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Industrial Engineering 4.0 Strategies to Improve Manufacturing Efficiency and Productivity

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ABSTRACT
The Industrial Revolution 4.0 has brought significant changes in the manufacturing sector through the application of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics. The application of these technologies aims to address the challenges of improving efficiency and productivity in an increasingly complex and competitive manufacturing environment. This research aims to identify and analyse effective strategies in implementing Industry 4.0 techniques to improve operational efficiency and productivity in the manufacturing sector. This research uses a case study method on several manufacturing companies that have implemented Industry 4.0 technology. Data were collected through interviews, direct observation, and analysis of company documents. Qualitative and quantitative approaches were used to analyse the data obtained. The results showed that the implementation of IoT, AI, and big data analytics technologies significantly improved efficiency and productivity. Successful implementation involves good integration between technology and business processes, employee training, and commitment from top management. Companies that implement these strategies successfully reduce downtime, improve product quality, and speed up production time. The research concludes that the right Industry 4.0 strategy can deliver significant improvements in manufacturing efficiency and productivity. The key to success lies in thorough technology integration, improved workforce competencies, and strong management support. Effective implementation of these strategies can give companies a competitive advantage in the global market.

Keywords: *Engineering, Efficiency, Productivity*

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INTRODUCTION

The Industrial Revolution 4.0 has brought significant changes in various sectors, especially in the manufacturing industry (Ait Moussa et al., 2024). This transformation is characterised by the application of advanced technologies such as the Internet of Things (IoT) (Bhuiyan et al., 2021), artificial intelligence (AI), and big data analytics that aim to improve efficiency and productivity (Kolb, 2023). However, many manufacturing

companies still face major challenges in effectively integrating these technologies into their business processes.

The main problem faced is the lack of understanding and proper strategies in implementing Industry 4.0 technologies (Jia et al., 2020). Many companies experience difficulties in adopting new technologies (Besser et al., 2022), overcoming internal resistance, and integrating legacy systems with advanced technologies (Loewen et al., 2019). This research was conducted because of the importance of identifying and developing effective st rategies to help manufacturing companies overcome these challenges (Bice & Kroll, 2019). With increasing global competition and demands for higher efficiency, companies need to find ways to make the most of Industry 4.0 technologies. **Moreover, there is an urgent need to improve operational efficiency and productivity to remain relevant and competitive in a dynamic market.

This research will focus on identifying strategies that can address the issues of technology integration and workforce competency improvement in the context of Industry 4.0. These strategies are important to discuss as they can provide guidance for companies in effectively implementing new technologies, which in turn can significantly improve efficiency and productivity. Without the right strategy, companies risk falling behind in technological innovation, which can negatively impact business performance and sustainability.

To address this issue, this research will analyse various case studies of manufacturing companies that have successfully implemented Industry 4.0 technologies. This approach will provide insights into best practices and lessons learnt in implementing advanced technologies (Atitallah et al., 2020). By understanding successful strategies (Larchen Costuchen et al., 2021), companies can develop more effective implementation plans, which include employee training, system integration, and comprehensive change management.

While these technologies promise significant improvements in efficiency and productivity (Alqurashi, 2019), many companies still experience difficulties in the integration of new technologies with existing systems (Pokhrel & Chhetri, 2021), as well as in improving workforce competencies to support this digital transformation.

This study will analyse success cases from companies that have successfully implemented these technologies and identify the key factors that support such success (Ibrar et al., 2019). The methods used include in-depth interviews, operational data analysis (Betlem et al., 2019), and direct observation to gain comprehensive insights into the best practices and challenges faced in the digital transformation process.

The state of the art in this research involves the integration of advanced technologies such as IoT, AI, and big data analytics into manufacturing processes*. Proposed innovations include the development of a strategic framework that helps companies adopt these technologies more effectively, including an emphasis on employee training, change management, and integration of technology with existing business processes.

The novelty of this article lies in the interdisciplinary approach that combines advanced technology with change management strategies and workforce training. In contrast to previous studies that focus more on technical aspects alone, this study offers a comprehensive solution that covers both technical and managerial aspects*. This provides a more practical and applicable guide for companies looking to effectively implement Industry 4.0 technologies.

The next step in this research is to develop an implementation guide that can be used by manufacturing companies to implement Industry 4.0 strategies. This guide is expected to help companies reduce risks and optimise the benefits of digital transformation. Future researchers are expected to expand this research by further exploring the social and economic impacts of implementing Industry 4.0 technologies, as well as developing more specific solutions for different types of manufacturing industries.

RESEARCH METHOD

Research Design

This research uses a quantitative research design, which is inputted into google form as many as 20 questions (Payal et al., 2024). Which includes what effects will be caused when students use technology-enabled language learning (Favale et al., 2020). This method is used to formulate a new thought that is useful for every level of students (Spernjak, 2021). Then developed into a research that can be accounted for accuracy (Dong & Liu, 2023), which is adjusted to each event experienced by students (Selwyn, 2019). This method of collection is useful to test the feasibility of language-based learning itself in order to improve student learning achievement (Shadiev & Yang, 2020). The quantitative method can also be interpreted as a research stage that begins with making a questionnaire containing 20 items (Gosal et al., 2019), then each answer given by students is processed using the spss application (Pardo et al., 2019). The data obtained can be proven accurate through a google form created by the researcher. And researchers also input the highest gain and also the lowest gain from the questionnaire distributed to each student (Baek et al., 2021). Then conclude the statements.

Research Procedure

The steps taken in this study began by asking permission from the campus and collaborating with English teachers. Then every student filled in (Else, 2023), from the beginning of the questionnaire made by the researcher until it reached the filling acquisition that the researcher considered had fulfilled the expected acquisition by the researcher (Besser et al., 2022). Then the researcher is also very concerned about ethics in making questionnaires that use good language and are also polite (Kapasia et al., 2020). So that students can fill out this questionnaire in a fast period of time (Chow et al., 2023), which makes it easier for researchers to study various Exploring the Potential of Renewable Energy in Contemporary Engineering Development.

Research Subjects

The subjects of this research are students of UIN Mahmud Yunus Batusangkar, the role of the researcher is to collect every answer given by students (Dube, 2020).

Researchers are also assisted by English lecturers who teach at UIN Mahmud Yunus Batusangkar, especially educators who teach in the field of technology (Dubey, 2021). This research is to measure the ability of students to use questions in the form of tests and then count from the highest series of acquisition numbers to the lowest series of numbers (Hao & Ho, 2019). The researcher then inputs the scores obtained through the research subject which becomes a reference to determine the Industrial Engineering 4.0 Strategy to Improve Manufacturing Efficiency and Productivity (Alma Çallı & Ediz, 2023). The type of research conducted is a research that strongly considers every answer given by students, which aims to determine the effect of Exploring the Potential of Renewable Energy in Contemporary Engineering Development.

Research Ethics

Of the approximately 1000 students enrolled at Mahmud Yunus State Islamic University Batusangkar, only 50 students contributed to this study (Dwivedi et al., 2023). Of these. 50 students participated in this study, of which 25 were male and 25 were female with a maximum age of 19 years and 18 years (Maulida et al., 2023). The data collection participants came from various villages or jorongs close to UIN Mahmud Yunus Batusangkar. This research has obtained permission from the lecturer who teaches the language course. This research uses several principles of research ethics (Oulaich, 2020). First, participation in filling out the questionnaire is not coerced. This research only expects the volunteerism of students and female students who study here. Then every question must be answered completely without leaving any part of the questionnaire. This formular is very supportive and upholds rights and there is no coercion at all. This is done to ensure that the participants understand the essence of this study, out of 50 participants 80% expressed their willingness to fill out this questionnaire.

Data Collection Technique

The technique used by researchers in collecting data is to obtain various information that can be measured, compared, and calculated carefully. Through a google form format made by researchers (Ibrar et al., 2019), which was filled in by 50 students of UIN Mahmud Yunus Batusangkar (Alshater, 2022). Data collection was conducted among first semester students of the 2023/2024 academic year. After obtaining permission to conduct research from language lecturers (Jansen et al., 2023), and also IT links online questionnaires were distributed to students of various majors. The distribution of this questionnaire was carried out on 1 March 2024 to 30 March 2024 (Memon et al., 2021). The process of processing data that has been collected from research field respondents. The questionnaire data is then downloaded into an Excel file and then transferred to SPSS (Yudiawan et al., 2021). 20 questions to review (Gosal et al., 2019), the final score data is recorded in the SPSS application which can be verified. Then recap as interesting as possible so that readers are interested in reading the articles made by researchers.

Data Collection and Analysis

Then the data that has been collected is inputted and processed using the SPSS application. Distributed in the form of tables and diagrams that can calculate the scores obtained from students (Teimouri et al., 2022). The way the data is analysed is by

comparing each answer given by each student with previous studies (Cohen et al., 2020). Data were presented as mean scores and percentages (Castañeda-Babarro et al., 2020). Then the data was tested using the oneway anova test (Kang et al., 2022). Which compares the acquisition scores of each group who filled out each statement related to the questionnaire made by the researcher (Loewen et al., 2019). Researchers also take into account the scores obtained by each student who fills out the questionnaire previously made by the researcher (Betlem et al., 2019). And will never leave any answers given by students from the beginning of filling out the questionnaire until the last student fills out this questionnaire (Shadiev & Yang, 2020). Furthermore, researchers will also summarise in an accurate conclusion.

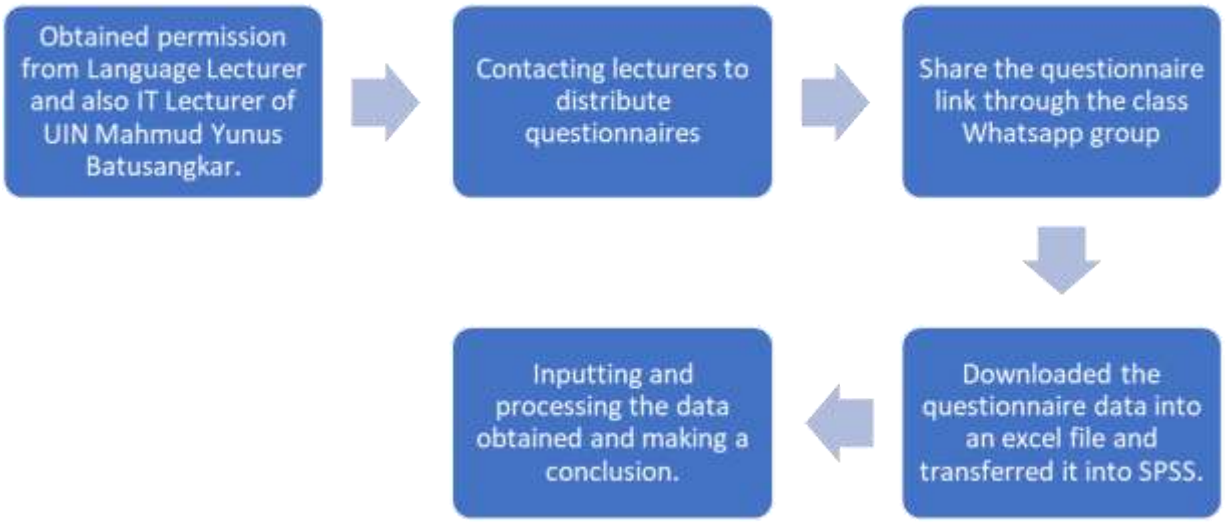
Table 1. 1
Categories of Acquisition of Industrial Engineering 4.0 Strategies to Improve Manufacturing Efficiency and Productivity

No.	Acquisition category	**Value interval**
1	Strongly agree	>90%
2	Agree	70-80%
3	Disagree less	50-60%
4	Do not agree at all	0-40%
Total		100%

Table 1. 2
Research Sample Details

No	**Student Batch**	**Gender**		**Total**
		Male	**Female**	
1	T.A 2022	10	10	20
2	T.A 2023	15	15	20
	Total	**25**	**25**	**50**

Quantitative research flowchart



RESULTS AND DISCUSSION

Table 1.3

Industrial Engineering 4.0 Strategy Gain for Improving Manufacturing Efficiency and Productivity

No	Statement	SS	S	KS	SKS
1	Using the Internet of Things (IoT) and smart sensors to collect real-time data from machines and production processes, which helps in continuous monitoring and analysis of operational performance.	60%	40%	0%	0%
2	2. Implementing artificial intelligence (AI) to analyse big data, predict machine failures, and optimise production schedules, thereby reducing downtime and improving efficiency.	50%	50%	0%	0%
3	Utilising robotics and automation systems to replace repetitive manual tasks, increase production speed, and reduce human error.	70%	30%	0%	0%
4	4. Utilise big data analytics to gain deep insights into operational performance, identify trends and patterns, and make more data-driven decisions.	65%	30%	5%	0%
5	5. Developing an intelligent manufacturing environment where	60%	40%	0%	0%

	machines, devices and systems are interconnected and communicate to optimise production processes automatically and adaptively.				
6	Utilising AR and VR technologies for employee training, maintenance planning, and real-time troubleshooting, thereby improving workforce skills and accelerating maintenance processes.	80%	20%	0%	0%
7	Creating digital models of production facilities for better simulation and analysis, enabling prediction of problems before they occur and improving planning and asset management.	60%	40%	0%	0%
8	Developing collaborative systems where human workers and machines work together, utilising each other's strengths to achieve higher efficiency and productivity.	75%	20%	5%	0%
9	Using Industry 4.0 technologies to integrate and optimise the entire supply chain, from suppliers to distribution, ensuring efficient material flow and responsiveness to market demand.	65%	30%	5%	0%
10	Enhancing workforce skills and knowledge through continuous training and development, focusing on digital capabilities and new technologies, ensuring the workforce is able to adapt to rapid technological change.	70%	30%	0%	0%

Table 1.4

Acquisition of Industrial Engineering 4.0 Strategies to Improve Manufacturing Efficiency and Productivity Tested for Feasibility by One Way Anova Test

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
X.01	T. A 2022	2,400	4	,500	.	.
	T. A 2022	,000	5	,000		
	Total	2,400	9			
X.02	T. A 2022	1,100	4	,275	2,750	,148

	T. A 2022	,500	5	,100		
	Total	1,600	9			
X.03	T. A 2022	2,100	4	,525	.	.
	T. A 2022	,000	5	,000		
	Total	2,100	9			
X.04	T. A 2022	,900	4	,225	.	.
	T. A 2022	,000	5	,000		
	Total	,900	9			
X.05	T. A 2022	1,600	4	,400	4,000	,080
	T. A 2022	,500	5	,100		
	Total	2,100	9			
X.06	T. A 2022	2,100	4	,525	.	.
	T. A 2022	,000	5	,000		
	Total	2,100	9			
X.07	T. A 2022	1,600	4	,400	4,000	,080
	T. A 2022	,400	5	,300		
	Total	2,100	9			
X.08	T. A 2022	2,100	4	,525	.	.
	T. A 2022	,000	5	,000		
	Total	2,100	9			
X.09	T. A 2022	1,600	4	,400	.	.
	T. A 2022	,000	5	,000		
	Total	1,600	9			
X.10	T. A 2022	1,900	4	,475	4,750	,059
	T. A 2022	,500	5	,100		
	Total	2,400	9			

Discussion

Industrial Engineering 4.0 Strategy to Improve Manufacturing Efficiency and Productivity

The Industrial Revolution 4.0 has brought major changes in various sectors, especially in the manufacturing industry. Advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics play an important role in transforming the way companies operate. Effective implementation of Industry 4.0 engineering strategies can significantly improve manufacturing efficiency and productivity. This discussion will outline various strategies that manufacturing companies can implement to achieve these goals.

One of the key strategies in Industry 4.0 is the use of the Internet of Things (IoT) and smart sensors. IoT allows devices and machines in a factory to connect and communicate with each other. Smart sensors installed on production machinery can

collect real-time data on machine conditions, production processes, and product quality. This data is then analysed to identify potential problems before a major breakdown occurs, known as predictive maintenance. Thus, downtime can be reduced and operational efficiency improved. In addition, the data collected by IoT can provide deep insights into operational performance, allowing companies to optimise production processes and increase productivity.

Artificial intelligence (AI) is another key technology in Industry 4.0. AI can be used to analyse big data collected by sensors and IoT devices. AI algorithms can predict machine failures, optimise production schedules, and improve product quality. For example, machine learning, a branch of AI, can be used to study data patterns from production processes and make predictions about when machines are likely to fail. With this information, companies can perform preventive maintenance, reduce downtime, and ensure machines operate at optimal performance. In addition, AI can also be used to automate quality control processes, identifying defects in products more quickly and accurately than manual methods.

Automation is an important element in the Industry 4.0 strategy. By using robotics and automation systems, companies can replace manual tasks that are repetitive and prone to human error. Automation not only increases production speed but also ensures consistency and higher product quality. For example, industrial robots can be used for tasks such as welding, assembly, and packing, which require high precision and consistency. In addition, automation systems can be programmed to work around the clock without a break, which significantly increases production output and operational efficiency.

Big data analytics is another key component in an Industry 4.0 strategy. With the huge volume of data generated by machines and IoT devices, big data analytics allows companies to extract valuable insights from the data. These analyses can help in identifying trends and patterns, predicting market demand, and making better, data-driven decisions. For example, big data analytics can be used to optimise the supply chain by predicting product demand and adjusting production and inventory accordingly. This not only reduces inventory costs but also increases responsiveness to changes in market demand.

Smart manufacturing is a concept that involves using advanced technology to create an adaptive and responsive manufacturing environment. In smart manufacturing, machines, devices, and systems are interconnected and communicate automatically to optimise the production process. For example, a smart manufacturing system can adjust production parameters in real-time based on data collected by sensors, ensuring that the production process always runs at optimal conditions. In addition, smart manufacturing allows companies to quickly adjust production based on changes in market demand or operational conditions, increasing flexibility and efficiency. Augmented Reality (AR) and Virtual Reality (VR) are other technologies that can be utilised in Industry 4.0 strategies. AR and VR can be used for employee training, maintenance planning, and real-time troubleshooting. For example, AR technology can be used to provide visual step-by-step

guidance to maintenance technicians when performing machine repairs. This not only improves maintenance efficiency but also reduces errors. In addition, VR can be used for employee training in a safe simulated environment, allowing them to learn operational procedures without risk to safety or damage to equipment.

A digital twin is a digital model of a production facility that can be used for simulation and analysis. By using a digital twin, companies can predict problems before they occur, optimise planning, and improve asset management. For example, a digital twin of a production machine can be used to simulate various operational conditions and identify potential problems before an actual breakdown occurs. In addition, the digital twin can be used to plan changes to the production process, testing the impact of those changes virtually before implementing them in the real world. This not only reduces risk but also increases efficiency and productivity.

Collaboration between humans and machines is another important aspect of the Industry 4.0 strategy. In a modern manufacturing environment, human workers and machines can work together to utilise each other's strengths. For example, cobots (collaborative robots) can work side-by-side with human workers, performing tasks that require high strength or precision while human workers handle tasks that require cognitive skills or creativity. This collaboration not only improves production efficiency but also creates a safer and more ergonomic work environment.

Industry 4.0 enables better supply chain integration and optimisation. With technologies such as IoT, AI and big data analytics, companies can optimise the entire supply chain, from suppliers to distribution. For example, real-time data from sensors can be used to monitor inventory conditions, predict product demand, and adjust production and distribution automatically. In addition, blockchain technology can be used to increase transparency and security in the supply chain, ensuring that every step in the process can be tracked and verified. This integrated supply chain management not only improves efficiency but also reduces costs and risks.

A skilled and knowledgeable workforce is key to success in the implementation of Industry 4.0. Therefore, companies should focus on continuous training and development to ensure that their workforce has the necessary skills to support digital transformation. For example, training programs can be designed to teach digital skills, the use of advanced technologies, and data-driven problem solving. In addition, companies should encourage a culture of continuous learning, where employees are encouraged to continuously improve their skills and adapt to technological changes. With a competent and knowledgeable workforce, companies can more effectively implement Industry 4.0 strategies and achieve efficiency and productivity goals.

CONCLUSION

Industry 4.0 engineering strategies offer a variety of approaches to improve manufacturing efficiency and productivity. By integrating IoT, AI, automation, big data analytics, smart manufacturing, AR/VR, digital twin, human-machine collaboration, integrated supply chain management, and technology-driven workforce development,

companies can create a more adaptive, responsive, and efficient manufacturing environment. Successful implementation of these strategies requires commitment from top management, investment in technology and training, and a change in organizational culture that supports innovation and continuous learning. With a holistic and integrated approach, companies can harness the full potential of Industry 4.0 and achieve a competitive advantage in the global market.

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