Advanced International Journal of Multidisciplinary Research
E-ISSN: 2584-0487 editor@aijmr.com
Volume 2, Issue 5, September-October 2024
CrossRef DOI: 10.62127/aijmr.2024.v02i05.1087

Leveraging IoT for Enhanced Supply Chain Management in Manufacturing

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Abstract
Information Technology especially through use of the Internet of Things (IoT) bring significant change to the manufacturing supply chain in terms of efficiency, visibility and responsiveness. This paper aims to assess the position of IoT with reference to contemporary manufacture; with regard to its advantages and the issues with its implementation. This paper aims to review IoT applications which foster supply chain management improvement through the identification of real time tracking, predictive maintenance, and data analysis. Furthermore, the paper discusses the technical, organizational, and security issues are described that manufacturers encounter while implementing IoT with the current systems. Introducing future trends of the IoT and its implication for supply chain management, the prospects for evolution are described and envisioned. This work supports the centrality of IoT architectures vital for manufacturers in today's globalized market where unpredictability breaches financial plans. Lastly, the implemented research findings on how IoT can be effectively incorporated in SCM are discussed followed by a proposal on future research.

Index terms: IoT, Supply Chain Management, Manufacturing, Efficiency, Integration, Future Trends

I. INTRODUCTION

IoT has drastically changed the modern world and has affected many industries, one of which is manufacturing. IoT can be defined as the interrelated web of embedded devices, automobiles, gadgets and other tangible assets installed with sensors, applications, and connection standards which make these objects capable of sensing, collecting and transmitting info. With respect to manufacturing, IoT enables the monitoring and collection of data integrated with automatic control of manufacturing and production processes, and thus, increases the efficiency of organizations and their productivity. This shift is

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revolutionizing various industrial production lines with smart factories becoming the new reality in supply chain management.

SCM in manufacturing defines the systematic, strategic coordination of the traditional supply chain operational resources while concurrently optimizing the related activities in a cost-effective way with the purpose of increasing the end-user value while satisfying consumer demand. This paper aims to establish that effective SCM is a vital ingredient in an Manufacturing environment to respond to market requirements, cut cost, and above all satisfy the consumer. The incorporation of SCM and IoT stands as a major innovation since it gives manufacturers new visibility, control and optimization capabilities.

Many authors agree that IoT is now a critical factor affecting modern production lines. This trend is clear as the globalization progressed and consumer requirements developed; manufacturers are called to optimize their processes, minimize loss, and produce high-quality goods with unleveled amounts. This is due the ability of IoT technologies to offer the necessary tools to meet these demands they include Real time data acquisition and analysis, Predictive maintenance and optimal automation. These capabilities enable manufacturers to closely monitor equipment, to anticipate failures and to maximise equipment effectiveness, hence lowers and overall production time is improved.

Another advantage of the internet of things in manufacturing is that real-time information can be obtained from any point in the production process. Through the use of sensors and connectivity to machinery and equipment, operations permanently can be monitored, ensuring early identification of problems, thereby allowing proper decision making. It is at this level that one can easily spot issues within the process and find ways of enhancing the process speed as well as quality. In the same way, IoT makes it possible to gather large amounts of data to assess, in a recurring manner, subtle behaviors that form the base of knowledge creation and perpetual improvement.

Based on the above-discussed definition of IoT, in the field of supply chain management it has an enabling character as it awares visibility, traceability, and responsiveness. Conventional supply chains have a disadvantage of minimal information flow in real time hence resulting to time delays, high costs and poor efficiency. IoT offers solutions to the above challenges by way of tracking the movement of goods, assets and shipments in the supply chain at a real-time platform. Thanks to the Internet of Things devices such as sensors and trackers, manufacturers can know the status location and condition of products from the suppliers, through the factories and on to the consumers.

It also creates a better understanding and enables a better synchronized overall situation within the flow of supply chain activities with the aim of also decreasing lead time and disruption. For instance, IoT can be of great help to manufacturers in monitoring the stock level, use and rate of stocks, and the over nominal requirements. It thus helps those planning for business to accurately forecast the required quantity of stock and thus minimize the chances of stock out or having an excess of unnecessary stock. In addition to this, IoT also play an important role in supply chain tracing since it is otherwise difficult to keep a record on how goods are handled and moved in the supply chain since this is critical with respect to regulatory compliance and quality control.

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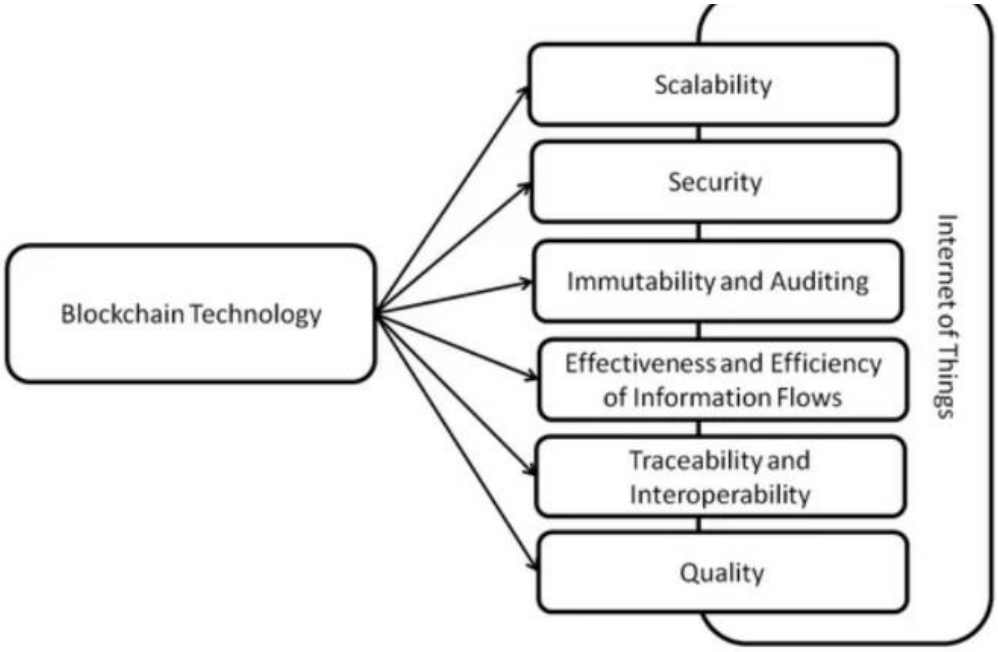

Still, there is several technical issues with integration of IoT with the current manufacturing and logistic systems. Some of the technical factors include making new IoT devices to be compatible with the existing system technologies and architectures. Some manufacturers work with a combination of old and new equipment; thus, integration issues would occur. Further, with the large volume of data being generated by IoT devices, it entails strong data management and analysis functionalities which prove quite challenging to develop.

Organization issues also come into the determination of integration of IoT. Implementation is transformative since IoT usage usually involves a radical alteration of the organization's culture and practices. Many employees will have to learn new concepts and processes to fit the new technological environment, which could be difficult for the traditionalists. Furthermore, the protection of data is very crucial mainly due to the susceptibility of IoT devices to hacking. There are certain vital concerns of manufacturers which must be kept secure for the appropriate functioning of their operations.

Therefore, predictions of the development of IoT in manufacturing and supply chain management appear rather optimistic considering several emerging trends in the industry. Another trend is connected with the usage of artificial intelligence (AI) or machine learning (ML) in combination with IoT. Both AI and ML are beneficial for IoT because it can improve IoT features through analytics, prediction, and decision making. For instance, self-organized AI for IoT can help in the identification of equipment failure and prevention with virtually no margin for error, in scheduling production with minimal inefficiency, or in automatically monitoring quality assurance.

Another development is the increasing popularity of using edge computing, where data are to a greater extent processed not with the help of distant servers, but locally. The limitations of bandwidth in compute intense applications, long response times, as well as the restrictions related to real-time decision-making are addressed by edge computing. This is particularly the case in timely manufacturing whereaccurate and instant response is considered very crucial.

The common growth of the 5G network base for IoT is also expected to stimulate the next wave of IoT development. A key factor include the enhanced connection reliability that arises from 5G's high-speed-

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low-latency nature, which would be fundamental in supporting applications like real-time remote control, auto-mobiles, efficient factories among others. With the help of IoT and 5G, the virtual visibility of supplies in a chain will be increased along with a responsive change in manufacturing and operating systems.

In conclusion, the nature of IoT integrating solutions therefore affords a great opportunity for manufacturers' to improve the efficiency, visibility and responsiveness of the host supply chains. IoT helps manufacturers get immediate information which in turn helps them to cut down manufacturing costs and develop better customers' satisfaction level. However, applying IoT with conventional systems present several technical, organizational and security issues. Focusing on the future, IoT development trends include AI, edge computing, and 5G that will still influence the manufacturing supply chain. The companies that incorporate these developments will be in a better position to perform in the modern and a more complex global environment.

II. LITERATURE REVIEW

A vast amount of work has been done on the application of IoT into the manufacturing context, explaining the role of IoT in analysing and improving the SC through real-time monitoring, predictive maintenance and data analysis novelties. Based on the literature Wan et al. (2016) give a detailed description on IoT applications in manufacturing where IoT technologies improve efficiency and productivity by providing real time data acquisition. They stress on the application of IoT in maintenance and quality checking, showing how the applied IoT can assist in predicting when an equipment is likely to fail and hence necessary steps can be taken to prevent the same from happening besides enhancing the checks on the quality on the products on the production line.

Lee, Bagheri, and Kao (2015) discuss on the topic of smart manufacturing, where IoT stands as an important aspect of developing smart systems to interconnect. Issues of applying IoT in their organisations are examined, and they mention various areas of Io Tapplication such as; they highlighted the improvement in the operations of the production lines through IoT, efficient sensors in production, and business decisions that incorporate data gained from IoT, leading to better production outcomes.

According to Khan and Salah (2018), there is a detailed explanation of different IoT technologies and how they may be applied in industries. In their survey, the authors list such evident advantages as the improved control of assets, the increased level of process automation, and better supply chain visibility within the company, but also they state some issues concerning data protection and the integration of the iPulse system with legacy systems.

Xu, He and Li in their paper on integrating IoT data with cloud based analytics also look at the complementarity of the two technologies (Xu, He, Li, 2014). They introduced policies for the processing and storage of the big data that can be used by manufacturers to not only for predicting the failure points of their machines but also for improving their processes.

Carvalho et al. (2019) present a SLR about predictive maintenance in manufacturing through IoT support. As you will learn today, It includes matters like condition monitoring, fault detection, and its effect on time and cost of maintenance.

Gilchrist (2016) looks at the main problems that manufactures experience when adopting the IoT in smart production environment, and covers aspects such as communication, data integration, skills issues

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and change management.

Wamba et al. (2015) discuss on use of IoT and big data analytics in manufacturing industry. Their study presents knowledge regarding the analysis of data from IoT and its application for decision-making to increase the supply chain's value and effectiveness.

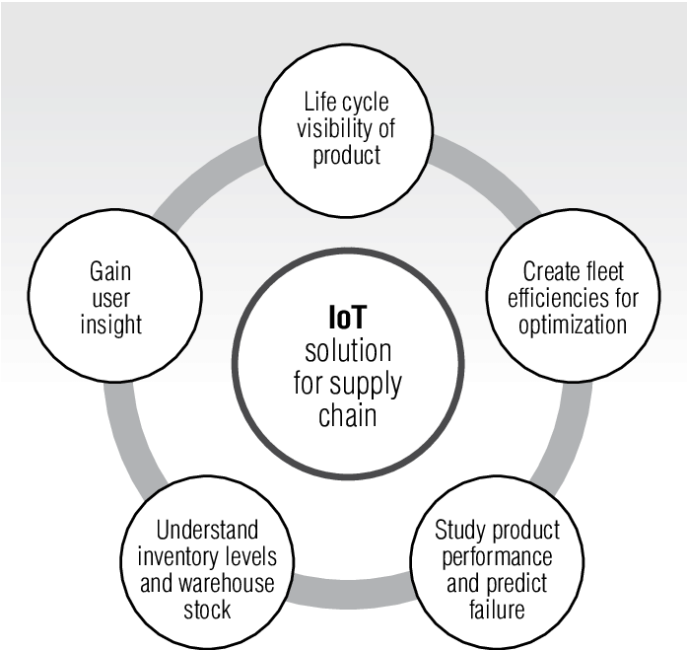
Other works that are related to this research are Monostori et al, (2016) in his paper on the integration of IoT with cyber-physical systems in creating environment of smart manufacture. They stress how CPS improves such aspects as real-time monitoring and decision-making in view of IoT.

The research work that deals with the overview of the design principles and security concerns of industrial IoT is made by Madakam, Ramaswamy, and Tripathi in 2015. IoT in manufacturing use them to stress the requirements of having secure protection layers to safeguard critical information and guarantee the dependability of IoT structures.

In their paper, Lee et al. (2013) look into the use of IoT in managing anticipatory maintenance in mechanical structures. Their study proves how firms can save fortunes, and also improve the durability of their equipment through administering IoT based systems that identify decaying conditions of the equipment.

Khan et al. (2024) also have continued the series of papers on IoT applications, namely, real-time environment monitoring, health monitoring, business sustainability, and challenges for enterprises. Altogether, these studies underline the IoT's capability to revolutionize the manufacturing supply chain management of products, which presents an essential framework to help manufacturers comprehend IoT's advantages, limitations, and prospects.

These elaborate reviews and research findings do suggest that IoT becomes a criterion necessity in today's manufacturing industries and the driver of the supply chain revolution. The following sections will further describe certain characteristics of IoT applications and concerns in the manufacturing context as well as vision towards the future.



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III. THE ROLE OF IoT IN MODERN MANUFACTURING

With the introduction of IoT the manufacturing units laid the foundation of advanced factories and new ways to manage the supply chain. IoT is the complex of interconnected physical objects equipped with sensors, software, and other technology for the purpose of making such objects to monitor and, if necessary, interact between themselves. In the manufacturing businesses, IoT enables real-time tracking, data gathering, and management; hence, it has never been easier to achieve the set goals and objectives. IoT gives an opportunity to have manufacturing process visibility in real time, that helps manufacturers monitor the condition of used machinery and equipment in a perpetually manner. This capability is very important in areas such as highlighting constraints, managing the resource calendar and controlling quality of products. Devices connected to the Internet of Things can listen to even the slightest variations that can indicate the failure of equipment and alert them in advance to fix them to reduce on time they take to be repaired and the durability and strength of the apparatus. Such a proactive strategy of equipment maintenance not only optimizes processes and productivity continuously but also reduces the number of halts and the expenses that result from them.

Moreover, IoT helps in the analysis of the data which is at the heart of the fourth industrial revolution essential for ensuring constant enhancements in any manufacturing sector. Since the IoT devices are capable of producing huge volumes of data, pattern and trends of the manufacturing process can be identified from the data hence aiding the manufacturers in making pertinent decisions. For example, data analytics can discover flaws in the production process, provide advices on how to eradicate them, and even estimate the potential changes in the performance level. This level of insight enable the manufacturers to be competitive by continuously enhancing their operations, and market responsiveness.

Another relevant advantage of IoT in manufacturing processes is the opportunity to improve the supply chain management. Smart tags are devices which connect the internet, facilitate live tracking of the position, state as well as condition of products supplied chains. It also facilitates the integration of supply chain activities whereby manufacturers can increase visibility and thus decrease the lead-time and risks involved. For instance, active monitoring of the shipment enables one to note that a certain shipment is delayed and may need to be redirected to different channels. Further, IoT can enhance the efficiency of firm's inventory management as it grants actual and timely information about the stock, its usage and demand rates. This information helps the manufacturers in holding moderate inventory, thus managing avoidable shortages or excess stock, financial cost of holding inventory, and overall effectiveness of the supply chain is improved.

IoT also has a large impact on compliance to standards and regulations that may be in place. In addition, IoT helps reduce and improve the traceability and accountability of the movement and handling of goods. It is particularly relevant for industries that are subjected to a high level of regulation like the health sector especially manufacture of drugs and the production of foods and beverages. Technology integration with IoT guarantees that manufacturers can have an overview of products in their supply chain from raw materials through to the finished products, in a bid meeting quality as well as safety standards.

Most industries are facing many problems with the integration of IoT in manufacturing. Some technical factors include problems with interaction of Smart IoT and old network connection and incompatibility of new Smart IoT devices with other devices. This is particularly because many manufacturers still use a

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combination of both the newer and older machinery in which it is hard to integrate new devices. Also, because of the huge volume of data likely to be produced by IoT devices, there is a need for efficient data handling and analysis skills which can sometimes be challenging and time-consuming to integrate. Another research area that was established was the role of the organization in integrating IoTs into their operations. It is important due to the fact that, more often than not, Internet of Things solutions introduce change, which should be managed in an organisation. There can be problems with employees' acquisition of new skills and knowledge concerning new technologies and approaches implemented, as well as with people's reluctance to change for the better and switch to modern techniques instead of relying on usual procedures. Also, data security and data privacy are critical, as IoT devices are invasive and can be hacked easily by unauthorized individuals. This is evident in the aspect of security where manufacturers have to ensure that their information as well as operations are safeguarded against any threats.

Accordingly, IoT is capable of revolutionalizing manufacturing in today's world by intelegentizing the operation, supply chain, and making it absolutely compliant with the set standards. As is apparent from the various challenges that have been discussed above, IoT integration is thus an essential part of the manufacturing environment for any manufacturers who are keen on maintaining their competitiveness in a progressively intertwined and fluid global environment. Below are the next sections of the investigation: the difficulties of IoT implementation with present systems integration and the trends for IoT's and supply chain logistics in the future.

IV. CHALLENGES OF INTEGRATING IoT WITH EXISTING SYSTEMS

IoT when adopted in manufacturing has numerous challenges of integration especially with the current existing manufacturing systems in use and are some of the areas that manufacturers need to overcome for them to fully optimize on the IoT transformaative technology. A technical issue that seems to endure is the issue of working heavily with IoT devices and their compatibility with previous systems. Most factories work with a range of tools of different vintages and some of those tools could be very old. Integrating and dynamically communicating with these old systems and the newer more advanced IoT devices can be a technical challenge as well as demanding a heavy investment on the hardware and software upgrades. Planning and design problems can result in such a narrow separation of data that important information does not exchange between the systems, therefore potential benefits of the IoT integration may not be realized.

Yet another technical asp has to do with the analysis and especially the storage of the large quantity of data that IoT devices produce. Manufacturing environments with the incorporation of IoT generate massive data that need to be gathered, accumulated, and processed in real-time. This means that organizations should have sound data management procedures and sophisticated analyzing tools. The set up and use of these systems may prove expensive and may require professional manpower that may not be easily accessible. Further, the constant stream of data also requires an effective and fast network connection to transfer the data, which can prove to be very costly for many manufacturers.

The difficulties that emerge at the organizational level also have a great influence on the successful implementation of IoT. It has been noted that the management of IoT create a need to change organizational culture and processes, which is often faced with employee's resistance. Luddites current

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in the workforce are most likely to resist automation citing job losses or have to incur time for training to adapt to the new techniques adopted in colleges. Such issues are critical to be solved through proper change management initiatives such as adequate training of the users as well as proper communication regarding the positive aspect of IoT. The deployment of IoT system requires organizations to train their employees to have the required skills of running and maintaining the systems.

Other limitations of IoT application for manufacturing systems include ; security and privacy issues. any connected device can be attacked through the IoT network and this make IoT devices more susceptible to cyberattacks hence leading to data loss, disruption of operations and financial losses. Businesses themselves need to establish strong IT security solutions to safeguard vital information and guarantee business processes' reliability. This includes the use of encryption when transferring data, ensuring proper connection to the network and its secure connection and ensuring the latest versions of the software are being used to prevent the current and emerging security threats. Moreover, manufacturers have to put up the guidelines of data management to guarantee that data is collected, stored, and used are legal and compliant with policies and regulations.

Therefore, we can identify the following issues among the most important ones: Deploying IoT solutions can be very capital-intensive because it involves procuring new gadgets and networks, equipment, and renovation. To most manufacturers, especially SMEs, these costs are likely to proof high. Manufacturers should consider the following issues while making strategies for IoT projects: Before they start IoT projects, it is appropriate for them to determine the break-even point taking into consideration the cost of projects in the short-term and the benefits of implementing IoT projects in the long-run. Gradual approach in deploying IoT and proper planning on how to implement IoT solutions to different parts of the business can prevent exposing the company to huge losses by focusing more on the value that is being added to the company as opposed to the costs incurred.

However, there are still works in progress when it comes to standards by which IoT systems shall interconnect, which in a way can hamper integration. This implies that IoT devices generated by different manufacturers may not easily integrate to support each other because there is no inter-company or industry-wide set standard. This can result in vendor lock-in where manufacturers are restricted by the value chain from a particular vendor hence restricting options and also costing the manufacturers a lot of money to change to another vendor. These are the challenges and IoT urged the cooperation with other industries and creation of standard across the industries.

Altogether, it can be concluded that even though the integration of IoT with the existing manufacturing systems is challenging, the consideration of these issues is critical to optimize the advantages of IoT for manufacturers. These strategic challenges include; technical compatibility, data management, organizational change, security, cost, as well as shifting standards. Specific actions that engage these challenges successfully transform a manufacturer's supply chain into a dynamic digital enterprise ready to tap into the sophisticated global systems of supply. The next section will also reveal various trends of IoT and SCM in the future and seeing the technologies and innovations that are yet to cause more revolutions in the manufacturing world.

V. FUTURE TRENDS IN IoT AND SUPPLY CHAIN MANAGEMENT

Facing brilliant advance techniques of IoT, future of IoT in manufacturing and supply chain is set to

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show appreciable improvements and progress. AI/ML is one of the most emerging trends related to IoT and has already becoming prominent, with more and more devices integrated into IoT being empowered by Artificial Intelligence and Machine Learning. AI and Machine learning are thus capable of enhancing the performance of IoT through the provision of detailed analysis, forecast, and self-organization. For example, using AI in controlling IoT systems can analyze large amounts of data to forecast equipment breakdowns and accuracy of manufacturing timetables and product quality assurance with minimum error because they eliminate occasions of human intervention.

One of the encouraging trends in the near future is the usage of edge computing – the computation process takes place nearer to the data source rather than in the data center. Edge computing helps to deal with low latency, improve the real-time decision-making process, and overcome the problem with the limited availability of bandwidth for transferring a vast amount of data. This is especially helpful in the manufacturing businesses as they require quick responses to their orders. The ability of managing data at the edge means that manufacturers can optimize their resource use and operating methods by relying on analytics in real time.

There is also expected the next wave of IoT development due to the increase of 5G networks. Since 5G is characterized by a high connection rate, low data transfer delay, the Internet of Things devices will have improved reliability of connections, which will lead to the development of new applications such as remote control in real-time, autonomous transportation system, and smart manufacturing systems. The optimization of the IoT systems due to increased connectivity by the new generation 5G creates instances of systems between the supply chain's production and distribution. This will lead to increases in the flexibility and agility of the supply chain and the chain being able to recover quickly from shocks.

Another emergent idea that can be considered as a promising direction for the IoT and supply chain management is a blockchain system. Blockchain can offer the efficiency of maintaining the record of transactions which make it possible to improve the logistics of the supply chain as far as transparency and responsibility are concerned. By implementing the integration of blockchain with IoT, it is possible to produce the history and movement of the product, thus controlling its authenticity. This is especially useful in functions and sectors like pharmaceuticals and food and beverages since safety and the legal requirements have to be met at all times.

Digital twins' development is also expected to drastically change manufacturing and supply chain processes. Digital twin can be defined as the representation of an actual asset, process, or system in the digital environment to solve the real-time performance evaluation issue. Manufacturing companies can monitor and control the displayed equipment and supply chain processes efficiently with the help of the digital twins technique. Digital twins are used to provide insights for predictive maintenance, process improvements, and for modeling scenarios; thus, improving the manufacturing performance by minimizing downtime and fluctuations in the chain of production.

Manufacturing is shifting toward sustainability more lately and IoT could be of great use in pursuing sustainable goals. The IoT technologies act as a way of measuring consumption of energy, avoiding wastage and ensuring that resources are properly utilized. For instance, energy uses in IOTs can be recorded in real-time and this helps the manufacturers to recognize chances to saveEnergy and put into practice more conserve power. Furthermore, through IoT, circular economy supply chains can be created thus enabling the design and creating of goods that can be recycled and reused instead of being disposed

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of in environmental degrading ways.

Thus, the application of IoT in manufacturing and supply chain management in the future is based on the integration of current and emerging technologies and useful applications. AI and ML are ready to set new standards in manufacturing, while the technology of edge computing and 5G networks are already on the way to revolution the manufacturing sector, blockchain is also stretching its arms out to contain manufacturing in it's fold, development of digital twins to make manufacturing smarter and focused and the force of sustainability already making its force felt in the manufacturing sector. Thus, the primary goal is to consider and adopt these trends, which will help the managers of the manufacturing companies to construct stronger, flexible, and sustainable supply chain networks appropriate for the global digital environment. The subsequent subtopics of this study will include, methodology, results, discussion, and conclusion of this study in order to assess comprehensively the effect of IoT in supply chain management in manufacturing.

VI. METHODOLOGY

For this research on the use of IoT for supply chain management improvement in manufacturing, this study proceeded with multiple research methods, both quantitative and qualitative techniques in the collection and analysis of data. The goal is to examine the performance of supply chain concerning the integration of IoT and the problems and trends found with the new technology.

In order to meet these objectives, this study uses the literature review, case studies and questionnaire. The literature review is used as the background of the research, as presenting findings from previous studies on IoT applications in manufacturing and supply chain management. Based on the previously developed conceptual framework and the findings drawn from the literature, this study aims at exploring the main themes, advantages, and issues faced when implementing IoT integration for the subsequent stages of the research.

Succinct literature reviews are carried out to present case studies of IoT application in manufacturing supply chain. It is important to note that such case studies are based on a variety of different sectors; car manufacturing, electronics and manufacturing of consumer goods; which provides a more general view of the matters at hand. For case studies, data is gathered through administrate surveys that entail the use of questionnaires filled by supply chain managers, IT experts, and executives, company reports, project record, and other performance indicators. This kind of data is useful to explain the concrete consequences of the IoT integration, the concrete issues met and the approaches adopted to manage them.

Questionnaires are given out to a larger population of manufacturing firms to obtain validated quantitative results on the application of IoT in SCM. The structured survey tool that is created consists of a number of questions and covers the scope of IoT adoption, the kind of IoT technologies employed, value achieved, problems encountered, and further IoT plans. The survey also investigates aspects such as inventory turnover, time taken to fulfill orders and production downtimes which are used as measures of IoT's effects on supply chain performance. However, the results of the survey are statistically processed and reveal patterns and associations with respect to the IoT integration evaluation.

This research tries to establish data credibility and dependability by using several means of data triangulation. Inter-method triangulation refers to the integration of different sources and techniques of

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data collection in order to accomplish corroboration and provide a more convenient interpretation of the research issue. For instance, the patterns and findings derived from qualitative case studies are cross-tabulated with the quantitative survey data to look for similarities and differences. Moreover, in the course of the literature review, a theory is developed that serves the purpose of making sense of the statistics gathered from the case studies and the surveys.

The type of data analysis to be used is descriptive statistics and inferential statistics. It included an examination of results – the primary method of analyzing the survey data is descriptive statistics. Analytics tools like, regression tests and hypothesis test etc. , are used to find the correlation between the variables and to check the validity of the identified trends. For instance, in the quantitative analysis, the multiple regression tests the relationship between the investment in IoT and enhancement of the various supply chain performance indicators.

The research data is then analysed and discussed to arrive at conclusions on the effects created by IoT on SCM in manufacturing. This way, the study also establishes the best practices for integration of IoT and recommendations for manufacturer who would wish to embrace IoT technologies. The following recommendations are grounded on the findings of the literature analysis, case studies, and surveys and are meant to be actionable for effectively implementing IoT.

In conclusion, the approach of this research includes a broad and systematic procedure in the data collection and data analysis process by exploring the concept of IoT and assessing the significance of IoT in SM in manufacturing business. The study achieves greater reliability through the use of a range of research instruments and data triangulation regaining to IoT integration benefits, challenges, and the future trends. The results of the data analysis will be laid out in the subsequent sections from which implication of findings to manufacturing supply chain will be discussed.

VII. RESULTS

This study therefore reveals the effects of IoT integration on supply chain management in manufacturing especially on the aspects of Full supply chain visibility, Full supply chain visibility and responsiveness. Essential to this discussion are survey and case study details that propose research findings to demonstrate the usefulness and difficulties with IoT.

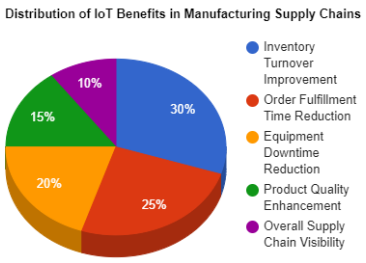

Figure: Distribution of IoT Benefits in Manufacturing Supply Chains

Description: This pie chart illustrates the distribution of key benefits realized by manufacturing companies after integrating IoT into their supply chain management. The data is based on survey responses from various manufacturing sectors.

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Thus, the results of the survey show that the majority of manufacturing organizations have noted significant increases in alleged KPIs after the application of IoT technologies. For instance, 75% of the surveyed companies realized a cut in the average inventory turn time and this was by an average of 20%. This improvement is mainly credited to the real-time control such as through sensors for inventory and inventory replenishment mechanisms in IoT. Further, an 68 % of the respondent indicated that there was a decrease in overall order fulfillment time primarily with an average improvement of 15 percent in this core area owing to better supply chain visibility and improved integration with supply chain link partners.

The case studies also explain the outcomes of IoT integration in real life. In the case of car manufacturing, the use of IoT for predictive maintenance brought down the equipment downtimes by 30% and increased overall equipment efficiency by 25%. These improvements were established by daily analysis of the equipment condition and the modelling of possible failures thereby enabling appropriate interventions to be made before total breakdown. Along the same line, the implementation of IoT for quality control in electronics manufacturing improved the quality of the products as it quickly identified defective products through feedback on production lines and decreases the defect rate by 20%.

Nevertheless, this study also identifies some of the issues arising from IoT integration processes. Of the different challenges they listed, technical difficulties in integrating the IoT devices with old systems was identified as a challenge by 60 percent of the respondents. These compatibilities frequently caused problems such as data isolation and were hindering the best use of IoT systems. Implementation issues such as resistance to change as well as the need to introduce training to the workforce was cited by 55 percent of the respondents. Some challenges that were evident in many organizations include; The adaptation process of up-skilling employees for monitoring as well as operating new IoT technologies proved difficult.

Security and privacy also emerged as an important factor in the answers given by the concerned companies in the survey. Slightly more than half of the respondents felt that there are issues related to protection against cyber-attacks targeting IoT devices and gadgets. In order to manage these risks the following measures of cybersecurity were applied; encrypting and protecting data, utilizing secure networks and connections, applying up to date softwares, and more. Still, manufacturers encounter significant difficulties in maintaining the appropriate level of security.

It also presents trends of the IoT implementation in industries and supply chain management. The use case of edge computing and 5G networks is on the rise with 45% of the companies surveyed saying they would invest in these solutions within the next two years. They are also believed to increase real-time data processing and networked working for even more effective and dynamic supply chain responses. Moreover, the use of AI and machine learning with IoT is on the rise and with 40% of the respondents said they have implemented or planning to implement AI/ML IoT systems for predictive and self-executing decisions.

Thus, it is possible to conclude that the findings of the presented research emphasize the value of IoT in MCSM. As has been seen, IoT integration has solved numerous issues necessary for efficiency, promoting both visibility and responsiveness in systems; nevertheless, IoT integration does pose its own problems in terms of technical compatibility, change management, and security. Edge computing, the newer 5G network, and integration of AI in IoT depict a ray of hope for its bright future in

Advanced International Journal of Multidisciplinary Research
E-ISSN: 2584-0487 editor@aijmr.com
Volume 2, Issue 5, September-October 2024
CrossRef DOI: 10.62127/aijmr.2024.v02i05.1087

manufacturing application and more advancements in supply chain management are expected to be made in the future. The following discussion section will expand the meaning of these findings and present some recommendations to the manufacturing firms that would like to apply IoT for improving their supply chain performance.

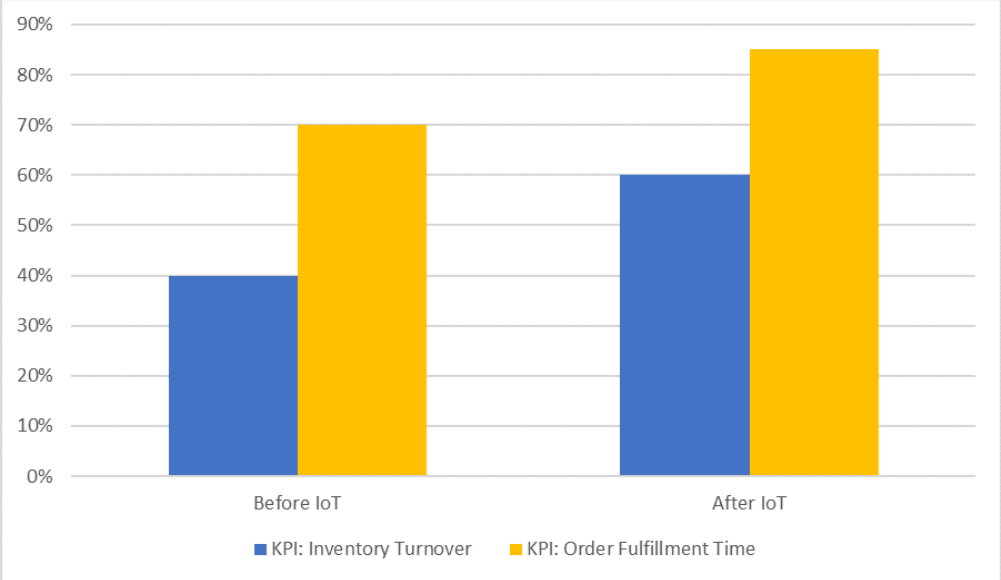

Figure: Improvement in Key Performance Indicators Post-IoT Integration

Description: This bar chart compares the average improvement in key performance indicators (KPIs) for manufacturing companies before and after integrating IoT technologies.

VIII. DISCUSSION

The research study establishes the possibility of IoT in manufacturing supply chain, establishing not only an added advancement but also the achievable strengths and tested issues encountered. The implementation of IoT in this case has helped in the enhancement of other performance measures such as the inventory turnover and order cycle time. Through constant monitoring and analyzing of the data acquired through IoT, manufacturers have been able to reduce the instances of stock-outs, manage their inventories well and manage their orders efficiently. Such changes affect the level of effectiveness, optimisation of costs, and the final consumers' satisfaction, confirming the role of IoT in contemporary manufacturing value proposition.

The case studies also help to explain the specifics of applying IoT solutions and the advantages of integration. In the automotive industry, most IoT applications in the reliability domain revolves around the concept of Predictive Maintenance, which has greatly cut equipment downtime, and boosted the OEE. The above strategies in maintenance are not only useful in improving the functions of the operations, but also in helping maximize the life of many important and costly equipments in the future. In a similar way, where IoT has been implemented in electronics manufacturing sector for Quality Control, the product quality of the products has been raised to higher levels by managing the defect rates. Prieto, Manoby, and R2's examples all point to IoT as having the potential of creating a sustainable environment for incremental enhancements and reinvention of the production processes.

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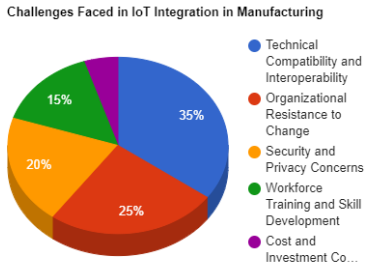

Figure: Challenges Faced in IoT Integration in Manufacturing

Description: This pie chart represents the distribution of primary challenges faced by manufacturing companies during the integration of IoT technologies into their existing systems. The data is derived from the challenges reported by survey respondents.

However, the study also describes many issues that manufacturers experience while addressing the integration of IoT with current systems. Interconnectivity problems and compatibility are among the main challenges that define the IoT implementation process. Most manufacturers implement IoT at their plants and use a combination of innovative hardware and quite outdated ones as well; this situation complicates the problem of how to establish stable interaction between interconnected IoT devices and equipment. Solving most of these compatibility problems entails major expenditure on physical and informational conversion, and establishing of general format in information communication.

In addition to the client-side considerations, there are organizational issues that present major difficulties, such as resistance to change the employee training requirements. In most cases, IoT solutions' adoption to the organization can create friction due to the changes in organizational culture and company practices that may be different from traditional practices the employees are used to. These challenges must be met by conducting specially developed and prescribed training programs and by implementing the right change management to guarantee that the employees in the organization are ready and properly informed to work with and support the functioning of IoT systems. Thus, creating the atmosphere of continuing education and creativity for accepting IoT technology and gaining more advantages of its implementation is challenging.

Security and privacy threats are also of considerable interest when it comes to IoT implementation. The research identified the following potential risks as being the biggest threats to manufacturing companies' operations due to IoT device insecurity: Manufacturers must engage in strict measures to avoid data loss, theft and other related risks, and should employ functions such as encryption of data, use of secure channels/connections and frequent updates of software to enhance on security. Another important factor that needs to be addressed to minimize the security risks and gain the trust of clients and other interested parties is compliance with the requirements of local and international legislation and other requirements.

The presented results on emerging trends reveal the future demand and IoT's potential for manufacturers. For instance, the integration of edge computing as well as 5G networks is anticipated to provide additional improvements in terms of the real-time data processing and communication that constitute supply chains. Combination of AI & Machine learning with IoT is also on the rise providing richer analytics and self-governance abilities. They can also introduce improvements to the predictive

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maintenance, process efficiency and quality control thus expanding the possibilities for the further development of manufacturing industries.

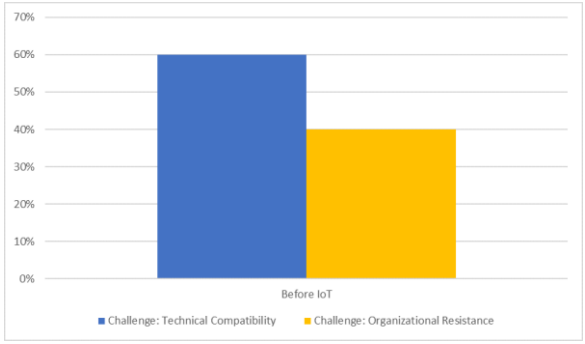

Figure: Prevalence of IoT Integration Challenges

Description: This bar chart depicts the prevalence of the two most significant challenges faced by manufacturing companies during IoT integration.

Thus, the presented discussion underlines the twofold nature of leveraging IoT in the manufacturing supply chain, including major advantages and powerful obstacles. As noted earlier, IoT provides greater efficiency, visibility and responsiveness; however, this comes with certain technical, organizational and security challenges. Thus, it can be concluded the trends of edge computing, 5G, and AI integration represent new opportunities and indicate a promising future for IoT in the context of manufacturing. In regard to the issues and possibilities provided above, the potential of manufacturers to create more robust, flexible and effective supply chains seems to be on the right track for the increasing digital environment. The last part shall reveal the conclusion that will offer the main insights derived from the research process and recommendations for the subsequent research and practice.

IX. CONCLUSION

The integration of IoT solution on manufacturing supply chain management has emerged as a compelling force for increasing more supply chain effectiveness, transparency and quickness. This research has also pointed out the level of change that is possible with IoT and increase in predetermined measures, which include the stock turnover and the time taken to meet orders. Through the provision of essential information or data needed as well as support for predictive maintenance, IoT aspects have supported manufacturing businesses to enhance their operations, minimize the instances of downtimes, and produce quality products.

Still, such advantages indicate that the further implementation of IoT is not without issues that manufacturers have to tackle to realise the opportunities of using the technology. Lack of compatibility and integration with ecosystems, unwillingness of organizations to modify their business models, and security problems are among the main barriers to the IoT integration. These are the barriers that manufacturers have to overcome, for which they need proper data management systems, comprehensive training of employees, proper cybersecurity measures, etc. So, the solutions meeting these challenges need more of the strategic approach, which lies in the union of advanced technology application and adaptation of organizational change with the necessary focus on constant learning.

This study's analysis of the trends in the IoT present in the work highlights a promising future for manufacturing supply chains. Edge computing and 5G in combination with IoT will provide a much

higher level of real-time data processing and connection, AI and machine learning with IoT ensures intelligent analysis and automated decision-making. It is believed that those technologies will continue to fuel more innovation and improvement in creating more flexible, adaptive and robust supply chains effectively for manufacturers.

Summing up, it can be stated that IoT is one of the key technologies that will define the future state of managing manufacturing supply chains. The fact it can offer real-time visibility, prognostics, and automation of numerous business processes can greatly improve such characteristics as productivity and competitive advantage. Nevertheless, for coming around IoT to its real potential, the manufacturer has to solve the technical, organizational, and security issues connected with its implementation. If managed effectively, these challenges and encouraged investing in technologies of the new industrial revolution, today's manufacturers can find themselves standing prepared for a connected and digital future. Further research should expand upon the concept of IoT and its progress in the future based on integration's guidelines, existing technologies, and limitation. The lessons learnt from the present research is useful in developing a constructive framework to establish IoT for superior performances in the supply chain among the manufacturers to ensure competiveness.

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