INTERNET-OF-THINGS AND ITS IMPACT ON INVENTORY, PRODUCTION, LEAD TIMES, AND FORECASTING: EVIDENCE FROM A TIER-1 AUTOMOBILE SUPPLIER IN KARACHI, PAKISTAN

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ABSTRACT

The automobile industry of Pakistan is developing at a fast pace and, despite its relatively small size, is among the fastest-growing sectors of the national economy. This growth, coupled with its potential to stimulate other industries, makes it an important focus for technological advancement. The purpose of this study is to examine the mediating influence of the Internet of Things (IoT) on supply chain forecasting within Tier 1 suppliers of the automobile industry in Karachi, Pakistan. Traditional supply chain forecasting methods are largely based on historical data and static models. Traditional approaches to supply chain forecasting, which mainly rely on historical data and fixed models, often fall short when it comes to dealing with the rapidly changing environment of today's supply chains. These issues cause problems with managing inventory effectively, making the most of production capacity, and keeping lead times on track. The study explores how integrating IoT technology can address these issues and improve the accuracy of forecasts. A cross-sectional study using a quantitative approach was conducted to explore the topic. The group studied consisted of supply chain experts who work with Tier 1 suppliers in the automotive industry. Using Morgan's sample size determination table, a sample size of 384 respondents was established, ensuring a 95% confidence level with a 5% margin of error. Data was collected through a structured questionnaire distributed via convenience sampling. The data was analyzed using SPSS to evaluate the hypotheses. The findings reveal a strong consensus among respondents that IoT adoption has a positive impact on supply chain forecasting. IoT makes it possible to gather data instantly. This real-time information supports better predictions, smarter decisions, and smoother collaboration across everyone involved in the supply chain. These capabilities enhance inventory visibility, optimize production processes, and improve lead time reliability, resulting in more agile and competitive supply chains. This research addresses a notable gap in the limited literature on IoT applications in Pakistan's manufacturing sector and offers practical implications for industry practitioners and policymakers. The results show that IoT can really help make operations smoother, make supply chains more reliable, and make customers happier. Future research could expand the scope to other sectors and explore the long-term impacts of IoT adoption.

Keywords: Internet of Things (IoT), supply chain forecasting, tier 1 suppliers, automobile industry, Pakistan

APPROVAL

This is to certify that this thesis conforms to acceptable standards of scholarly presentation and is fully adequate, in quality and scope, for the fulfilment of the requirements for the degree of Doctor of Philosophy.

The student has been supervised by: **Assistant Professor Dr Dazmin Daud**

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Professor Dr Siow Heng Loke
Asia e University
Chairperson, Examination Committee
(31 July 2025)

DECLARATION

I hereby declare that the thesis submitted in fulfilment of the requirements for the Degree of Doctor of Philosophy is my own work and that all contributions from any other persons or sources are properly and duly cited. I further declare that the material has not been submitted either in whole or in part, for a degree at this or any other university. In making this declaration, I understand and acknowledge any breaches in this declaration constitute academic misconduct, which may result in my expulsion from the programme and/or exclusion from the award of the degree.

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Indeed, all praise is due to Allah, we praise Him, we seek His aid, and we ask for His forgiveness. We seek refuge in Allah from the evil of our actions and from the evil consequences of our actions. Whomever Allah guides, there is none to misguide and whoever Allah misguides there is none to guide. I bear witness that there is no god worthy of worship except Allah and I bear witness that Muhammad is the servant and messenger of Allah.

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LIST OF ABBREVIATION

AeU	Asia e University
AI	Artificial Intelligence
DV	Dependent Variable
FPCCI	Federation of Pakistan Chamber of Commerce and Industry
GPS	Global Positioning System
IoT	Internet of Things
IT	Information Technology
IV	Independent Variable
KPI	Key Performance Indicators
ML	Machine Learning
MV	Mediating Variable
PAAPM	Pakistan Association of Automotive Parts and Accessories Manufacturers
PAMA	Pakistan Automotive Manufacturers Association
RFID	Radio Frequency Identification
SC	Supply Chain
SCM	Supply Chain Management
Tech	Technology

CHAPTER 1

INTRODUCTION

The emergence of the Internet of Things (IoT) has reshaped industrial processes around the world, and supply chain management (SCM) is one of the most deeply affected areas. In the new world order of global business, where adaptability, productivity, and precision are the drivers of competitiveness, IoT is a key facilitator of digital transformation. This technology enables companies to gather, process, and analyze real-time information across the whole supply chain—from inventory management to forecasting—and hence change decision-making. The automobile sector will benefit greatly from the adoption of IoT technologies, especially in Tier 1 supplier businesses that are key to Original Equipment Manufacturers (OEMs).

In Pakistan, especially Karachi—a city with an industrial base—the auto industry is growing at a fast pace. Even though small in size as compared to the world's other players, it is one of the country's fastest-growing industries. Yet the supply chains of Tier 1 suppliers in the industry are usually beset by manual processes, traditional forecasting, low visibility, and little integration, resulting in inefficiencies, high operating expenses, and customer unhappiness.

Precise supply chain forecasting is important for improving inventory management, maximizing production capacity, and reducing lead times. However, conventional methods of forecasting are usually rooted in historical data and assumptions and do not factor in real-time market realities. This deficiency brings forward the requirement for more intelligent, data-based approaches. IoT enables the connection of sensors, devices, GPS, and other digital devices, thus allowing real-time collection of data and smart analytics that aid in predictive and prescriptive forecasting.

These abilities can be important in helping to overcome the operational challenges of Tier 1 suppliers operating in Pakistan's automobile industry.

The integration of IoT into supply chain operations offers several benefits. It enhances inventory visibility and replenishment accuracy, reduces production downtime through predictive maintenance, and improves lead time reliability by identifying and eliminating bottlenecks. By enabling real-time collaboration among supply chain stakeholders i.e. suppliers, manufacturers, and retailers, IoT helps achieve a more synchronized and responsive network, improving the quality of decision-making across the supply chain.

With Pakistan's growing urbanization and rising demand for automotive products, it is critical for companies to adopt technologies that can automate operations and enhance forecasting capabilities. Although the IoT's potential has been well understood across the world, its use in Pakistan, particularly in automotive sector is under-explored. This offers a critical opportunity for empirical research and practical input into the discipline.

This research, thus, endeavors to examine the mediating effect of IoT on supply chain forecasting through an analysis of its bearing on three critical components i.e. inventory levels, production capacity, and lead times among Pakistan-based Tier 1 suppliers of the automotive sector in Karachi. The research will add value to both academic research and practical applications by providing a strategic guide for organizations interested in transforming their supply chains with IoT-based solutions.

1.0 Background of the Study

Supply chains have proven to be more convoluted, interconnected, and prone to disruption than ever before given the highly competitive world economy of recent times. Enterprises are under sustained pressure to produce faster, customised and more

available products while maintaining low costs and efficient operations (Hines, 2024). These demands necessitate supply chain architectures that are responsive, transparent, and capable of adapting to fluctuations in market demand, raw material supply, and capacity constraints (Shoushtari & Ghafourian, 2023).

The ability to accurately forecast demand in supply chains is key to meeting these demands. Accurate forecasting gives organizations the capability to strategically plan to replenish, plan production capacity, and synchronize distribution schedules (Raza & Faisal, 2023). However, traditional forecasting methods—primarily based on past sales history, manual estimates, and irregular review cycles—are likely to falter in volatile environments where demand patterns change abruptly. These shortcomings result in common operational inefficiencies such as overstocking, stockouts, long lead times, and ineffective utilization of production capacity (Neethirajan, 2023).

Advances in technology, particularly in the Internet of Things (IoT), in recent years have opened the doors to new avenues for increasing the accuracy of forecasts (Elgazzar et al., 2022). The IoT refers to a network of connected devices and sensors that collect, transmit, and analyze real-time information from around the supply chain. These devices are employed to monitor inventory levels, recognize and classify goods, analyze equipment performance, and detect bottlenecks or delays in manufacturing and logistics processes. When combined with predictive analytics, cloud computing, and artificial intelligence, IoT data enables companies to make timely and near real time based decisions that maximize operational efficiency, reduce waste, and enhance customer satisfaction (Rajan, 2024).

Across the globe, IoT-based supply chain management has been associated with enhanced inventory visibility, predictive maintenance, demand sensing, and end-to-end visibility. For example, real-time tracking of materials and components allows

manufacturers to respond quickly to disruptions, while predictive equipment maintenance lessens unplanned downtime and maximizes the production capacity output. These directly address some of the most long-standing supply chain forecasting challenges, such as data inaccuracy, information delay, and inability to integrate processes (Bokhari et al., 2023).

In the case of Pakistan, the potential benefits of adopting the Internet of Things (IoT) are especially relevant (Kumar & Aziz, 2023). The nation's manufacturing sector, including its automobile sector, is faced with certain issues such as the unpredictable availability of raw materials, poor infrastructure, political instability, and changing demand patterns. Karachi, the nation's industrial hub, has an incredible number of Tier 1 automobile industry suppliers—companies that offer major components directly to Original Equipment Manufacturers (OEMs) (Umair, 2024). Tier 1 suppliers form the backbone of the manufacturing value chain, and inefficiencies in their operation directly and immediately impact the performance of OEMs (Tébar-Rubio et al., 2023).

Even with technology's contribution to supply chain modernization, which is more and more widely accepted, IoT adoption is low among Tier 1 suppliers in Pakistan (Kumar & Aziz, 2023). Companies still continue to have manual processes, disjointed information systems, and traditional forecasting practices not suited to the dynamics of today's business arena. This results in a disconnect between operational needs and the capabilities of technology — a disconnect that might be closed considerably by IoT implementation, improving forecasting accuracy, lowering costs, and raising the level of customer service (Sallam et al., 2023).

In addition, empirical studies examining IoT's application in supply chain forecasting in Pakistan's automotive industry are scarce. Despite the fact that

international literature records numerous instances of IoT application for improved forecasting and operational efficiency, local research is scarce, and hence, industry players lack context-specific strategies for implementing IoT (Schöggl et al., 2023). The absence of research and practical guidance leads us to special research to explore the potential of IoT's influence on key forecasting-related indicators such as inventory level, production capacity, and lead time. Against this backdrop, the current study seeks to bridge this knowledge gap by examining the mediating role of IoT among Tier 1 auto industry suppliers' supply chain forecasting in Karachi, Pakistan. Through empirical evidence, the study not only adds to the body of academic literature but also offers actionable recommendations to managers, policymakers, and technology adopters on how to make Pakistan's manufacturing sector competitive in a rapidly digitalizing world economy.

1.1 Supply Chain Forecasting Gap in Karachi, Pakistan

Research on the role of IoT in SCM is extensive, however, the majority of the works give general insights about its application in supply chain which doesn't consider the necessities of individual sectors and places. It is clearly evident that the IoT utilization varies based on the character of the industries such as automotive, pharmaceutical, agricultural industries among others due to issues such as; strategies, legalities, and working atmospheres which are unique for each industry (Rath et al., 2024). As with many ICT initiatives, the extent of technological advancement, legislation and corporate culture in different parts of the world plays a big role on how IoT can be properly harnessed (Mahmood et al., 2024). Thus, to achieve more profound understanding of IoT usage in SCM further targeted, special, and locally oriented researches should be conducted to provide valuable recommendations adjusted to the aforementioned issues.

This research will provide a clear understanding of the prospects and limitation of IoT implementation in Pakistan supply chain network. Through constructing a study based on the peculiarity of a developing country, the research would provide more practicable recommendations that would benefit the businesses, policy makers, and technology suppliers to design approaches towards embodying IoT in the specified supply chain, in optimizing its operations, thus improving the general performance of the industries of the specified developing country.

This paper aims at identifying some of the challenges affecting the supply chain sector in the Pakistan economy and how such challenges affect its functionality, precision in estimates and overall success. Among these challenges are poor physical infrastructure, low technology, and innovation, low human capital development, and inadequate and ineffective regulatory frameworks. These bring about a chain of inefficiencies along the supply chain, forcing even the most fundamental processes in an organization or business to be unsuitably slow and uncompetitive for globalization. Most of the transport systems involving roads, railways and port facilities in Pakistan are congested, poorly maintained and work inefficient (Adeusi et al., 2024). This has a direct impact on the delivery movement as it delays deliveries and raise cost of transportation. In addition, these markets lack strong transportation networks that will enable timely and effective delivery and distribution of the products particularly to rural areas. These transportation constrains hinder the supply chain process and timetable, lead to stock out, overstock, and supply chain miss-synchronization (Ahmad & Al-Bazi, 2025). Another challenge of Pakistan's supply chain industry is the low technology proficiency; there is not enough technology used by companies in Pakistan. Today's modern supply chain technologies including ERP, IoT, and data analytics adoption rates are relatively low among SMEs (Basu & Jha, 2024). The absence of

procedure to apply technology affects real-time data gathering and processing crucial for timely and accurate company outlook and visibility in supply chain management. For these technologies are helpful instruments allowing businesses to monitor inventory, track shipments, and react to disturbances. The implication of this approach is that information flow is not transparent and effective and decision making consequently becomes ineffective apart from exacerbating problems of inefficient supply chain management. Another challenge perceived is low human capital development and this is so since there is inadequate population of trained personnel in supply chain and in the knowledge of other current technologies (Agarwal et al., 2022). Consciously, the profession related to logistics, data analysis, and supply chain management is becoming increasingly popular, but the Pakistani education and training ecosystem seems not to have been adjusted to match the demand of this industry. This lack of skills means that firms are not able to optimally apply up-to-date effective supply chain tactics for enhancing performance. The presence of few training programs and certification in the supply chain management lead to the stagnation of improvement strategies in the sector (Munguti et al., 2024). There is also a major problem regarding the absence of relevant legal and regulatory systems that would encourage supply chain transformation as well as increased use of technologies. Supply chain management best practice within countries with well-developed supply chains can be well-defined regulatory policy on data sharing, product tracking and logistics: the Pakistani context is not well-developed as its regulatory framework is fragmented and weak. For example, there are few regulations with regard to privacy of data, and protection against cyber threats besides general agreement on technology best practices throughout supply chain networks, which leaves many firms in a state of ambiguity while seeking to integrate new technologies. Also, unequal implementation of the trade and customs rules creates

a problem such as lengthy time and unpredictability of the flow of goods hence posing an operational challenge to the companies (Akram & Salman, 2023). Combined, all these challenges result to unsuitable supply chain forecasting, long lead time, and less effective visibility in the supply chain. Fluctuating transport links make it very difficult for companies to know when their consignments are likely to be delivered and a low level of technological advancement means they cannot be sure of the likely demand for their products, or monitor their stocks in real time. It also blocks the occasional end-to-end view of supply chain activities, which means it is difficult to determine areas of constraint or to grasp a problem when it occurs, which lowers the flexibility and reaction to them. These challenges, therefore, must be addressed in an endeavour to enhance the supply chain sector of Pakistan. Policymakers target enhancement of infrastructure, acquisition of technology, training human capital, and development of policies to create more transparent and sustainable supply chains will be critical in eliminating most of the inefficiencies, improving the forecasting capacities, and shaping better supply chain wellbeing. Through eliminating these hurdles, Pakistan has an opportunity to establish its position regarding both domestic supply as well as international market (Raza & Faisal, 2023).

Only a limited number of research papers have pointed out the need for enhancing the supply chain forecasting in Pakistan. A survey by (Akbari 2023) mentioned that a major issue that SMEs face is to be able to predict their Supply Chain requirements in the right way. It pointed out that these enterprises usually do not have adequate capital and human capital for forecasting and the exercise ends up being substandard and costly. Accordingly the study suggested that technology be used in this case through use of the internet of things (IoT) devices to enhance the forecasting capability. If IoT technologies are incorporated by SMEs, they would be able to have

an opportunity of acquiring an insight of inventories, demands, and hurdles in the supply chain processes and thus make improved decisions and increase supply chain efficiency. Another study by (Altamash & Muzaffar, 2023) recognized the lack of adequate supply chain forecasting framework appropriate for the Pakistan environment. It was revealed in this research that conventional forecasting techniques are inadequate when it comes to managing the supply chain problems of Pakistan as factors like demand volatilities, market, and infrastructural factors that affect the efficiency of forecasting techniques place a major constraint on the overall results. Literature review of the study recommended the formulation of a sound framework that addresses local market factors, technological trends, and specific industry needs where business entities wished to improve their forecasting processes and supply chain agility. However, the effect of the Internet of Things (IoT) on the inventory, capacity, lead time and the predictability of supply chain has not been highlighted based on the Pakistan's context. The article titled "A grey decision-making trial and evaluation laboratory model for digital warehouse management in supply chain networks" by Zaman et al. (2023) finds that sensor-based forecasting is becoming more important today in Pakistan for the textile sector in Faisalabad, which is a manufacturing city. Internet of Things also known as IoT technologies with the emphasis on higher level technology such as sensor based systems is vital in supply chain and improving the accuracy of the forecasting systems. When implemented in the framework of forecasting, IoT makes it possible to obtain actual time information triggering businesses' better demand prediction and management of inventory as well as improved adaptation to market fluctuations. Although the article takes its focus from the textile industry, it agrees to the need for extending research to other sectors in Pakistan. Textile industry is among a few industries, which might be interested in the