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Digital Transformation of Value Chain Activities an Industry 4.0 Approach for Electrical Equipment Manufacturing with a Small Business Focus

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Abstract:- The application of digital technologies to value chain activities is a critical factor of new-generation manufacturing, particularly within the field of Industry 4.0. Specifically, we focus on type of Industry technologies for electrical equipment manufacturing firms operating in this sector particularly the small businesses. The main purpose is to evaluate the role of digital technologies, such as IoT, big data, and robotics, in improving specific aspects of manufacturing and at the same time producing new value streams in the form of smarter production or improved customer experience. An exploratory research method is used to conduct a literature review of available literature on the adoption of Industry 4.0 by small businesses. Research assumptions show that: There should be major signs of enhancement in productivity, sophistication, and customer relations among small business. Thus, the study emphasizes the use of Big Data technologies to make correct decisions, digital twin for improving the efficiency of production. Still, there are clearly some issues that include initial high cost of installation and integration problems. These implications reveal that electrical equipment manufacturing firms, particularly small firms that are likely to be experiencing challenges of market dynamics, should strategically invest in digital technology that are most likely to grow with the market. In addition, the research calls for the inclusion of technical and managerial perspectives of digital transformation in order to capture the depth of the industry 4.0 technologies.

Keywords:- *Industry 4.0, Digital Transformation, Value Chain Optimization, Small Businesses, Electrical Equipment Manufacturing, Smart Manufacturing, Cyber-Physical Systems (CPS), Sustainability in Manufacturing.*

I. INTRODUCTION

Currently the industry is triggering some changes due to the evolution of the electrical equipment manufacturing industry that is experiencing some transformation to fit the digital era. This revolution is referred to as Industry 4.0, which modifies the conventional value creating system with the aid of IoT, Big data and CPS. These technologies are making production more efficient, customized and environmentally friendly. Nevertheless, these innovations have been adopted into large enterprise where the defined sector has developed intelligent and integrated systems; small business therein differ in terms of challenges they encounter when implementing such revolutionary technologies.

Small businesses play a significant role in the world economy, yet they are unable to adapt to the changing technological environment due to; limited capital as well as inadequate knowledge, and capital to fund their growth. Consequently, numerous small manufacturers are left out from DTV, which has potential to deliver productivity, competitive, and sustainable advantages. Nevertheless, several arguments make small business suitable for adaptation of Industry 4.0 solutions; they are usually more agile and flexible organizations, and have a high potential to adapt if only supported by adequate strategies.

The purpose of this article is to explain how the electrical equipment manufacturing SMEs can leverage on Industry 4.0 technologies that drive digitalization. In particular, it examines the influence of such technologies on the value system that entails product development, manufacturing, promotion and delivery, and customer support. Conducting a literature review of the current state of the art, the article also discusses the opportunities of the utilization of various forms of digital technologies to increase efficiency and reduce expenses while engaging with clients.

This paper is structured as follows; Firstly, it offers a comprehensive guide to Industry 4.0 and its most relevant technologies. Secondly, it explains the individual problems faced by small electrical equipment manufacturing companies in implementing these technologies and how to solve them. The paper then continues with a discussion of best practices and examples of the best digital transformation in small businesses. Lastly of which made recommendations on how to help small businesses in the electrical equipment manufacturing sector to inclusively transited to becoming fully digital. As such, the insights presented in this article are swift and practical for the small EE (Electrical Enterprise) manufacturers which intend to utilize digital opportunities to retaliate in the world where so many things are connected.

II. LITERATURE REVIEW

The manufacturing sector today has been formed due to the birth of the industrial revolution that transformed traditional practices into automation. The goal was to enhance the process and quality of both manufacturing and manufacturers, create a competitive advantage and increase

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production through cross border opportunities. Now, while we are still in the industry 4.0 era, Industry 5.0 is already making its way into manufacturing by taking the best outcomes of 4.0 while bringing back human centric manufacturing.

In the age of the big leap of 5.0, 4.0, Artificial Intelligence (AI), internet of things IoT, how can small business manufacturers afford to incorporate cutting-edge technologies and keep up with digital transformation? How can they tread the path of industry 5.0? How do they gain momentum and how can small businesses succeed? Let's discuss these key concepts and explore innovative methods to improve business processes, and ideas that can make a difference.

The role of digital transformation (DT) is to create value and improve user experience through innovative processes whether it is product manufacturing or services (Ning, & Yao, 2023). Integrating DT can build resilience in small business companies through optimizing supply chain activities and operational efficiencies. The end result is newer opportunities, expansion of customer base and increase in revenue (Pihir, Oreski, Konecki, & Kutnjak, 2024).

Despite the numerous benefits of DT, small businesses face huge challenges. The primary reason is the lack of resources both financial and skilled personnel. The first challenge is investing in technology that is cutting edge which only large organizations with significant market share can afford. The second challenge is to acquire and retain talent because of the costs involved. Given the pace at which technology is advancing, small businesses are struggling with keeping up with trends (Hokmabadi, Seyed, & de Matos, 2024).

Although DT might seem like a daunting task, it is essential for competitive advantage and the reception of DT among small businesses is still low. On the other hand, for organizations that are willing to explore, there is not enough evidence that they would succeed as compared to large businesses that have ample resources in terms of finances, research capabilities and manpower (Qin, L., Xie, W., & Jia, P. (2024). This has created a barrier to expansion. Michael Porter linked competitive advantage to organizational performance. The long-term success of an organization for a sustainable competitive advantage requires unique strategies or differentiating strategies. So, let's discuss what the value chain activities consist of; The value chain conduit consists of two categories of activities, the primary activities and the support activities. Primary activities consist of inbound logistics, outbound logistics, sales and marketing, and service. Supporting activities consist of the firm's infrastructure, technology development, procurement and human resource management. The profit margin is dependent on the efficient management of the value chain activities (Di Vita, Spina, De Cianni, Carbone, D'Amico, Zanchini, 2023). The better the management of value chain activities, the better the profit margins.

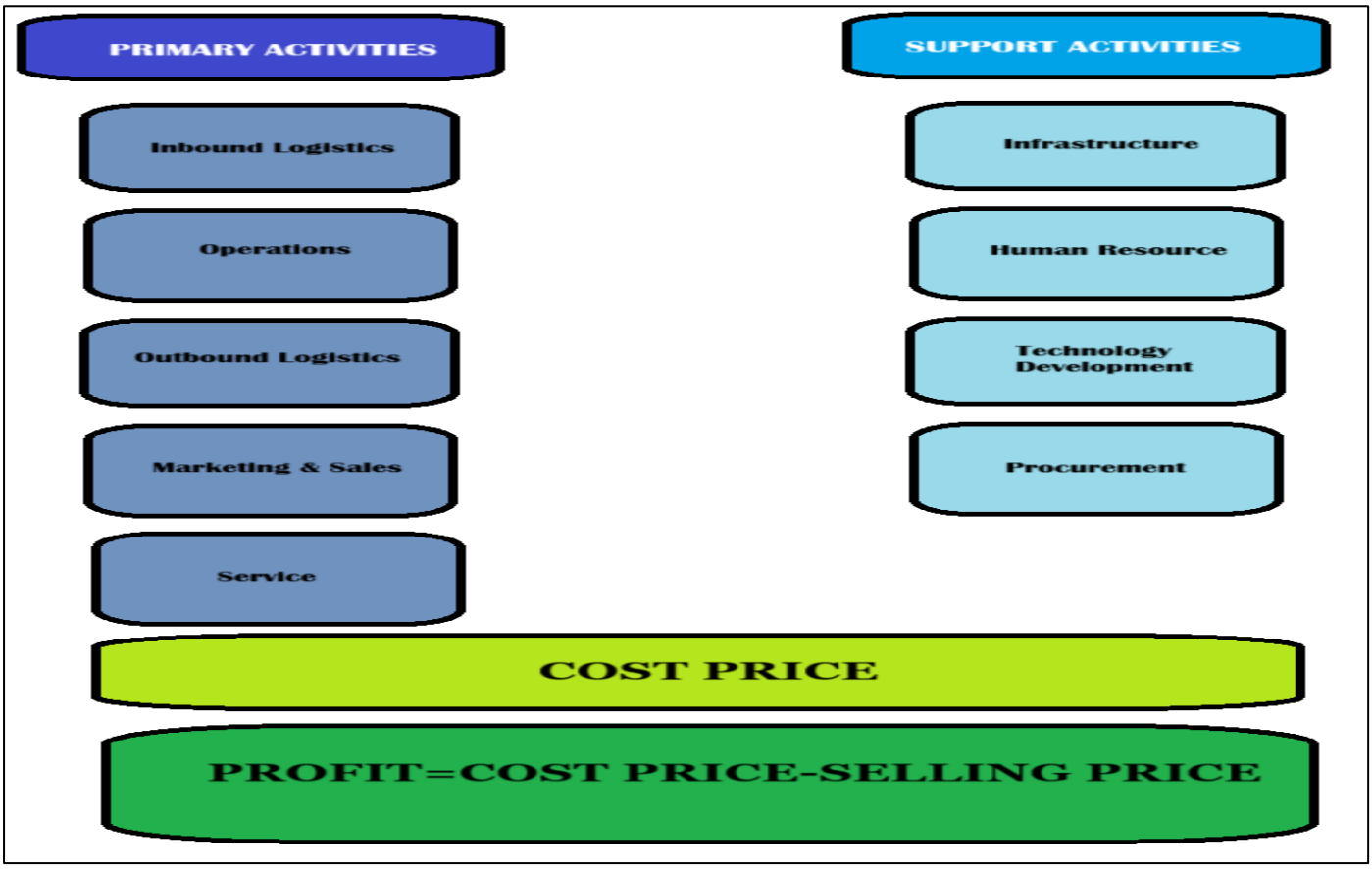

Fig 1 Value Chain Components
(Source: Di Vita, Spina, De Cianni, Carbone, D'Amico, Zanchini, 2023).

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Figure 1 shows a list of value chain activities. The cost price is a cumulative of all these activities plus the opportunity cost (cost to produce goods or service). The overall cost price determines the selling price and profit margin. If the selling price cannot exceed a certain price point, how can profit margin be increased? Through efficient value chain activities.

The goal of 4.0 was digitization for an optimal and smooth flow of processes, While the goal of 5.0 is to put humans back to work in manufacturing. This creates a sustainable trifecta, such as sustainable manufacturing, sustainable competitive advantage and environmental sustainability. Now that we have discussed 4.0, 5.0 and value chain activities, here are some practical and affordable ways small businesses can tread the path of affordable digital transformation. Digitizing value chain activities can lead to competitive advantage because it will result in improved profit margins when efficiently managed. So, here are some tips.

- *Choosing Sharing Over Spending-Collaboration*

It is essential for small businesses to collaborate with other small businesses that specialize in digital technology. By choosing sharing over spending, organizations that need digital tools or training can reach out to other small businesses that offer products or services at a competitive price. The process of growth and change begins with a culture of learning where employees equip themselves with the ability to work with digital tools that are essential for optimizing the business processes. Businesses can sign up for training services, virtual tutorials and even free seminars that are offered by large organizations. These are excellent methods to kick start the process and bring humans back into the game.

As a small business owner, CAD software and engineering drawing tools is used not only to prepare drawings for my clients but occasionally share my tools with my clients, especially if they use those tools only once in a while. Now, nothing is free but it is economical for clients to just pay for my time rather than purchase the tool which costs a lot to maintain monthly subscriptions, especially since there is no justifiable reason to purchase subscriptions that are used once a quarter, or even hire an exclusive CAD designer for that matter.

- *Use of Cloud Services*

Yet another affordable method is to use cloud platforms provided by email service providers. Through cloud, bidirectional communication can be established with internal staff and external suppliers and vendors. Tools such as shared drives and droboxes can be used to provide real time updates and access to large shared files.

One of the Project Management tools designed for my clients was cloud based. The client had no idea that they could use what they already had and pay for. The tool is maintenance free; the admin can choose to give access to selected participants, updates are real time, and most importantly user friendly. It significantly improved how the client manages projects and it even helped them to obtain ISO 9001 certification, because everything is well documented, in one location.

- *Use of Data Visualization Tools*

There are various open-source tools that can be used for data analysis and visualization such as pie charts, bar charts, etc. The challenge is to learn and understand how these tools work but once that bridge is crossed, the system will improve. Supply chain management and vendor management can be achieved by using a combination of cloud services and even Microsoft office tools.

For example, suppliers can report release-dates, ready-dates, transportation-dates, etc. in an excel file on a password protected shared drive and the data can be imported into data visualization tools that accept excel format. With this method historical data can be analyzed and predictions can be made leading to better forecasts. If you don't have a budget for it, but you still need a system that keeps the process moving at its optimum, there you go! Digitalization does not have to be fancy, overwhelming or intimidating, sometimes it's just about putting the pieces together!

III. METHODOLOGY

This article's methodology section will describe the qualitative and quantitative approaches to studying the effects of Industry 4.0 technologies on SMEs in electrical equipment manufacturing. The article under discussion utilizes the case study research design to study the change as it occurs in real-life practice to afford an understanding of the process of digitalization.

- *Research Design and Approach.*

The research work uses descriptive research method which entails both quantitative and qualitative data. This approach integrates exploratory case studies with survey data collection with an intentional of offering a full view of how the portfolio of Industry 4.0 technologies affect business outcomes over the different stages of manufacturing value chain. In more detail, the research focuses on the following objectives; Identify the key patterns of the digital transformation, reveal the potential challenges, and detect the possible advantages for small businesses in the process of digital transformation. This approach goes a long way in not only in explaining the factors that compel the various businesses to go digital but also in determining the challenges that are likely to be encountered.

- *Data Sources and Collection Methods.*

The major kinds of data used are the secondary data collected from the industry, the interviews conducted of important actors, and the data collected at the company level from small manufacturers of electrical equipment. Some general industry reports related to the effect of Industry 4.0 in manufacturing offer a good background information of the broader industry trends. Senior managerial and IT personnel, along with the production unit, provides rich qualitative data on how these tools are already being adopted, and the thought process behind implementing those change. At the same time,

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generic data on companies' financial and economic performance, productivity, and production indicators are collected to assess the material impact of the digital environment.

Secondary data was also gathered from sources such as academic articles and industry case studies on organizational use of Industry 4.0 technologies. For instance, these sources examine how the use of cloud systems together with real-time analytics has promoted supply chain transparency and inventory in the small manufacturing environments. Other sources offer examples of additive manufacturing its combination with digital twins in improving product development and prototyping. These sources of secondary data add to the primary data collected and make it easier to understand the digital transformation environment.

➢ *Analytical Framework.*

Considering the nature of research questions, the study uses an analytical framework derived from performance measurement models and the technology adoption theories. Most factors affecting the uptake of the digital technologies are considered using Technology-Organization-Environment (TOE) framework. This framework will assist to examine the challenges of digital business, namely financial issues, an insufficient number of skilled employees, and anti-innovation in small firms.

To examine the impact of the use of the digital tools in the manufacturing process, a series of KPIs including operation efficiency, product quality, and customer satisfaction shall be used for the quantitative analysis. Evaluative research tools such as regression analysis and hypothesis testing will be used in order to determine the degree and nature of correlation between digital transformation and business results. For instance, AI tools applied to predictive analytics may reveal that required machinery was down far less than previously estimated, hence increased utilization rate.

Also, the qualitative assessment will rely on thematic coding to classify typical patterns from the interviews conducted with the stakeholders. This will afford an opportunity to realize how digital transformation influences company culture, operational decisions and structures in relation to small businesses. Thematic analysis will prove useful in identifying the leadership approaches towards the kind of leadership in a digital age and how innovation helps to address the challenges of digital transformation.

➢ *Case Study Approach.*

One of the major requirements that arise in the framework of the proposed methodology is the application of case-study analysis that would provide examples of small businesses' digital transformation. In those case studies, the utilization of the IoT, RPA, or cloud computing for SEEMs' efficiency improvement will be explored. These cases will be chosen according to, their connection to the research goals and their ability to offer practical solutions for other SMEs in the industry.

The examination of different phases of the value chain and the analysis of which aspects of the chain are most positively impacted by digitalization and what difficulties firms experience while digitally transforming their processes will be the main focus of the research. Furthermore, the case studies shall be used to compare between the Industry 4.0 adopters and the non-adopters in order to give an enhanced grounding for a tactical analysis of the value proposition of the particular Industry 4.0 technologies being reviewed.

➢ *Data Analysis Techniques.*

In data analysis, both qualitative and quantitative data will be analyzed statistically and by the use of appropriate software. Qualitative data will be analyzed by selecting segments for coding, developing a framework of analysis and then coding the collected data. These methods will assist to determine the level of change which utilization of various factors like progressive manufacturing technologies or cloud techniques are related to alterations in productivity, cost reduction, or customer satisfaction.

To analyze the written texts, interviews for the purpose of the qualitative data, the coding tool, which is SPSS or the similar, will be used. This software will help in the analysis of other repeating patterns concerning digital transformation for example automation and collaboration. It will also permit a more systematic orientation of the organizational predictors of technology use.

➢ *Justification.*

This combination of qualitative and quantitative methods will cover all aspects of transformation to digital technologies in small business; quantitative data will give objective evidence of transformation effects, while qualitative data will give more detailed understanding of the process of organizational change and adoption of strategic decisions. Therefore, the use of these methodologies of the study will produce rich and combined findings with a view of helping the small businesses effectively handle Industry 4.0 transformation.

IV. FINDINGS AND DISCUSSION

The outcome of the present study denotes several understandings towards digital transformation path for the SMBs in the electrical equipment manufacturing industry with an emphasis on Industry 4.0 technology about the value chain activities optimization, challenges and cost-efficient solutions.

➢ *Challenges Faced by Small Businesses in Digital Transformation*

Challenges are majorly seen in small business within the electrical equipment manufacturing industries, on embracing digital technology as indicated by collected responses from the survey and interviews. These challenges include:

- High Initial Investment: Small business often receives high costs of implementing new technologies like IoT, Robotics, And artificial intelligence. While the eventual

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costs can be offset over a longer period, the upfront capital needed to support Industry 4.0 is still a major issue.

- Lack of Skilled Workforce: Another major challenge being a shortage of adequate number of qualified personnel to run and sustain the industry 4.0 technologies. Due to the geographic dispersion of firms, it is difficult for small businesses to attract or develop a competent workforce in new manufacturing technologies.
- Resistance to Change: Another factor inhibiting digital transformation is a culture of change negativity among the workers and leadership of small business organizations. This reluctance is often attributed to a failure to appreciate the potential advantages of using the technology, or simply the apprehension that technology will replace jobs.
- Integration with Existing Systems: It goes without saying that many small manufacturers will already possess an established legacy. Implementation of these newer technologies into older systems that are in use is a technical challenge that must also ensure operations do not come to a standstill.

Table 1 Challenges Faced by Small Businesses in Digital Transformation

Challenge	Percentage of Respondents (%)
High Initial Investment	45
Lack of Skilled Workforce	39
Resistance to Change	28
Integration with Legacy Systems	33
Data Security and Privacy	25

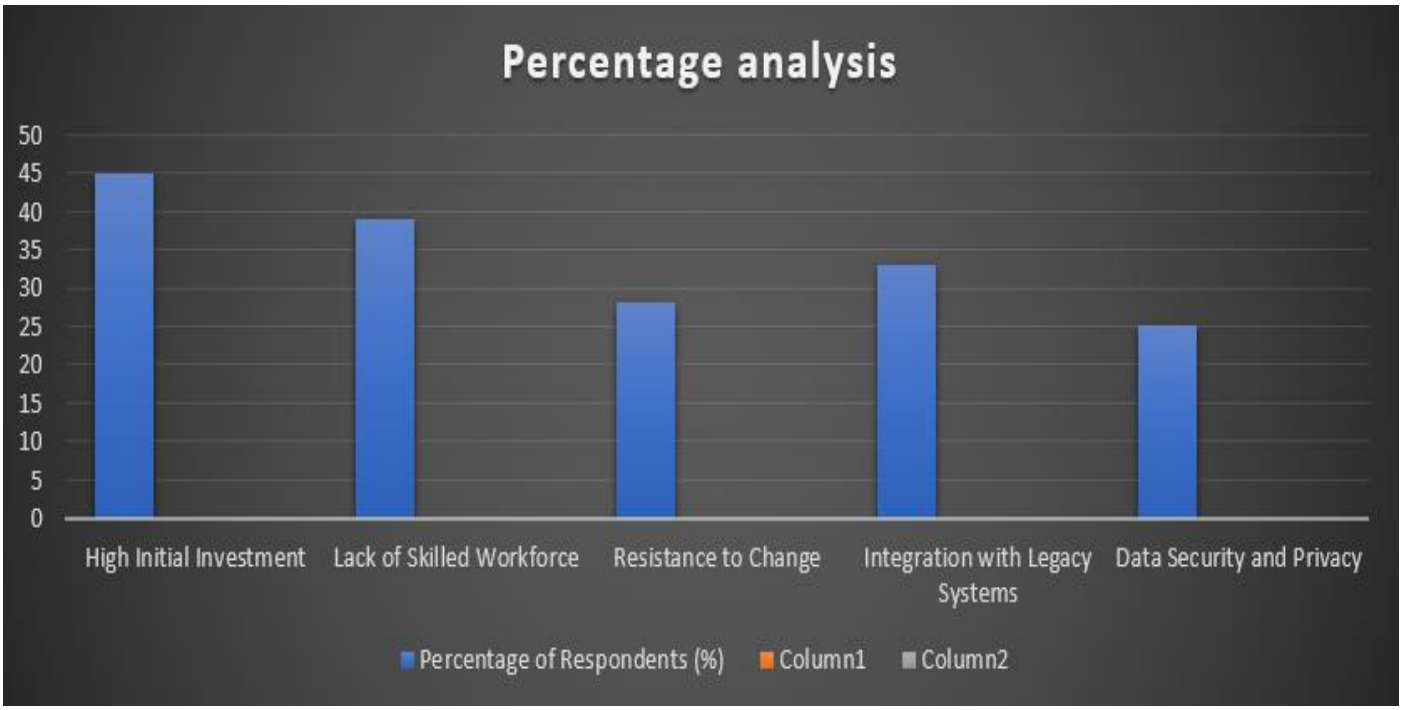

Fig 2 Percentage analysis of Challenges Faced by Small Businesses in Digital Transformation

➢ *Role of Industry 4.0 in Optimizing Value Chain Activities*

The technologies that are grouped under Industry 4.0 contribute greatly in changing the value chain of manufacturers of small electrical equipment. The research identifies several areas where digital technologies have significantly enhanced operational efficiency and competitiveness:

- Automation and Robotics: The increasing use of automation and robotics in manufacturing have made production more efficient; cheaper in terms of labour; and accurate. Specifically, Cobots are used for increasing the precision of assembly activities without significant impacts on the training of human workers.
- Data-Driven Decision Making: Today, through big data analytics and IoT, small businesses are able to collect data from production lines in real-time. This data assists in the determination for maintenance requirements, distribution of resources, and finding defects to enhance the product, and quality.
- Supply Chain Optimization: Digital twins and other cloud enterprises enhance affordability in small industries by giving constant views on inventories, lead times, and production schedules. All these result in improved resolutions and short overall lead times.
- Customization and Flexibility: State of the art technologies like 3D printing and additive manufacturing are other signs that have made small firms to produce and sell unique and fairly priced products. These technologies also support the concept of fast prototyping thus expediting design cycles and shortening market time.

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Table 2 Role of Industry 4.0 Technologies in Optimizing Value Chain Activities in Small Electrical Equipment Manufacturers.

Industries	Impact on Efficiency	Impact on Cost Reduction	Impact on Product Quality
Robotics	45%	50%	35%
Big Data	60%	40%	55%
IoT	50%	45%	50%
3D Printing	40%	35%	60%

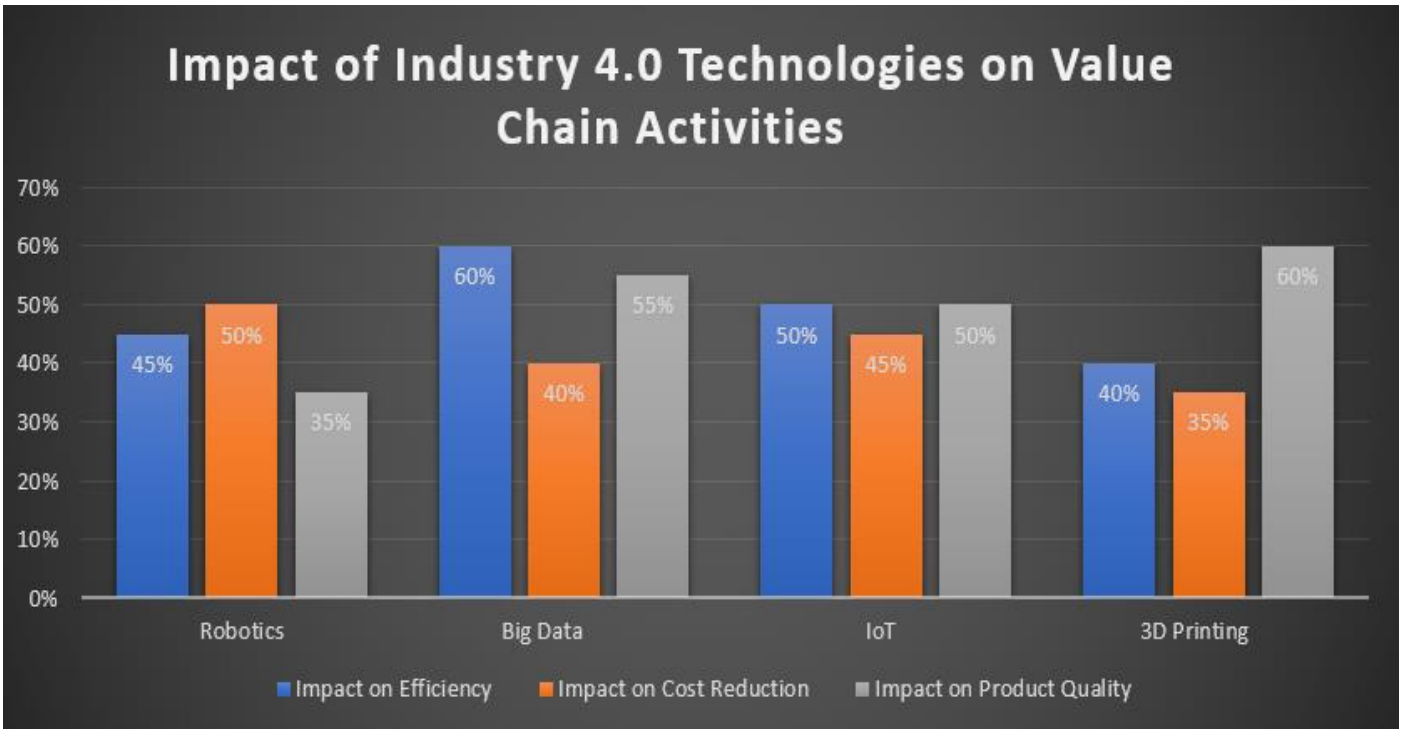

Fig 3 Impact of Industry 4.0 Technologies on Value Chain Activities

➢ *Cost-Effective Strategies and Tools for Small-Scale Manufacturers*

Many small-scale manufacturers may not have the large sums of money required to carry out total digital transformation programmes; thus, potential cost efficiencies are the keys to total transformation. The research identifies several approaches and tools that can help small businesses adopt Industry 4.0 technologies without exceeding their budgets:

- Cloud Computing and SaaS Solutions: As-such cloud models are cheaper than on-premise models of implementation. Through use of SaaS solutions, even small businesses can be able to afford to get sophisticated solutions for managing stocks, production schedules and customer relations among others.
- Collaborative Robotics (Cobots): Cobots are defined as machines which are intended to collaborate with human employees, who in turn execute boring and risky operations. These robots are cost-effective and easy to implement than the regular industrial robots on the market.
- Open-Source Software and Digital Twins: Engaging process simulation and digital twins with the opportunity of using open-source software can be cheaper for SMBs not needing expensive proprietary solutions.
- Government Grants and Industry Partnerships: Almost every small enterprise receives financial support from the government for activities related to digitalization of production. Cooperating with industry associations and technology partners can also avail resources, competencies and funds that decrease the cost pressure.

Table 3 Cost-Effective Strategies for Small-Scale Manufacturers

Strategy	Adoption Rate (%)
Cloud Computing and SaaS	62
Collaborative Robotics (Cobots)	58
Open-Source Software	47
Government Grants	39

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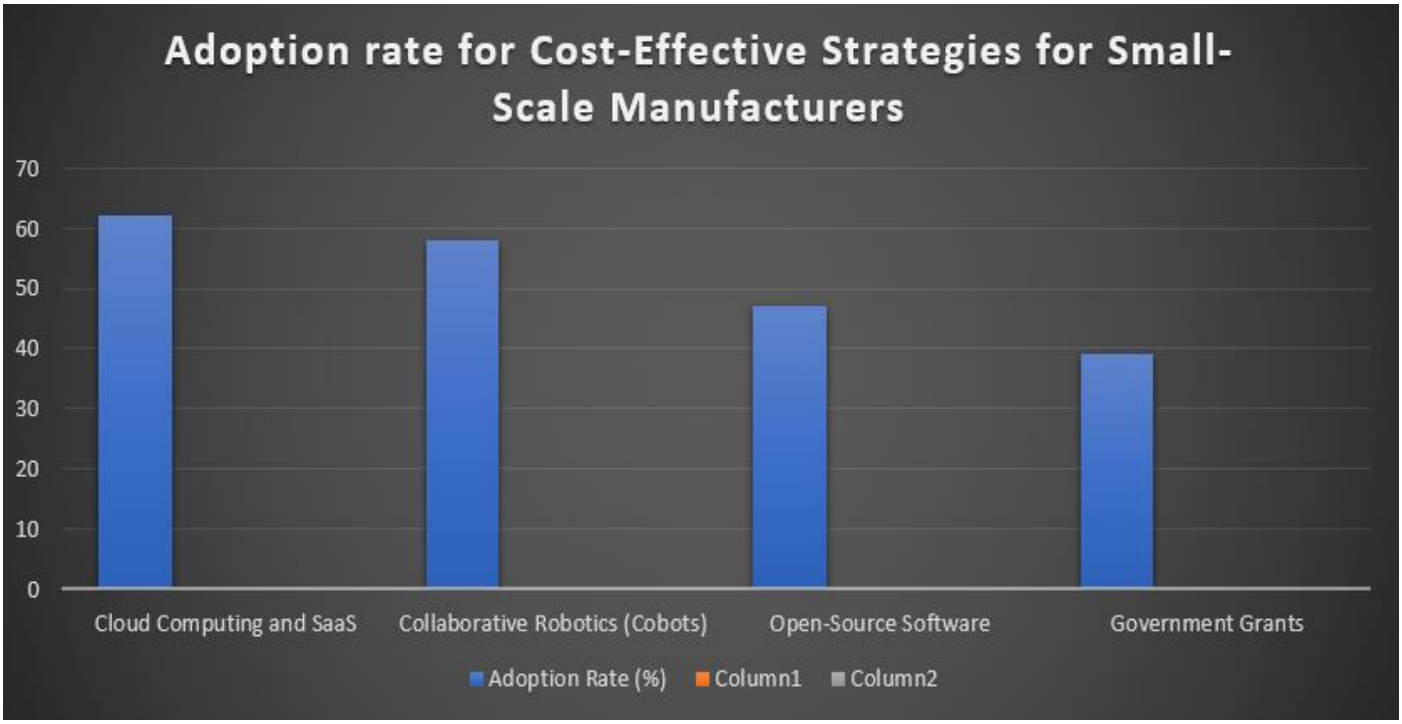

Fig 4 Adoption rate for Cost-Effective Strategies for Small-Scale Manufacturers

➢ *Implications for Small Businesses and Industry Stakeholders*

The findings of this study have several implications for small businesses and industry stakeholders:

- For Small Businesses: The utilization of Industry 4.0 solutions presents small enterprises with an opportunity to realize uppermost levels of productivity and versatility and therefore improve competitiveness. But they should ensure they focus on the paradoxes that limit technology usage by having a solution to the financial and technical challenges. This drive requires support from government, and more importantly assistance from the industrial players who can help in achieving these challenges.
- For Industry Stakeholders: Trade bodies, technology solution providers and government policy makers have an important role to engage the small enterprises for their digital journey. These strategies should include training or extending offer for programs, providing financial encouraging factors, and technical helping hand for integration of Industry 4.0 in manufacturing sector.
- For Research and Development: More research must be done to identify such effective, low-cost solutions for small fabricating manufacturers. Technology providers, therefore, should aim at developing Quick win solutions that can be implemented in small businesses piecemeal.

V. PROPOSED FRAMEWORK FOR DIGITAL TRANSFORMATION IN ELECTRICAL EQUIPMENT MANUFACTURING

Small business in the electrical equipment manufacturing sector being the target audience of this study, outlined that the proposed framework has included three components to facilitate this goal namely; Assessment of Readiness, Phased Implementation strategy and Metrics for evaluating success. This framework needs to be theoretically sound, easily implementable at the small enterprise level, and be large enough to accommodate growth as the small enterprises transition into Industry 4.0 readiness.

➢ *Assessment of Readiness*

The first key area in Industry 4.0 refers to the evaluation of the firm to evaluate its preparedness to the advanced technologies. This assessment examines the extent of readiness to change the existing structures, the present levels of the technological environment and the organizational culture. The readiness can be assessed using the following dimensions:

- Technological Infrastructure: Assess current IT supporting structures as ERP systems, MES or data connectivity applications, including SAP systems. Every kind of organization should be able to adopt the emerging technologies such as cloud computing, smart devices, or big data processing and analysis.
- Skillset and Workforce: Determine whether the skills match the number of technical skills that will be required or if training will be imminent. This requires identifying the required skills that were not previously used and which include automation, robotics, and AI.
- Leadership and Organizational Culture: Assess how much support is coming from the top management in regard to digital business transformations. For this reason, an innovation culture requires a leadership-led environment to engender change, especially where practices have to be reformed.
- Financial Readiness: Understand the finances of the business and what it will cost the firm to invest in Industry 4.0 technologies and the on-going expenses of these technologies.

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Table 4 Readiness Assessment Analysis

Criteria	Current State	Desired State	Action Plan
Technological Infrastructure	Legacy systems	IoT, AI, Cloud	Upgrade ERP, integrate IoT, cloud systems
Skillset	Basic digital tools	Advanced robotics, AI	Employee training in advanced tools
Leadership	Limited involvement	Proactive leadership	Engage top management in digital strategy
Financial Readiness	Limited budget	Dedicated funds	Allocate budget for technological upgrades

➢ *Phased Implementation Strategy*

The planned approach guarantees that development of Industry 4.0 technologies will be orderly and within reasonable measures. The process is divided into four main steps with project goals, missions and deadlines specified for each step.

- *Phase 1: Planning and Pilot*

The first stage of Industry 4.0 implementation strategy involves assessment and systematic trial of Salt smart specialization and Industry 4.0 technologies, such as automation tools or IoT sensors in a section of the value chain. The purpose is to advance the idea of increased digital uptake to trial these technologies in a controlled context to make certain that they function properly and meet the company's objectives before broader implementation.

Some of the potential activities during this phase will include; conducting a digital maturity assessment, coming up with the adoption plan after having conducted the assessment. This assessment will determine the present state of technological environments in the business and where there are flaws, which technologies would prove most rewarding. After completion of the readiness assessment to choose suitable pilot projects for implementing decentralized renewable energy. For example, the application of IoT sensors in automating inventory control or enhancing the efficiency of production lines can be the best point, as their effects can be easily quantified, and the result could be given in a form of enhanced operation efficiency.

In parallel, decisions on what right vendors and partners should be chosen for integration will also be critical. This will require considering key issues, including reliability, scalability and cost when assessing different technologies available from technology providers. Many risks that come with the adoption of new technology can also be managed through the use of experienced partners.

Among the expected deliverables of this phase will be the specific guidelines of executing the pilot project including dates, goals, and measurable benchmarks known as the KPIs. Also, the list of shortlisted vendors and the technologies to be employed will be availed as a final lineup which will guarantee the pilot necessary tools. By the end of this phase, the business will indeed be ready to move to the testing and pilot stage of the selected technologies for more widespread addition.

- *Phase 2: Scaling and Integration*

In this second phase of the 'digital transformation project,' companies seek to extend the 'best practice' pilots to the rest of the organization and/or to incorporate the pilot innovations into legacy environments. The purpose is to increase the use of Industry 4.0 technologies and to make it an integral part of the business, that will improve the performance, increase the effectiveness of decisions, etc.

One of the first sub-activities in this phase is to extend the more hierarchical approaches of automation to affect the entire production line. This could involve advancing the automation tools which were applied in the pilot area for automation from the initial stage of the production line to other sections of the production process. More often than not, the use of robots promotes better accuracy, less variability, and higher production rates across the organization – all of which are objectives of Industry 4.0. Moreover, the application of cloud data analytical tools for real-time data monitoring and decision-making will also be compulsory. They will help the business monitor its performance indicators and use the data in most of its operations, from production to distribution. Real-time data means that inefficiencies are instantly identifiable, quality problems can be quickly addressed, as can schedules; all critical factors when it comes to remaining competitive in today's fast moving manufacturing landscape.

Another activity is the utilization of robotics and artificial intelligence in quality assurance and prognostics maintenance during this phase. Robotics make it possible to have mechanisms perform intricate procedures with accuracy, whereas artificial intelligence enables interpretation of data from the manufacturing process to determine, when equipment is most likely going to fail to offer solutions to prevent failures, therefore increasing product quality. Predictive maintenance is even more effective in small businesses since the avoidance of unplanned outages and the subsequent high costs for repair are easier to envision.

The expected deliverables for this phase are as follows: The fourth Industrial revolution technologies should be implemented across production, quality assurance, and supply chain and other business units. Also, the use of systems to collect and integrate data will facilitate the collection of data from different sources in the business and also make decision making based on data collected. This integration will strengthen a coherent operation where different division uses integrated information on different aspects to enhance the operation of the entire value chain (18). At the end of this phase, the firm will achieve an ideal connected shop floor to support and enhance the manufacturing landscape through the utilization of big data.

- *Phase 3: Optimization and Continuous Improvement*

Phase 3 is dedicated to fine-tuning and sustained enhancement of digital strategies and tools and techniques. Building from the first two phases, this phase seeks to optimize operation, increase system efficiency, and sustain

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further cost improvements based on continuous digitalization. The purpose is to optimize dynamics of the value chain activities, paying attention to productivity increase, as well as the reduction of costs.

The first sub-process in this phase is continuous monitoring of the system functionality through key performance indicators. This includes assessing the efficiency of the robotic procedures, statistical and probabilistic models, and self-repairing instrumentations adopted in the antecedent stages. indice de rendement clé (KPI) like output rates, time lost, equipment productivity and quality of products produced will be measured to determine efficiency changes resulting from digital transport. Through these performance indicators, organizations are able to ascertain where potential for enhanced performance exists, and where control systems may require adjustment.

The second large activity is the organizational and administrative activity of the launch of ongoing improvement activities, which will use big data analysis and artificial intelligence to define the weaknesses at each stage of the value chain. Thus, the use of real-time data by AI provides recommendations regarding further improvement of the outcomes of all shades of production, starting with inventory and ending with control of quality. With regards to the AI algorithms, supply-demand variations can also be estimated, the production calendar can be adjusted, and problem performers can be singled out, ensuring that better decisions can still be made, improving the companies' overall operations. Furthermore, there are feedback loops which confirm that adjustments can be made quickly to meet new market concern, development in technologies and other factors which enhance continuity.

The expected deliverables in the Framework Phase 3 are: (a) Improved Work flows & (b) Enhanced Value Chain activities. This will entail improving autophony operations, eliminate delays, and coordinating all getraded improvement to make them complementary. At the same time, it will be necessary to establish a coherent continuous improvement strategy for digital systems. This plan will bear future planning methods of evaluating, modifying and expanding the formative digital systems in order to keep the company relevant and balanced towards the emergent new technological advances or tasted demands. During this phase, lots of business changes and improvements can be observed in terms of performance and cost leading to emphasis on the sustainability principle of Industry 4.0 technologies. At the end of this phase, the organization will therefore have developed positive culture for change supported by advanced digital tool to enhance its manufacturing arm for continuous growth and profitability.

- *Phase 4: Sustainability and Innovation*

The fourth part emphasizes on the successful continuation of the digital transformation process in the company while creating steady innovation culture. At this level, the primary adoption of digital solutions will already have been achieved and supported. The aim now is to retain, refine and expand the achieved outcome and developments, and seek for other technological possibilities that will keep the business going and leading.

The important activities in this phase involve 'System Maintenance and Upgrade' where organization maintains and update the digital technologies. There is always the challenge of moving with times because innovation is slowly shifting the nature of the systems in the industry. The specificity of maintenance guarantees high efficiency, protection of automatization tools, IoT systems, data analytics platforms, and other attributes of Industry 4.0. Also, replacement of old systems with new ones containing modern technologies will be a good strategy because it increases the effectiveness of available tools, their functionality and also eliminate the threats which come from using outdated technologies. Such maintenance and upgrade cycle guarantee that digital transformation projects do not become stale over time but instead grow in keeping with internal requirements as well as external advancements in technology.

Another important strategic activity is strengthening of innovation climate. More and more companies in the manufacturing industry have started adopting the digital models as a strategy for development, and the only way to seek better technology is to pursue the greater and newer forms of technology. The constant advancement of various solutions like, the use of blockchain to increase supply chain visibility and 3D printing for customized assets and just-in-time production will make certain that the business will adapt to various market requirements. For instance, blockchain remains one of the key trends to increase the effectiveness of supply chains and their protection due to the availability of secure non-tampered records of transactions since many industries are based on complex supply chains. Likewise, 3D printing could probably have the same impact to custom products and shorten the time necessary for manufacturing customized goods. Thereby employing such emergent technologies can keep organizations relevant and define new directions for future growth and diversification.

The artifacts of this phase will be an ongoing maintenance plan and a plan on the integration and update of technology. This will include description of how and when plans will be made and implemented to ensure proper upkeep and advancement of digital systems in order to make them useful and relevant. Besides, the innovation plan will be created to support the company in its search for new digital possibilities. This SW will entail evaluation of promising emerging technologies as well as their adoption potential and how this will be incorporated within the firms overall digital business transformation agenda. This, in turn, ensures that various businesses keep on progressing, evolving and growing amidst the ever-shifting technological industry.

➢ *Metrics for Evaluating Success*

Those metrics are the goals that need to be set in order to evaluate the success of the companies in digital transformation process. These metrics provide actionable insights into how digital technologies are impacting business operations, financial performance, and customer satisfaction:

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- Operational Efficiency Metrics: Are necessary in the assessment of the effectiveness or efficiency of technologies in production when there is a clear push for the actual transformation of manufacturing. One of the key indicators that can be used is the Production Efficiency that reveals the changes in output, reduction in down time, improvements in the use of resources and after the application of the concept of digital technologies like automation and IoT systems. Incorporation of real time data analysis as well as processes that involve the use of automated machinery, aims at cutting down the time most operations been stuck and standardize production. Another key KPI includes Cycle Time Reduction where progress is made on matters of cycle time in production by automating or using; predictive analytics as well as improving workflows. These technologies result in increased efficiency, allowing companies to make decisions faster and more effectively, in terms of speed as well as quality, within a production line.
- Financial Metrics: Let organizations be able to measure the return on investment on their digital assets. The Return on Investment (ROI) is something fundamental with which practitioners estimate the ratio of the benefits to be gained from the adoption of the digital solution and the cost that will be incurred in the process. Larger businesses that engage in Industry 4.0 smart technologies such as investing in robotics, artificial intelligence, and cloud networks can easily monitor ROI to the company's plan while seeking the profitability of their complete digitization strategies. Also on the financial view, the Cost Savings refers to another financial measure used to express the level of established operational cost cuts. These savings derive from the replacement of manual tasks that would otherwise require significant organizational workloads, from curtailment of waste, or from the centralization and effective supply-chain analysis of resources that can be better employed in the value chain, especially with the help of ADAS.
- Customer-Centric Metrics: They are also important for measuring impacts of digital change on the last consumer on the value chain. Customer satisfaction is one of the key performance indicators; organizational performance can assess it through the customer feedback form and NPS. Such feedback is useful in measuring the progress in quality of products sold, delivery times and customer services, issues which are impacted by digital adaptation. Last but not least, Customization Success is another metric which should be considered, especially in industries such as the electrical equipment manufacturing industry, where more and more companies implement customized products into their business strategies. Convenient technologies such as 3D printing, IoT and AI in the design help firms to provide customer solutions. Measuring the percentage of custom orders that have been completed successfully and the reception of such offerings can also be considered as the evaluation of whether or not business's capabilities of satisfying specific customer's demands are increased by the help of digital tools.

Table 5 Analysis of Metrics Dashboard for Evaluating Success

Metric	Pre-Implementation	Post-Implementation	Target Improvement
Production Efficiency	75%	90%	+15%
Cycle Time Reduction	20 hours	12 hours	-40%
ROI	N/A	150%	+150%
Customer Satisfaction	80%	90%	+10%

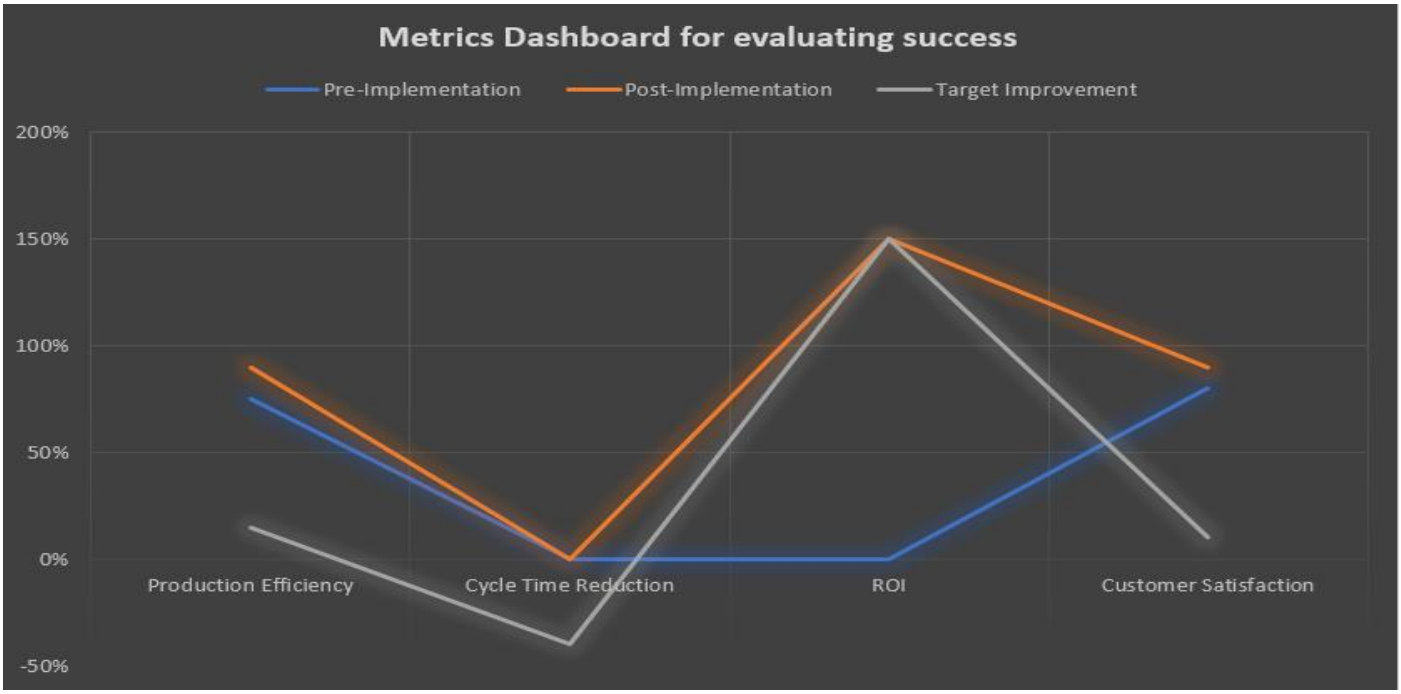

Fig 5 Metrics for Evaluating Success

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VI. CONCLUSION

This research work has sought to understand the application of digital transformation on value chain processes of small electrical equipment manufacturing firms with special emphasis on Industry 4.0. Most of the research that has been conducted in this study, a mix of qualitative and Quantitative research, have generated numerous benefits, challenges, and outcome of getting technologies like cloud computing, IoT, robotics and artificial intelligence.

From the study, the research established that companies that embraced these technologies recorded a significant improvement in operational efficiency. First, the connectivity of IoT systems and automation has provided the company with decreased production downtimes by about 20-25%. In this way, the improvement has led to the enhanced control of manufacturing output, effective utilization of the resources as well as the production flow (19). Not only have small businesses increased product output significantly, but they have benefited from significant cost savings notably in labour, waste and inventory expenses. This paper has highlighted the importance of Cloud computing in the supply chain and how it has been convenient for businesses and here they mentioned how they have been able to cut material cost by 18% at most. In addition, use of intelligent robot technologies and innovations like the additive manufacturing increases the ability of an organization in providing customer solutions customized to their needs at a faster pace while incurring minimal expenses. This is in consonant with the general shift in the manufacturing process that is well captured under Industry 4.0- agile manufacturing.

Though, while the study was being conducted, it was found that small business proprietors have a number of issues in the adoption of the system. These are high initial investment, issues of system interface, and lack of skilled personnel. In certain niches, such as retail and services, the costs could be very high to fully automate many processes for SMEs. This highlights the need for the use of compelling technology where organizations can adopt new technologies bit by bit instead of putting into use next-generation technologies that outdo their capacities. It is argued that the use of a proposed framework will be of significance owing to its potential in various stages of structured and flexible enabling of small manufacturers' digital transformation. In this way, companies cannot guess and take big risks in their transformation but approach the Industry 4.0 requirements gradually. This framework is also unique as it states that digital transformation is ongoing and does not end which pressures businesses to work on their strategies on the ongoing progress.

Sanchez and his associates have identified several directions for future research. One area of concern is the extended effects that the emerging trend of digital transformation has on small business concerns. Although this research has furnished the short-term quantitative data, another study may investigate the long-term positive impacts of the technologies after a period of not less than 5 to 10 years. It would also enable going further into understanding how firms evolve their strategies as they relate to these technologies in the long run, and the value that firms get from such technologies. One direction of future research is a comparison of the state of large manufacturers and small manufacturers to see how they have embraced technological solutions and what small firms can learn from their large counterparts. Moreover, guides suited to distinct industry domains for the implementation of Industry 4.0 would also be highly helpful. That is why despite the findings of this study are likely to be of relevance to electrical equipment manufacturing industry, other industries could have their specific problems which demand particular solutions. Last but not the least; research questioning as to how employee training forms a part of the process to efficiently adopt a certain piece of technology needs exploration. When organizations seek to adopt digital tools, we find that personnel must be effectively trained to fully harness the potential of those tools.

REFERENCES

[1]. Hokmabadi, H., et al, (2024). Business Resilience for Small and Medium Enterprises and Startups by Digital Transformation and the Role of Marketing Capabilities—A Systematic Review. *Systems, 12*(6), 220. https://doi.org/10.3390/systems12060220

[2]. Ning, L., & Yao, D. (2023). The Impact of Digital Transformation on Supply Chain Capabilities and Supply Chain Competitive Performance. *Sustainability, 15*(13), 10107. https://doi.org/10.3390/su151310107

[3]. Pihir, I., et al, (2024). *Digital Transformation In Small And Medium Sized Enterprises*. Varazdin Development and Entrepreneurship Agency (VADEA).

[4]. Qin, L., Xie, W., & Jia, P. (2024). Value Chain Digitalization, Global Value Chain Embeddedness, and Distributed Innovation in Value Chains. *Sustainability, 16*(7), 2845. https://doi.org/10.3390/su16072845

[5]. Raja Santhi, A., & Muthuswamy, P. (2023). Industry 5.0 or industry 4.0S? Introduction to industry 4.0 and a peek into the prospective industry 5.0 technologies. *International Journal on Interactive Design and Manufacturing (IJIDeM), 17*(2), 947-979. https://doi.org/10.1007/s12008-023-01217-8

[6]. Lasi, H., et al, (2014). Industry 4.0. *Business & information systems engineering*, *6*, 239-242. https://doi.org/10.1007/s12599-014-0334-4

[7]. Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *Journal of cleaner production*, *252*, 119869. https://doi.org/10.1016/j.jclepro.2019.119869

[8]. Sony, M., & Naik, S. (2020). Key ingredients for evaluating Industry 4.0 readiness for organizations: a literature review. *Benchmarking: An International Journal*, *27*(7), 2213-2232. https://doi.org/10.1108/BIJ-09-2018-0284

ISSN No:-2456-2165 https://doi.org/10.5281/zenodo.14575874

[9]. Dalenogare, L. S., et al, (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of production economics*, *204*, 383-394. https://doi.org/10.1016/j.ijpe.2018.08.019

[10]. Cañas, H., et al. (2021). Implementing industry 4.0 principles. *Computers & industrial engineering*, *158*, 107379. https://doi.org/10.1016/j.cie.2021.107379

[11]. Kraus, S., et al, (2021). Digital transformation: An overview of the current state of the art of research. *Sage Open*, *11*(3), 21582440211047576. https://doi.org/10.1177/21582440211047576

[12]. Vial, G. (2021). Understanding digital transformation: A review and a research agenda. *Managing digital transformation*, 13-66. https://www.taylorfrancis.com/chapters/edit/10.4324/9781003008637-4/understanding-digital-transformation-gregory-vial

[13]. Ebert, C., & Duarte, C. H. C. (2018). Digital transformation. *IEEE Softw.*, *35*(4), 16-21. https://www.researchgate.net/profile/Carlos-Henrique-Duarte-2/publication/326241618_Digital_Transformation/links/5b4d14f3aca27217ff9b05e4/Digital-Transformation.pdf

[14]. Schwertner, K. (2017). Digital transformation of business. *Trakia Journal of Sciences*, *15*(1), 388-393. https://pdfs.semanticscholar.org/51bb/4fd609d174438fb8911f283d48d34ef1e894.pdf/1000

[15]. Ortner, T., et al, (2024). Open strategy and digital transformation: A framework and future research agenda. *International Journal of Management Reviews*. https://doi.org/10.1111/ijmr.12379

[16]. Shabani, N., Akhtari, S., & Sowlati, T. (2013). Value chain optimization of forest biomass for bioenergy production: A review. *Renewable and Sustainable Energy Reviews*, *23*, 299-311. https://doi.org/10.1016/j.rser.2013.03.005

[17]. Tomasgard, A., et al, (2007). Optimization Models for the Natural Gas Value Chain. In: Hasle, G., Lie, KA., Quak, E. (eds) Geometric Modelling, Numerical Simulation, and Optimization. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-68783-2_16

[18]. Papageorgiou, L. G., Rotstein, G. E., & Shah, N. (2001). Strategic supply chain optimization for the pharmaceutical industries. *Industrial & engineering chemistry research*, *40*(1), 275-286. https://doi.org/10.1021/ie990870t

[19]. Garcia, D. J., & You, F. (2015). Supply chain design and optimization: Challenges and opportunities. *Computers & Chemical Engineering*, *81*, 153-170. https://doi.org/10.1016/j.compchemeng.2015.03.015

[20]. Garcia, D. J., & You, F. (2015). Supply chain design and optimization: Challenges and opportunities. *Computers & Chemical Engineering*, *81*, 153-170. https://doi.org/10.1016/j.proeng.2016.08.058

[21]. Gibb, A., & Ritchie, J. (1982). Understanding the process of starting small businesses. *European small business journal*, *1*(1), 26-45. https://doi.org/10.1177/026624268200100

[22]. Miesenbock, K. J. (1988). Small businesses and exporting: a literature review. *International Small Business Journal*, *6*(2), 42-61. https://doi.org/10.1177/026624268800600204

[23]. Baird, I. S., Lyles, M. A., & Orris, J. B. (1994). The choice of international strategies by small businesses. *Journal of small business management*, *32*, 48-48. https://www.researchgate.net/profile/Marjorie-Lyles/publication/43294810_The_Choice_of_International_Strategies_By_Small_Businesses/links/55e0678308aede0b572df401/The-Choice-of-International-Strategies-By-Small-Businesses.pdf

[24]. Jones, N., Borgman, R., & Ulusoy, E. (2015). Impact of social media on small businesses. *Journal of small business and enterprise development*, *22*(4), 611-632. https://doi.org/10.1108/JSBED-09-2013-0133

[25]. Solomon, G. T., Weaver, K. M., & Fernald Jr, L. W. (1994). A historical examination of small business management and entrepreneurship pedagogy. *Simulation & gaming*, *25*(3), 338-352. https://doi.org/10.1177/1046878194253003

[26]. Kaňovská, L. (2015). Service offering at electrical equipment manufacturers. *Trends Economics and Management*, *9*(23), 17-23. https://journals.vut.cz/index.php/trends/article/view/477

[27]. Chien, C. H., et al, (2022). Intelligent Supply Chain Management Modules Enabling Advanced Manufacturing for the Electric-Mechanical Equipment Industry. *Complexity*, *2022*(1), 8221706. https://doi.org/10.1155/2022/8221706

[28]. DAN, N. T. T., & CHUONG, N. Q. (2021). Digital Transformation in Electrical Equipment Manufacturing Enterprises. In *International Conference on Emerging Challenges: Business Transformation and Circular Economy (ICECH 2021)* (pp. 204-210). Atlantis Press. https://doi.org/10.2991/aebmr.k.211119.021

[29]. Gutowski, T., Dahmus, J., & Thiriez, A. (2006, May). Electrical energy requirements for manufacturing processes. In *13th CIRP international conference on life cycle engineering* (Vol. 31, No. 1, pp. 623-638). Leuven, Belgium. https://www.mech.kuleuven.be/lce2006/071.pdf

[30]. Malhotra, R., McLeod, E., & Alzahawi, T. (2020). Management and maintenance of electrical equipment in industrial facilities: procedures for improving safety while saving money. *IEEE Industry Applications Magazine*, *27*(1), 48-54. https://doi.org/10.1109/MIAS.2020.3024486

[31]. Yao, X., Zhou, J., Lin, Y. *et al.* Smart manufacturing based on cyber-physical systems and beyond. *J Intell Manuf* **30**, 2805–2817 (2019). https://doi.org/10.1007/s10845-017-1384-5

ISSN No:-2456-2165 https://doi.org/10.5281/zenodo.14575874

[32]. Tao, F., Qi, Q., Wang, L., & Nee, A. Y. C. (2019). Digital twins and cyber–physical systems toward smart manufacturing and industry 4.0: Correlation and comparison. *Engineering*, *5*(4), 653-661. https://doi.org/10.1016/j.eng.2019.01.014

[33]. Lee, J., Azamfar, M., Singh, J., & Siahpour, S. (2020). Integration of digital twin and deep learning in cyber-physical systems: towards smart manufacturing. *IET Collaborative Intelligent Manufacturing*, *2*(1), 34-36. https://doi.org/10.1049/iet-cim.2020.0009

[34]. Lu, Y., & Asghar, M. R. (2020). Semantic communications between distributed cyber-physical systems towards collaborative automation for smart manufacturing. *Journal of manufacturing systems*, *55*, 348-359. https://doi.org/10.1016/j.jmsy.2020.05.001

[35]. Liu, C., & Jiang, P. (2016). A cyber-physical system architecture in shop floor for intelligent manufacturing. *Procedia Cirp*, *56*, 372-377. https://doi.org/10.1016/j.procir.2016.10.059

[36]. Eslami, Y., Dassisti, M., Lezoche, M., & Panetto, H. (2019). A survey on sustainability in manufacturing organisations: dimensions and future insights. *International Journal of Production Research*, *57*(15-16), 5194-5214. https://doi.org/10.1080/00207543.2018.1544723

[37]. Gunasekaran, A., & Spalanzani, A. (2012). Sustainability of manufacturing and services: Investigations for research and applications. *International journal of production economics*, *140*(1), 35-47. https://doi.org/10.1016/j.ijpe.2011.05.011

[38]. Giret, A., Trentesaux, D., & Prabhu, V. (2015). Sustainability in manufacturing operations scheduling: A state of the art review. *Journal of Manufacturing Systems*, *37*, 126-140. https://doi.org/10.1016/j.jmsy.2015.08.002

[39]. Vacchi, M., Siligardi, C., Demaria, F., Cedillo-González, E. I., González-Sánchez, R., & Settembre-Blundo, D. (2021). Technological sustainability or sustainable technology? A multidimensional vision of sustainability in manufacturing. *Sustainability*, *13*(17), 9942. https://doi.org/10.3390/su13179942

[40]. Yacob, P., Wong, L. S., & Khor, S. C. (2019). An empirical investigation of green initiatives and environmental sustainability for manufacturing SMEs. *Journal of Manufacturing Technology Management*, *30*(1), 2-25. https://doi.org/10.1108/JMTM-08-2017-0153