrate how Wärtsilä has successfully leveraged both traditional and modern approaches to achieve operational excellence, customer satisfaction, and environmental sustainability.

## Author Contributions

Chandan Chandra Sheel and Seyyed Ahmad Edalatpanah jointly conceptualized the study. Chandan Chandra Sheel conducted the primary research, including case study observations, interviews, and data analysis. Seyyed Ahmad Edalatpanah contributed to the theoretical framework, methodology design, and result interpretation. Both authors collaborated on writing and revising the manuscript.

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## Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

## Conflicts of Interest

The authors declare no conflicts of interest.

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