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IoT-Based Industrial Automation for Small and Medium Enterprises in Pakistan

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ABSTRACT:

The adoption of Internet of Things (IoT) based industrial automation futurizing manufacturing processes all over the world, improving productivity, operational costs and quality control. In Pakistan, Small and Medium Enterprises (SMEs) is an important segment in the country's economic growth and jobs and many of them are struggling due to inefficiency in the working of enterprises, technology related problems, lack of digital adaptation of the enterprise. This investigation is about discussing the potentials of IoT driven automation in Pakistani SMEs by emphasizing on production optimization, predictive maintenance and data driven decision making. The research speculates the current trends in adoption and technological infrastructure and barriers like financial constraint, technical expertise and cybersecurity risks. Findings highlight that implementation of IoT can make a significant difference in boosting competitiveness of SMEs, but at the same time identifies key challenges and strategies for successful IoT adoption. The study shows the importance of policy levels, trainings and investments on digital infrastructure to have a massive impact on industrial automation in the SME sector of Pakistan.

Keywords: IoT, Industrial Automation, Small and Medium Enterprises Penetration, Pakistan, Smart Manufacturing, Predictive Maintenance, Productivity Improving, Digital Transformation, Industry 4.0, Operation Efficiency.

INTRODUCTION:

Small and Medium Enterprises (SMEs) is a very important foundation of Pakistan's economy and about thirty percent of the economy's GDP and eighty percent of the industrial workforce (Khan & Ali, 2021). These enterprises are spread across various sectors including textiles and agro-processing, automotive components and electronics and are instrumental for providing the pressing goods and services as well as promoting entrepreneurship. Despite their economic significance, many SMEs in Pakistan are being faced by challenges such as poor production efficiency, use of outdated machinery, low adoption of digital technologies and limited access to financial resources (Ahmed & Rehman, 2020). Globally, the industry sector has undergone a significant, profound change with the fusion of the digital technologies especially the Internet of Things (IoT) which has enabled automation, monitoring of activities in real time and decision-making based on collected and analyzed data (Li et al., 2020). For SMEs, IoT is

strategically regarded as an opportunity for increasing operational efficiency and saving costs and competitiveness both at the domestic and international markets (Raza et al., 2021).

The Internet of Things, as a network of connected devices that can collect, transmit, and analyze data has become one of the pillars of the Industry 4.0 and smart manufacturing (Gubbi et al., 2013). In industrial setting, IoT promotes predictive maintenance, process optimization, quality monitoring and effective supply chain management (Lee, Bagheri, & Kao, 2018; Zhou, Liu, & Zhou, 2019). Predictive maintenance system: Predictive maintenance systems are responsible for the performance of the equipment to be monitored in real time, which helps to reduce downtime and ensures a longer lifespan for assets. IoT-based process optimization: IoT can ensure the production lines are running at the maximum level, reducing waste, optimizing the resources, which helps in increasing the overall productivity. Similarly IoT enabled quality management systems track the parameters of production and pinpoint anomalies in production ensuring uniformity of standards of products. By providing a comprehensive data analytics capability IoT is beneficial in terms of enabling managers to make informed decisions about their operations and strategic planning that is pivotal for SMEs business that tend to have limited management resources to manage their business in a large-scale manner (Wang, Torngren, & Onori, 2020).

Despite the obvious advantages, the application of IoT-based automation for Pakistani SMEs is small. Financial constraints is a major constraint, since many SMEs cannot afford to acquire the initial costs of IoT devices and sensors and integration platforms (Ahmed & Rehman, 2020). Technical expertise is another key challenge; as majority of SMEs do not have employees, who are trained in the field of implementing IoT, data analytics, and maintaining it (Khan & Ali 2021). Additionally, infrastructural limitations, such as inconsistent supply of electricity, low-speed internet connectivity, and inadequate cloud computing facilities, affects the wide adoption (Raza et al., 2021). Cybersecurity issues also remain a deterrent to SMEs from the prospective of adopting IoT, with the fear of data breaches and lack of protection frameworks, it leads to uncertainty in the process of actualizing the adoption of digitalization (Hussain & Shah 2022). Nonetheless, there are some early adopters in the textile and agro-processing industry in Pakistan who have demonstrated that even low volume convergence of IoT, e.g. sensor-based tracking of temperature or inventory, can deliver improvement, both in terms of efficiency and operational management, measurably.

The strategic relevance of AoIoT adoption is not limited to operational efficiency, as the panel concludes it also extends to competitiveness, as well as sustainability in the market. Automated systems help SMEs to respond quicker to the market demands, improve the quality of the product, allocate the proper resources and reduce the errors in the operation (Lee et al, 2018;Zhou et al. 2019). Through the use of IoT data, SMEs will be able to make proactive decisions that will result in reduced downtime, increased customer satisfaction, and higher profitability. International examples from India and China point out that with the IoT technologies, the SMEs gain productivity, higher export potential and resilient response capacity against the market fluctuation (Wang et al., 2020). For Pakistan, whose small and medium enterprises industries are significant contributors to job creation and industrial production, automation for IoT to undergo an IoT-based path could help overcome the gap in productivity vis-a-vis large companies and help the development of the economy.

Although the prospect of IoT is visible, the successful implication of the use of this technology in Pakistan's SMEs needs to be addressed through a multi-dimensional approach which encompasses financial challenges, technical challenges and infrastructural challenges. Government support: Commercial banking, through low interest loans, subsidies & policy frameworks to spur digital adoption to mitigate the financial barriers. Training programs and capacity building exercises have to be done in order to prepare the SME personnel with necessary technical skills. Additionally, while the right sort of human provide for a safe and decent manner of life. Few research work have been performed in this area, particularly those are directed towards the small scale industries and specifically the problems of Pakistani SME. Existing literature is among larger industrial enterprises and leaves

huge void in understanding how feasible, what are the barriers and how IoT-driven automation impacts on smaller firms (Raza et al., 2021).

This study intends to overcome this gap by assessing potential and challenges of industrial automation on the basis of IoT in the Pakistani SMEs. It investigates how automation can positively or negatively affect productivity and thereby reduce the costs of operations, and provides assistance in building data-driven decision-making processes, and identifies some of the key challenges to automation adoption. The results are aimed at providing some insights for the SME owners, the policymakers and the stakeholders in the industry, to encourage the strategic integration of the IoT to help in the business of competition, resilient and long-term growth. By focusing on the practical uses and the implementation methods, the research is useful in exploitation of a sophisticated and conscious insight on how the technologies of the Industry 4.0 can be modified for the unique condition of Pakistan's SMEs to ensure that the transformation of the digital revolution is accessible, sustainable, fruitful.

LITERATURE REVIEW:

Internet of Things (IoT) technologies adoption in industrial automation have been widely acknowledged as a transformative development in the manufacturing industry, allowing for improved operational efficiency, predictive maintenance and data-driven decision-making (Li et al., 2020). Globally the integration of IoT in small and medium enterprises (SMEs) has had visible outcomes in productivity, cost reduction and quality control (Lee, Bagheri, & Kao, 2018). In the context of developing economies, factors such as technological infrastructure, financial capacity, workforce expertise and policy frameworks can play an important role in the adoption of IoT. Studies in India and China point to the existence of SMEs whose use of IoT for purposes of automation gains not only operational efficiency, but also impact market competitiveness as well as export - for example; important work highlighting the critical role of digital transformation in closing the productivity gap among small and large achievements (Wang, Tornngren, & Onori, 2020).

Research on IoT adoption in Pakistan however is just emerging. Ahmed and Rehman (2020) enumerates financial constraints and lack of access to technology as some of the major challenges for SMEs, which tend to rely on outmoded machinery and manual processes. These limitations cause advanced automation systems to be a more difficult task to implement, and limit the potential benefits previously mentioned through the implementation of advanced Industry 4.0 technologies. In addition, technical expertise is a major factor in successful integration of IoT. Khan and Ali (2021) mention that many SME owners do not have trained personnel to deal with IoT-enabled systems whereas Hussain and Shah (2022) highlight the shortage of skilled engineers familiar with IoT networks, sensor technologies and data analytics. This is a skill gap that is creating a barrier not only to implementation, but to long-term sustainability and maintenance of automated systems as well.

Several studies have been put forward for the practical applications of IoT in the industrial world. Raza, Malik and Tariq (2021) demonstrate that IoT based predictive maintenance can reduce the downtime by predicting the equipment failures even before they happen that's an advantages for SME since the unplanned downtime can do great disruptions to the business. IoT systems also enable the optimization process through monitoring of the production lines in real-time, reducing waste, and improving energy efficiency (Zhou, Liu, & Zhou, 2019). In addition, IoT allows visibility in supply chains by allowing firms to track raw materials, inventories and distribution of products and essential for enabling SMEs who conduct market in a competitive market and with very limited resources (Wang, Tornngren, & Onori, 2020). Quality control is another large area where IoT makes a large contribution, as automated monitoring and the detection of anomalies help to ensure the consistent quality of products, which better customer satisfaction and few returns or losses.

Despite all this and even though the IoT delivery is limited in the SME companies of Pakistan. For one, empirical evidence exists which proves that there are both financial and infrastructural challenges that are experienced by SMEs. Ahmed and Rehman (2020) show that high initial investment costs incurred on IoT devices, sensors and integration platforms is a deterrent on many SME owners. Infrastructural limitations such as unreliable electricity supply, poor-speed internet connectivity and poor availability

of cloud computing resource is further limiting the adoption (Raza et al., 2021). Cybersecurity concerns also play a big role as SMEs do not always have the right frameworks to protect sensitive data of their operations from cyber threats (Hussain & Shah, 2022). Consequently, even though small-scale implementation of IoT (i.e., sensor-based monitoring systems) has shown to be positive in some Pakistani SMEs, large scale adoption of industrial automation remains a rarity.

Various theoretical frameworks have been utilized to explain the topic of technology adoption in the context of SMEs. The Technology-Organization-Environment (TOE) model suggests that the choice to adopt or not a technology depends on the combined impact of the technological readiness, organizational resources and environmental situation (Tornatzky and Fleischer, 1990). Applying this framework to the Pakistani SMEs brings to a spotlight interplay of internal constraints i.e. technical expertise and capital limitations in conjunction with external elements such as policy incentive, market competition, availability of digital infrastructure etc. The Diffusion of Innovation (DOI) theory also makes certain suggestions regarding the pattern of adoption and emphasizes the importance of perceived benefits, compatibility with existing processes and trialability in driving acceptance of IoT technologies among SMEs (Rogers, 2003). Both of the frameworks emphasize the need for an enabling ecosystem with components including government support, training and access to technology to enable IoT integration in SMEs.

Recent researches show that for SMEs of Pakistan, the most feasible adoption strategies may be incremental in nature. Instead of going the whole mile towards achieving complete automation, SMEs can begin to implement IoT projects with pilot projects focusing on more critical functions such as predictive maintenance, inventory management, or energy monitoring (Raza et al. 2021). These smaller-size interventions not only have tangible benefits, they are also building the growth of the organizational capacity and confidence for large-scale IoT integration. Additionally, in collaboration with technology providers, universities and industry associations can provide technical assistance as well as help reduce costs of implementation, providing a further element of viability for adoption.

In conclusion, literature highlights that IoT based industrial automation has the potential of positively impacting the Pakistani industries by bringing in improvements in efficiency to lower operational costs and enable decision making based on data. However, adoption is still limited by financial, technical and infrastructural constraints. Strategies to overcome these barriers that depend on incremental implementation, capacity building and supportive policy frameworks are key. While lessons can be learned from around the world, further efforts in Pakistani industrial context would be very crucial in coming up with appropriate solutions for best utilising the benefits of IoT for SME's.

METHODOLOGY:

This study employs mixed method research design wherein an analysis of quantitative data is combined with qualitative understanding so as to determine adopting and the impact of IoT based industrial automation in SMGs of Pakistan. The research attempts to understand the current trends in implementation, the improvement of operational efficiency, to identify the barriers of adoption and how the IoT integration may be enabled. The research is concerned with the practical function, data-driven decision-making, as well as the role of organizational and infrastructural factors in the use of technology.

The limiting the study population to the SMEs of the important industrial sector of Pakistan, such as textiles, agro-processing, electronics and automotive components. A technique of purposive sampling was adapted in order to select 50 SMEs where either partial IoT solutions were implemented, or have the intention of adopting automation. The selection criterion ensured that firms of different sizes, production capacities and technological readiness to be included would be obtained to obtain an overall picture of the adoption patterns and problems.

Data collection was done through three main sources. First, structured surveys were distributed amongst SME managers and technical staff in order to gather quantitative data on current production processes,

levels of automation, use of IoT devices, operation efficiency measures, perceived barriers etc. The survey included questions concerning production volume, frequency of downtimes, cost savings, energy usage and employee skills. Second, I have done semi-structured interviews with 15 different experts, including Ludhe engineers, industry consultants, and representatives of technology providers, to obtain qualitative inputs on challenges of implementation, technical considerations, cyber security issues, and best practices, for decision making on the implementation of IoT. Third, secondary information was obtained from government reporting, industry reporting and research studies previously done on the topic to put findings in context and provide a comparison of the adoption trends with widespread practices found globally.

Quantitative data collected from survey were analysed by using descriptive and inferential statistical techniques. Production efficiency, reduction of downtime, and cost saving with the aid of IoT was summarized in descriptive statistics. Inferential statistics (correlation and regression analysis) were used to examine the relationship between IoT adoption levels and IoT operation performance indicators. Qualitative interview data was analyzed with the use of thematic analysis in order to capture recurring patterns, challenges and strategies for successful IoT integration. The results from qualitative and quantitative analyses were handled through triangulation to obtain the reliability of results as well as holistic understanding of IoT adoption in SMEs.

In order to have validity and reliability, pre-tested set of questionnaires were used in the study, and standard instruments of data collection were used. Survey questions have been reviewed by rising industry experts for spare and clarity and interviews were performed based on structured protocol so that consistency is preserved. Quantitative data were cross-validated with secondary sources and qualitative responses were compared between participants in order to check for common themes. Ethical considerations that were found throughout the research process include informed consent from all participants, confidentiality of organizational data, and responsible reporting of research findings.

The methodology allows to carryout holistic assessment on IoT-based industrial automation use at the Pakistani SMEs with both quantitative effect on productivity and operating efficiency; and qualitative obstacles on adoption. By combining quantitative and qualitative approach, the research has helped in identifying actional approaches which can be highlighted by the SME owners, policymakers & technology solution provider looking for promoting digital transformation in Pakistan's industrial sector.

DATA ANALYSIS AND FINDINGS:

This research was conducted on dataset collected from 50 SMEs that are involved in the texts, agro-processing, electronics and automotive components industries to assess the adoption and impact of IoT based industrial automation. Survey results of the quantitative research have been complemented by qualitative analysis from interviews in which 15 industry experts and technology consultants were asked. The dimensions that were considered in the analysis were three: IoT adoption levels, operational performance improvements and barriers to implementation.

Survey results show that still only 28% of SMEs have implemented some form of IoT-enabled automation, if only in sensor based monitoring of machinery, inventory tracking or a sensor for measuring energy consumption. Among the ones that adopted the technology, the average increase in reducing unplanned downtime was around 22% while the improvements in operational efficiency varied between 15-25% depending on the complexity in integrating IoT. Table 1 provides an overview of the patterns of adoption and impacts on the operations observed across different SME sectors.

Table 1:

Sector	Number of SMEs	IoT Adoption (%)	Avg. Downtime Reduction (%)	Avg. Efficiency Gain (%)	Notes
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Textiles	15	33	24	20	Mostly sensor-based monitoring
Agro-Processing	10	20	18	16	Limited automation use
Electronics	12	25	21	22	Inventory and process control
Automotive Components	13	31	23	25	Predictive maintenance focus

According to the analysis conducted, automotive component SMEs experienced the highest efficiency increase with the use of more sophisticated applications of IoT, such as predictive maintenance and real-time process monitoring. Textiles and electronics industries got better at a moderate pace, while the agro-processing industry, which is more labor-intensive and less amenable to automation, made little progress.

Featured below in interviews and industry establishments described that SMEs that adopted IoT reported improved decision making capabilities, better resource allocation and improved energy management. Real-time monitoring allowed the managers to spot anomalies in real-time, minimizing waste of materials and maximizing production schedules. Experts underlined the fact that even integration in IoT on small scales, i.e., in the form of a temperature sensor in textile machinery or automatic inventory tracking in electronics related set ups was reaping measurable benefits in terms of its operation.

Despite these gains however, there are some worrying barriers to IoT adoption as well as a shortage of sensors are identified in this study. Financial constraints were cited by 84% of the SMEs surveyed suggesting that the up-front investment costs of purchasing the IoT devices, the cloud infrastructure and the system integration is still prohibitive. Technical expertise limitations: 72% of SMEs faced limitations in technical expertise with managers saying that they do not have the trained personnel to operate, maintain and analyze IoT systems. Issues with infrastructure such as scattered electricity supply and slow internet baby card increased to 65% of people and 23% of them have issues regarding cybersecurity threats and protecting data. Table 2 summarises the perceived barriers of the SMEs surveyed.

Table 2:

Barrier	SMEs Reporting (%)	Key Observations
Financial constraints	84	High cost of devices, sensors, and software
Technical expertise	72	Lack of trained personnel for implementation and maintenance
Infrastructure limitations	65	Unstable electricity, poor internet connectivity
Cybersecurity concerns	58	Fear of data breaches, lack of protective measures
Awareness/knowledge	46	Limited understanding of IoT benefits and applications

Regression analysis revealed that there is a significant positive relationship between use of IoT and operational efficiency ($b = 0.62$, $p < 0.01$), this finding showed that higher the level of automation, higher was the increase in productivity. Similarly, predictive maintenance adoption was also seen to have strong negative correlation with frequency of downtime ($r = -0.59$, $p < 0.01$), which confirms that the SME's that have adopted IoT-enabled maintenance suffered less unplanned disruptions.

Qualitative feedback for Importance of incremental implementation SMEs which did pilot IoT projects -with one process or machine in mind - felt more confident and less risky than those trying to do full-

scale automation. Experts suggested that it could be achieved through collaborations with technology providers, universities and industry associations, in order to reduce costs as well as assist in providing technical support and accelerate knowledge transfer. Several SMEs said that they would plan to increase the adoption of IoT in the next 2-3 years, depending on access to financial support and training programmes.

The results of the analysis also provided sector specific variations also. Textile SMEs benefited mostly from quality monitoring and energy management while electronics SMEs benefited from improved inventory and processes track and automotive component SMEs even benefited from those predictive maintenance to reduce downtime. Agro-processing SMEs usually work in resource poor countries and they had the highest adoption challenges this speaks volumes of the need for targeted financial and technical assistance.

In summary, the results prove that IoT based industrial automation plays a significant role for improvement of industrial automation, reduction of downtime and decision making based on data in Pakistani SMEs. However, it is hampered by financial, technical as well as infrastructural cybersecurity challenges by the wide adoption. Incremental adoption approaches aided by training, financial incentives and collaborative partnerships are proving to be the best bet on how SMEs can harness the fruits of IoT technologies. These insights provide a base for policy makers and SME owners and providers to formulate specific interventions to promote digital transformation and integration of Industry 4.0 in the SME sector in Pakistan.

CONCLUSION:

IoT based industrial automation has proved immense potential in aiding Pakistani SMEs in becoming more productive, operational efficient and instinctive towards their decision-making process. The study shows that, despite its limited, the use of IoT technology by their business by SMEs has demonstrated measurable benefits, such as a reduction in the downtime of production processes, improved production processes and improved resource management. Automotive and Electronics industries are getting more served by predictive maintenance and real-time process monitoring. Textiles and agro-processing SMEs get moderate benefits from sensor quality/inventory monitoring.

Despite these advantages, the adoption of IoT in Pakistani SMEs are limited by the factors such as financial constraints, technical expertise, infrastructural problems and cybersecurity issues. The research points to incremental approaches to adoption strategies, pilot projects and partnerships with technology providers and academic institutions as a critical part of successful implementation. Overall, IoT based automation gives strategic SME opportunity to enhance competitiveness, operational resilience and be compliant to global Industry 4.0 standards.

RECOMMENDATIONS:

1. Policy and Financial Support

- Provide **low-interest loans, subsidies, and incentives** for SMEs adopting IoT technologies.
- Develop policies to promote **digital transformation and Industry 4.0 adoption** in SMEs.

2. Capacity Building and Training

- Implement **training programs for technical staff** to manage IoT systems and data analytics.
- Facilitate knowledge transfer through **collaborations with universities, industry associations, and technology providers**.

3. Incremental Implementation Strategies

- Encourage SMEs to adopt **pilot IoT projects** in critical processes before full-scale integration.

- Focus on **high-impact areas** such as predictive maintenance, quality monitoring, and energy optimization.
4. **Infrastructure Development**
 - Improve **internet connectivity, electricity reliability, and cloud computing access** for industrial zones.
 - Ensure secure and scalable IoT networks to support growing adoption.
 5. **Cybersecurity Measures**
 - Establish **guidelines and support for data protection and cyber threat prevention** in SMEs.
 - Promote awareness about **cybersecurity risks and best practices** among SME owners and employees.
 6. **Monitoring and Evaluation**
 - Regularly assess the impact of IoT adoption on operational performance and efficiency.
 - Document lessons learned and best practices to guide other SMEs in digital transformation.

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