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Robotics-Assisted Automation for Manufacturing Sector Efficiency

Saba Syed[1]

[1]PMAS Arid Agricultural University, Rawalpindi
Email: sabasyedsag@gmail.com

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Author:
sabasyedsag@gmail.com

ABSTRACT

Robotics assisted automation has become one among the most important strategies in the manufacturing industries for bettering the overall operational efficiency as well as reducing the cost of production and aiding in improving the quality of products. This paper analyses the effect of robotics assisted systems on the manufacturing processes as the robot systems help in doing the repetitive processes and errors are minimized and the process is optimized. From the qualitative and quantitative data gathered from multiple manufacturing units, this research identifies important factors related to successful implementation: technological infrastructure, adaptation at the workforce level, and economic viability. Strategic adoption is proposed to not only improve productivity but also introduce sustainable practices in the sector. The insights provided will enable industry stakeholders to take advantage of the potential of automation to maintain their competitive edge as the environment in industry continues to evolve.

Introduction

For a long time manufacturing sector has been accepted as one of the prime contributors to the development of both the economy and the industries. From its traditional reliance on human labour and mechanical procedure to the manufacturing process to build most times the modern manufacturing has experienced a strategic change by the adoption of advanced technology and automation assisted by robots has emerged as a critical enabler of operational efficiency for the manufacturing industry (Groover, 2020). Robotics assisted automation combines programmable machines and intelligent systems into production lines and therefore helps to perform tasks that are repetitive, hazardous or require high precision. Such systems will help address critical issues the manufacturing industry is facing in the form of labor shortage, increase in demand for customization of products, and the need for increased production speed with consistency (Bogue, 2018).

Robotics adoption is not merely a passing fad but an appropriate strategic response to perceived world market competition stresses. Firms are also gradually recognizing automation can be beneficial to them in reducing operation expenses and adequate allocation of resources to stay competitive in a swift changing industrial environment (Kamble et al. 2019). Robot assisted systems have higher productivity because task execution time is faster and more accurate than a manual operator, thus reducing faults and having uniform quality standards. In addition, human resources are free because of the automation that must carry out more value-added activities such as process optimization, quality management, and innovation, leading to a more competent and efficient workforce (Lu, 2017).

A major benefit of robotics-assisted automation is the ability to take on complex and dangerous operations that may pose a risk to human workers. Robots are widely applied in industries such as automotive industries, electronics, and chemical production mostly for heavy lifting of components, precision assembly, or working in extreme temperature or toxic substances (Fiorini & Bicchi, 2018). This not only adds to safety, but also contributes to operational reliability because an automated system can also keep working without getting tired. Advancement in the field has also seen the introduction of collaborative robotics or "cobots", to enable both human and machine to work synergistically to perform a task using the power of human dexterity and robot precision (Huang et al., 2020).

The advances in the field of artificial intelligence, machine learning and sensors technologies have fueled the evolution of robotics-assisted automation. Intelligent robots, which are capable of monitoring processes in real time and identifying defects, are able to make autonomous decisions in order to optimize their performance (Roldan et al., 2021). Such smart automation systems are a realization of the vision of Industry 4.0, which involves a totally integrated manufacturing environment, in which cyber-physical systems interact seamlessly in the spirit of greater productivity and sustainability (Lasi et al., 2014). In such case, the robotics assisted automation will play a major role in real-time data analytics, predictive maintenance and adaptive production strategies.

Despite many opportunities that arise from the use of robotics in automation, there are hindrances to complete diffusion of this technology in manufacturing: high initial investment costs, integration complexities, and workforce adaptation barriers are regarded as the key determinants impeding diffusion (Siciliano and Khatib, 2016). Organizations need to be very careful with planning with respect to the return on investment to be attained, identification of suitable robotic solutions, and training of employees to work with automated systems. These are among others social considerations which have to be tempered through effective change management and policy interventions against resistance to change and fear of job displacement (Bessen, 2019).

From empirical literature, it has been found that firms with robotics assisted automation observed measurable improvements in areas of production efficiency, throughput, and quality control. For instance, there is some evidence that automotive and electronics manufacturing units whose operations also involve robotic systems have greatly curtailed their cycle time, lower defect rates, and even guarantee more operations flexibility (Kraemer et al. 2018). Furthermore, robotics assisted automation can also be linked to competitiveness in the international market, as companies are now able to respond faster to diversified consumer demand and provide better quality products at lower prices (Peshin et al., 2020). The other important dimension of sustainability is where robotics-assisted automation also plays a positive role. It makes it possible to optimize the use of energy, reduced material wastage, and manufacturing eco-friendly products (Wang et al., 2019). With robotics as part of the smart manufacturing strategies, it would help organizations to minimize the environmental footprint while at the same time, it has continued to maintain high standards of productivity. This is in line with leading industrial trends around the world which put not only economic performance, but also environmental responsibility and social welfare at the heart of their operations.

In the end, robotics-assisted automation has come to define a whole new paradigm in manufacturing industries with great promises in efficiency, safety, quality and even sustainability. Its assimilation in the manufacturing mainstream has been a result of rapid technological change, compelling economic imperatives and strategic requirements (competitive edge). While there are challenges with regard to cost, workforce adaptation and integration of systems, the potential benefits greatly outweigh limitations in a thoughtful implementation. This research, therefore, aims at investigating the impact of robotics-assisted automation in manufacturing efficiency, concentrating on operational outcomes, implications for workforce and technological enablers that will provide an all-rounded understanding of how manufacturing automation is changing the modern industrial landscape.

Literature Review

Robotics assisted automation has come in the front and center in the transformation of modern industrial production as a result of a growing level of complexity in the manufacturing process and an upward spike in demands for efficiency and quality. The integration of robotic systems within production environments with a view to exploring both the technological advancements and the operational advantages that come with automation have inspired scholars and industry experts in the last few decades. Robotics assisted automation is the use of programme machines and sensors together along with intelligent control systems to perform repetitive and/or high precision or hazardous tasks that can barely be performed by humans. This reduces the amount of human intervention and provides greater levels of accuracy and consistency.

Early studies have been concerned with the potential of robotics to improve productivity by lowering the cost of production. For example, Siciliano and Khatib (2016) stated that industrial robots allow manufacturers to standardize operations, eliminating human error, and guaranteed high levels of throughput. Indeed, this view has received empirical evidence that the introduction of robots in assembly lines reduces significantly the cycle time and the rate of defects in the automotive and electronic industries (Kraemer, Linden, & Wiedenhofer, 2018). For example, Lu (2017) discussed the usefulness of robotics-assisted systems providing flexibility for production and this includes complex and customized tasks, and this is a critical requirement in today's highly competitive markets.

Recent publications have placed emphasis on their integration as part of Industry 4.0, which is characterized by cyber physical systems, IoTs and data-driven decision making. As indicated by Lasi et al. (2014), in this realm, the robotic assisted automation is not simply beyond the normal sense of executing the mechanical tasks and consequently follows the intelligent decision support, predictive-maintenance and real-time optimization of process. Roldan, Ruiz, & Velasco, (2021) also agreed with this assertion. Sensor-integrated and machine learning-enabled smart robots are capable of adapting on variations in the production needs autonomously, and performing anomaly detection and optimising the performance autonomously in a responsive and resilient manufacturing environment. Huang, Li, & Wang (2020) confirm this. Therefore, these modifications are a departure from traditional point-to-point automeum to smart human-machine collaboration.

Another important element is workforce dynamics which have been discussed in the literature. The early introduction of robotics was considered to have raised fears of replacing jobs, but research from the last few years is showing a different type of impact. According to Bessen (2019), automation more frequently complements human work than it replaces it entirely; particularly in addressing tasks requiring problem-solving, supervision, and needing innovation. This approach is best represented by the so called "cobots", that is, collaborative robots and they allow for the sharing of tasks between humans and machines, combining human dexterity, decision making, with robotic precision and endurance. As it was noted by Huang et al. (2020), this model guarantees not only an increase in the operational efficiency but also workforce upskilling which creates a more adaptive and capable labour force.

Literature also alludes to the economic utility of robotics assisted automation. Kamble et al. 2019 conducted an analysis of barriers and drivers for the adoption of automation and discovered that manufacturing firms are faced with high initial investment costs, integration of technology and organizational readiness. However, in most cases, the long-term benefits that are associated with greater in productivity, decreased cost of labour, and higher quality products outweigh the initial costs (Peshin, Singh, & Sethi, 2020). Firms which are able to strategically implement robotic systems can benefit from being able to provide the domestic and international competitive markets with consistencies in their products and a higher product quality with greater flexibility in their operation.

Besides, sustainability has also emerged as a new dimension of interest both in literature on robotics-assisted manufacturing. Automated systems provide a factory very close control of energy consumption, material waste and is possible for environmentally friendly manufacturing (Wang, Torngren, & Onori, 2019). In addition, robots would allow optimum utilization of raw materials and keep consumptions at the lowest level; this could be further dealt with by intelligent controlling to be energy-efficient. It is in the line with the global industrial trends where there is an importance of green manufacturing therefore apart from efficiency, robotics assisted automation contributes towards the goals of sustainable development.

However, to make robotics-assisted automation a fully implemented practice, there are still various issues. Common challenges that arise in the literature are linked with integration complexities, risks related to cybersecurity and the need for continuous maintenance and technical support (Siciliano & Khatib, 2016; Roldan et al., 2021). Besides, implementation requires structured change management strategies to ensure proper implementation for organizations; identifies concerns of the workforce and makes sure that adequate training is provided to close the gap in skills between the work and automated system requirements (Bogue, 2018). The common thread from most literature is that automation leveraging robotics promises enormous transformational opportunities that can only be successful through judicious planning, technological preparedness and organizational adaptiveness.

In short, the body of research about robotics assisted automation in manufacturing brings into the spotlight a multi-dimensional set of benefits including achievements in productivity, quality of output, collaboration of the workforce, economic competitiveness and sustainability. The progress made in robotics, AI, and Industry 4.0 frameworks has increased the scope of automation from simple, mechanical tasks, to smart, adaptive systems that add a significant contribution to operational efficiency. Simultaneously, aspects associated with integration, expensive and adaptable workforce requires the strategic implementation methods. The current literature review constitutes a background for experimentation on testing the practical impacts of robotics assisted automation with manufacturing sector efficiency and paves the way for empirical research into its effectiveness within the modern industrial context.

Methodology

The quantitative nature of this study is to present the influence which robotics assisted automation has in efficiency of manufacturing industry from Karachi. A quantitative approach would be suitable for this study, considering it will decide the statistical measurement and analyses of relationships between the implementation of automation andOperational efficiency indicators such as productivity as well as quality of production and process optimization (Creswell and Creswell, 2018). The research concentrates on gathering the primary data obtained from a sample of firms which comes under the category of manufacturing but have already implemented or are about to implement the robotics aid in the use of robotics.

Population and Sample

The targeted population includes manufacturing units located in Karachi belonging to different industries such as Automotive, Electronics and Consumer goods. The above based was estimated to the sample size of 150 respondents which were selected using purposive sampling techniques. Such a sampling method will ensure that the respondents are directly involved or well informed about the implementation and operational effect of robotics assisted automation like production managers, engineers and supervisors (Etikan, Musa, & Alkassim, 2016).

Data Collection Instrument

The survey instrument was a structured questionnaire comprising of three major parts. The first part gathered demographic information regarding the respondents and their company: company size, type of industry and years of experience with automation. The second segment assessed the intensity of the robotics uptake, the types of tasks being automated as well as the level of system integration. The third part was an evaluation of perceived impacts on operational efficiency caused by robotics-assisted automation in terms of enhancements in productivity, reductions in error, saving costs, and employee adaptation. Responses were measured on a 5-point Likert-scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Data Analysis Techniques

Collected data were analyzed by using descriptive and inferential statistics. Descriptive statistics were employed to summarize demographic information of respondents, and perceptions on robotics assisted automation such as frequencies, percentages, mean, and standard deviation. In the case of inferential analysis, the correlation analysis was done in order to explore the association of the level of automation adoption and operational efficiency outcomes. Besides, regression analysis was conducted in an attempt to analyze the predictive impact of robotics facilitated automation on the general manufacturing efficiency. The software package that was used for the statistical analyses was version 26 of the software named (SPSS) which ensure reliability and validity by the use of Cronbach alpha analysis and factor analysis of the survey instrument.

Sample Demographic Table

Demographic Variable	Category	Frequency (n=150)	Percentage (%)
Gender	**Male**	**110**	**73.3**
	Female	**40**	**26.7**
Age Group	**20–30**	**35**	**23.3**
	31–40	**60**	**40.0**
	51+	**15**	**10.0**
Position in Organization	**Manager**	**50**	**33.3**

	Engineer	**70**	**46.7**
	Supervisor	**30**	**20.0**
Industry Sector	**Automotive**	**50**	**33.3**
	Electronics	**45**	**30.0**
	Consumer Goods	**55**	**36.7**
Experience with Automation (Years)	**0–2**	**40**	**26.7**
	3–5	**60**	**40.0**
	6–10	**35**	**23.3**
	10+	**15**	**10.0**

Primary Data Analysis

The descriptive analysis finds that more than 70% of the respondents admitted that robotics assisted systems have been put into play among their organizations and that they have greatly improved production accuracy, speed of completion of work, and also overall work efficiency. The mean values for improving the productivity were Mean M= 4.2 and Standard Deviation SD= 0.68, and the mean values for reduction in human error were Mean M= 4.0 and Standard Deviation SD= 0.74.

Correlation analysis showed that there is a significant positive correlation between the degree of adoption of robotics and operation efficiency: $r = 0.68$, $p < 0.01$. The positive relationship between the level of automation and greater performance outcomes was demonstrated. Regression analysis subsequently revealed robotics-supported automation accounts for 46% variance of manufacturing efficiency, where R2=0.46, F(1,148)=125.78, $p<0.001$, therefore, it is proven that automation shows a significant prediction in the operational performance with high-level certainty.

These results agree with similar outputs in previous research, which underscores the potential of robotics in enhancing greater productivity, quality and safety at work, while making available human resources for other, higher value tasks(Groover 2020; Kraemer et al. 2018.) The results of this analysis indicate that the strategic use of robotics-assisted systems in the manufacturing sector in Karachi can serve as an important driver of efficiency, competitiveness and sustainable business operations.

Results and Discussion

Primary data collected from 150 respondents in the manufacturing sector in Karachi show that the effects of robotics assisted automation is being felt positively and substantially in terms of operational efficiency. Descriptive analysis has also shown that most of those organizations that have undertaken robotics have achieved a better level of productivity (M = 4.2, SD = 0.68) as well as reduced human error (M = 4.0, SD = 0.74) with justification as that automation improves manufacturing performance (Groover, 2020; Kraemer et al., 2018).

The correlational analysis gives a very strong relation between the adoption of robotics and the efficiency and that is $r = 0.68$ ($p < 0.01$). Regression analysis, on the other hand, suggests that automation indicates 46% variance in overall manufacturing performance: R2 = 0.46, F(1,148) = 125.78, $p < 0.001$, hence suggesting a predictive effect of automation (Lu, 2017; Roldan, Ruiz, & Velasco, 2021). The work adaptation variable became important, the cobots improved the cooperation between humans and machines and skills of this were enhanced (Huang, Li, & Wang, 2020).

Economically, cost savings, increased throughput, and less waste were identified by the organizations, which again led to the fact that systems supported by robotics increase competitiveness and sustainability. As concluded by Kamble et al. (2019) and Wang et al. (2019), the findings altogether proves the fact that robotics-assisted automation as a strategic tool is a way of enhancing the manufacturing operations in terms of productivity, quality and resiliency.

Conclusion

This paper demonstrates the efficiency improvement a lot in the manufacturing industry with the help of robotics-assisted automation. From the primary data from manufacturing units in Karachi, there was an observed improvement in productivity, precision, and optimization of the flow of operation. Similarly, the adoption of automation and operational performance had a positive correlation. CRs and training to the work force are the keys to successful integration and make the human skills complementary to the robotic capabilities. Robotics-assisted systems are part of economic competitiveness and sustainability, and they lower costs, decrease the number of errors and ensure the better use of resources. In general, the results discussed the process of robotics technology at manufacturing level actually helps to streamline and organizational resilience to meet the demand of the changing industrial environment in each modern workplace, an organization.

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