



Smart Technology Improves TPM on Material Handling System in Freight Facilities

التقنية الذكية تعزز مجموع انتاجية الصيانة في مرافق أنظمة الشحن

by

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ABSTRACT (IN ENGLISH)

Total Productive Maintenance (TPM) in material handling systems stands to benefit greatly from the introduction of smart technology into goods facilities. Manual labour-intensive conventional practises typically result in mistakes and higher overall expenses. Focusing on automation, data analysis, cost-effectiveness, security, and scalability, this study investigates the influence of smart technology adoption on TPM in goods facilities. This study takes a holistic look at the link between TPM practises, smart technology integration, and the perceived effects of each. The findings show that there is a strong correlation between the use of smart technology, improved TPM practises, and the perceived effects on TPM. This dissertation uses rigorous statistical analysis to offer useful insights that will help logistics firms improve their material-handling operations in the age of smart technologies.

ABSTRACT (IN ARABIC)

يهدف البحث التالي إلى استكشاف كيفية تحسين الشحن من خلال دمج التقنية الذكية. ينصب التركيز على تطوير نظام يعطي الأولوية لأتمتة البيانات وتحسينها وتحليلها، مع مراعاة الإجراءات التشغيلية الحالية والآلات والقوى العاملة. يتم أخذ عوامل مثل فعالية التكلفة وقابلية التوسع والأمان في الاعتبار. تدور منهجية البحث حول اختبار الانحدار والارتباط. يبلغ حجم العينة 114 شخصًا مع التركيز على عدد منشآت الشحن الإماراتية باستخدام العينات الهادفة. تشمل معايير الاختيار التكنولوجية الذكية في أنظمة مناولة المواد. تشير النتائج إلى وجود ارتباطات إيجابية بين اعتماد التكنولوجيا الذكية وتأثيرها المتصور على مجموع إنتاجية الصيانة.

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Chapter 1 Introduction

Adoption of advanced tech within freight facilities have transformed the way how materials are managed. Smart technology, not limited to data analytics, digital automations, and intelligent sensors are adopted to optimize material handling systems. Smart technology has revolutionised the field of ‘Total Productive Maintenance (TPM)’ and has offered vast insight in the process equipment, enabling predictive maintenance which leads to minimization of downtime (Rajput and Jayaswal, 2012). The dual association of smart technology & TPM has provided freight facilities with enhanced efficiency and effectiveness, increased safety levels and cost savings. In 21st century, production has been defined by the goods/commodities customized for the individual customers.

The tailored production faces fierce competition due to complex production planning and control systems. Businesses that use mass customisation tactics aim to meet the demands of each individual client while minimizing production efficiency loss in tumultuous markets. Hence, as being a significant topic, the following research paper looks forward to explore the different ways in which smart technology has improved TPM with a keen focus on material handling systems within the freight facilities. The paper will also discuss the benefits of adopting smart technology and TPM, with mentioning prominent examples. Lastly, the paper will consider the future of smart technology & its role of TPM in freight facilities.

1.1 Problem Statement

For several logistics companies, improving TPM remains a critical challenge in freight facilities. Despite the consistent efforts to address the challenges, there has been no valid success. The

conventional approach towards TPM is differentiated by dependence on manual workers and labours, which introduces elevated likelihood of human errors, operational setbacks, and increased operational costs (Jain, Bhatti, and Singh, 2014). Full pledge adoption of smart technology has the potential to offer efficient solutions to the addressed problems by automating the integral process and delivering accurate evaluations. The aim of this research is to explore the capacity of smart technology to augment TPM for material handling systems in freight facilities with consideration of cost-effectiveness, security, and scalability. The optimal strategy should give precedence to the automation, optimization, and analysis of data, while considering the existing operational procedures, machinery, and workforce.

1.2 Research Questions

- A. How the integration of smart technology into freight facilities does improves TPM for the material handling systems?
- B. What are the benefits of using smart technology in freight facilities' material handling systems?

1.3 Research Hypothesis

- A. Null Hypothesis (H0): Smart technology and TPM in freight facility material handling systems are unrelated and have no association.
- B. Alternative Hypothesis (H1): Smart technology and TPM in freight facility material handling systems positively correlate.

1.4 Theoretical Model

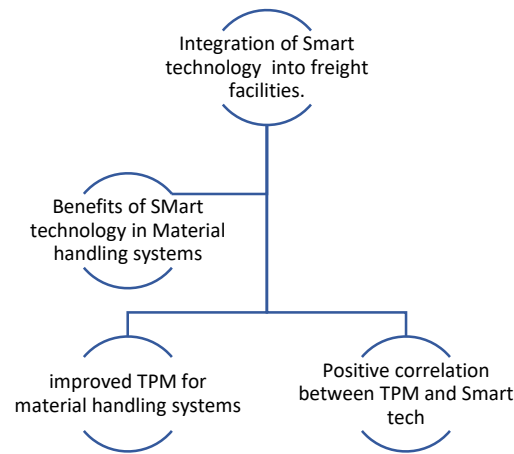


Figure 1: Exhibit – Theoretical Model As Per Study’s Research Objectives And Devised Hypothesis, Source (Self-Created)

1.5 Relevance and Importance of the Research

It is crucial and extremely significant to do study on smart technology's effects on Total Productive Maintenance (TPM) in freight facilities. To increase productivity and reduce expenses, the logistics industry is using smart technology more and more. Companies may obtain a competitive edge in the market by knowing how it can be utilized to enhance TPM. Furthermore, it can enable companies to reduce wastage, boost manufacturing, and reducing human errors throughout the material handling processes (Ahuja, and Khamba, 2008). Lastly, the following research provides critical insight on how TPM can be managed within the sphere of freight facilities, permitting business firms to attain largest shares of their investments in smart tech field.

Chapter 2 Literature Review

2.1 Material Handling in the Freight Industry

Material handling is an integral segment of freight facilities which are important towards supply chain of the business, not limited to distribution centres, warehouses and ports (Rodrigue, 2020). Moreover, efficient material handling is mandatory for seamless operations, reduction of operational expenses, minimization of downtime, and overall improving the productivity. With globalization and competitive business landscape, trade has become common and critical for developed and developing nations. Hence there is a critical need for effective material handling systems within freight facilities.

2.1.1 Importance of Material Handling in the Freight Industry

Existing literature is evident of the fact that material handling is an integral function within the freight industry as it constitutes of movement, control, storage and protection of the commodities throughout the supply chains. The logistics industry comprises of diverse activities, not limited to loading & unloading of commodities, intra facility transportation, the storage & retrieval of the merchandizes, selection of the orders, packaging & shipping (Tien et al., 2019). Moreover, effective material handling is mandatory for minimization of transit time, preventing any sort of damage to the commodities, enhancing the accuracy of the inventory, reduction of labour costs, and improving the consumer satisfaction.

Freight facilities comprise of functions related to distribution centres, warehouses, & ports; these are the critical nodes within the supply chain where material handling plays a crucial role. These facilities are authorised to manage a diversified array of products, constituting of

palletized & non-palletized merchandize, perishable products, and hazardous materials/substances and over dimensional freight (Xiao et al., 2021). Hence, effective material handling becomes significant for ensuring agile and dynamic optimization of the storing and moving activities, minimization of the handling errors, & fulfilling the elevated demands of stakeholders.

2.1.2 Challenges Faced by Freight Facilities

When it comes to material handling operations, freight facilities confront a variety of difficulties, every one of which has the potential to compromise their effectiveness or safety. The following are some of the main difficulties that need to be addressed:

A rising amount of Goods Freight facilities are managing a rising amount of goods because of the expanding globalization of trade and the advent of e-commerce (Allen, Browne, and Cherrett, 2012). This puts strain on the material handling systems to cope with the increasing demand for faster and more precise processing of items, which might lead to bottlenecks and inefficiencies if the systems are not able to meet the higher demand. There are many freight facilities that struggle to hire and keep experienced workers, which leads to higher labour costs and the possibility of disruptions in operations.

Dangers to employees' safety operations involving the handling of materials sometimes include the use of heavy machinery like forklifts, conveyors, and cranes. These machines present dangers to employees' safety and can lead to accidents and injuries. Freight companies have a significant challenge when tasked with reducing the incidence of workplace accidents and ensuring the health and safety of their workforce (Badri et al., 2018).

Many freight facilities are hampered by space restrictions, particularly in metropolitan locations where land is scarce and expensive to purchase. It can be difficult for freight facilities to make the most efficient use of the space they have available for material handling tasks including storing goods, picking them, and transporting them (Ciriello et al., 1999).

Complex activities the material handling activities that take place in freight facilities are complex and involve several different procedures. The procedures revolve around gathering, receiving, placing, storing, packaging, labelling & shipping to the desired destination. It can be dilemmatic as to assure all of the relevant activities are effectively coordinated and in agile way, specifically when it comes to bulk products (Bhandari, 2014).

2.1.3 Impact of Material Handling Systems on Efficiency and Safety

Considerable impact is evident of material handling systems on the freight facilities operations, especially when they are agile and diligent. When integrated in systematic manner, they tend to boost productivity, lower expenses, reduce human errors, and improve customer satisfaction as a whole (Avitabile, 2021). Furthermore, they also enhance the safety measures not limited to development of a working environment which ensures the welfare of the employees, and minimization of any work place hazards or accidents. This leads to several implications related to material handling systems on the efficiency and safety of the freight facilities as stated below:

Implications

Improved performance & productivity: effective and efficient material handling systems permit for rapid and precise transportation of commodities that in turn results in minimal transit time elevated order fulfilment, & improved consumer satisfaction (Heuwinkel, 2022). Utilization of

automations & robotics tech has gradually declined labour expenses, eliminated errors, and boost performance. IoT, the internet of things enables the monitoring and tracking commodities in real time. This leads to enhanced control and visibility, with optimization of operations such as route adjustments and inventory management (Patel et al., 2016).

Reduced expenses: the adoption of material handling systems within the freight facilities is mandatory towards the successful progression of cost management approaches. Efficient material handling processes can save resources such as labour expenses through automation of the repetitive jobs. This also reduces damage percentage (Bandyopadhyay, and Sen, 2011). In addition, the use of IoT and AI technologies for better inventory management and route optimization can cut expenses associated with keeping inventory, transportation costs, and overall operating costs (Singh, Gupta and Shukla, 2021). The implementation of sustainable material handling practices, which entail the utilization of environmentally friendly packaging materials and renewable energy sources, can potentially yield cost savings in the long term through the mitigation of waste and energy consumption.

Minimized Errors: Material handling errors, such as picking the wrong item, packing errors, and misplaced goods, can result in costly returns, delays, and customer dissatisfaction (Zhou and Wen, 2023). When it comes to material handling activities, having well-designed material handling systems, such as automated picking and packaging systems, augmented reality (AR) guided picking, and real-time tracking through IoT, may help reduce the number of errors that occur and increase the accuracy of such processes (Porter and Heppelmann, 2017). This results in fewer returns, a decreased amount of rework, and an increase in customer satisfaction, which eventually leads to cost savings and an improvement in efficiency.

Improved Safety: Operations that include the handling of materials can provide major safety concerns for workers, including the need to carry large objects, do jobs that are repetitive, and be exposed to toxic compounds (Schmidt et al., 2009). When it comes to the physical handling of heavy goods, there is a higher chance of accidents than there would be with properly built material handling technologies. These systems include automated guided vehicles (AGVs) and robotic pickers (Moshayedi, Jinsong, and Liao, 2019). IoT and connection have the potential to enable real-time monitoring of material handling equipment, so enabling predictive maintenance, lowering downtime, and ultimately reducing the risk of accidents caused by equipment failure.

2.1.4 Challenges and Future Directions

Even though material handling systems in freight facilities are becoming more advanced to keep up with the expanding requirements of the industry, these systems still confront obstacles that need to be resolved for additional advances to be made (Montreuil, Meller, and Ballot, 2010). The following are some of the issues and potential future directions that material handling systems may face in freight facilities:

The Cost of Implementation: The cost of implementing sophisticated material handling technologies, such as automation, robots, and IoT, can be rather high up front (Javaid et al., 2021). For certain freight facilities, particularly smaller and medium-sized firms that have limited financial resources, the costs that are associated with acquiring and installing such technologies, in addition to the costs that are paid for training and assimilation, may present a barrier. These costs are in addition to the costs that are incurred for training. The evaluation of cost-effective procedures and the evaluation of return on investment in relation to the

deployment of the technologies will be essential in playing a crucial role in promoting the broad adoption of these technologies (Wright and Monk, 1991).

Workforce Transformation: The implementation of automation, robots, and other forms of cutting-edge technology in material handling activities may need a workforce transformation (Eden et al., 2019). For workers to adapt to the shifting technology and processes, it is possible that their responsibilities and skills will need to develop (Humayun, 2021). It's possible that certain personnel may require further training or retraining to be able to operate and maintain these advanced devices. The difficulty that must be addressed by freight facilities is successfully managing the transformation of the workforce and ensuring that personnel are provided with the appropriate skills and expertise to operate and manage these technologies in an effective manner.

Concerns Regarding Personal Information and Safety: The Internet of Things, along with other digital technologies, introduces new challenges for data privacy and protection, making these issues of paramount importance (Abbas and Dervin, 2009). Material handling systems are responsible for the generation and processing of enormous volumes of data in relation to operations, orders, and inventories. It is very necessary, to maintain the reliability and validity of the system, to protect the data's privacy and ensure that it is not corrupted in any way. This involves securing the system against both cyber-attacks and unauthorized access (Dabbagh, and 2019). To secure their customers' data and continue to earn their confidence, freight facilities need to take stringent security precautions and adhere to all applicable data protection requirements.

Interoperability and Standardization: Material handling systems at freight facilities may require a variety of technologies, pieces of equipment, and software sourced from a variety of different manufacturers. The possibility of differences in communication protocols, interfaces, and data formats might make it difficult to achieve interoperability and standardization across a variety of technologies (Malhene et al., 2012). Due to this aspect, there can be constraints in the attainment of desired objectives. In order to have an effective tech integration, interoperability and standardization becomes critical. To achieve these goals, stakeholders throughout the industry, including technology providers, equipment makers, and freight facility operators, may need to collaborate and coordinate their efforts (Olson, 2013).

Effective performance & Maintenance: in order to have a 100% functional contemporary material handling system, it is necessary that every tech related entity is maintained and serviced by their providers on regular basis. The software needs to be updated with keen administration of the maintenance work (Beuscher et al., 1969). Furthermore, skilled professionals should be authorised to perform maintenance. It is critical that the freight facilities implement substantial maintenance processes to elevate system operations performance and reduce on downtime significantly (Falkenberg, and Spinler, 2022).

Adaptability & Scalability aspects: it is mandatory for the material handling systems to be adaptable and scalable in order to be aligned with the evolving company changes. These changing business needs might include fluctuating quantities, new product lines, and fluctuations in client demand (Montaine et al., 2011). Scalability refers to a system's capability of managing varying levels of demand, whereas flexibility refers to the capability of conforming

to changing needs without requiring significant adjustments. Scalability may be measured by a system's throughput capacity (Kim et al., 2020).

Ecological and sustainability related aspects: today within the corporate world, the topic of sustainability has become more critical as compared to previous decades. Hence, the freight facilities should be examining the complete impact of their material handling processes from every point of the operation. It is possible for material handling systems, particularly ones that use automation and robots, to consume a substantial amount of energy and emit pollutants (Lowenberg-DeBoer et al., 2019). It is possible for freight facilities to lessen their negative influence on the environment and foster a supply chain that is more ecologically conscientious by adopting sustainable practices. Some examples of such practices are the exploitation of renewable energy sources, the optimization of energy usage, and the reduction of waste (Carli et al., 2021).

To ensure the effective implementation and operation of material handling systems, freight facilities need to carefully plan, design, and manage their material handling processes. This includes conducting thorough assessments of the facility's requirements, selecting the appropriate technologies and equipment, integrating them seamlessly, training the workforce, implementing robust security measures, and establishing effective maintenance strategies (Ballou, and Srivastava, 2007). Freight facilities also need to consider the scalability and flexibility of their material handling systems to accommodate changing business needs and future growth.

Effective resolution of challenges pertaining to interoperability, standardization, and sustainability necessitates industry-wide collaboration and coordination among stakeholders, encompassing technology providers, equipment manufacturers, freight facility operators, and regulatory bodies (Huggins, 2002). Collaboration can facilitate the development of industry standards, best practices, and guidelines for material handling systems in freight facilities, ensuring seamless integration, optimal performance, and sustainable operations (Ann and Sullivan, 2018).

2.2 Total Productive Maintenance

The evolution of material handling systems in freight facilities to suit the shifting demands of the industry brings with it several issues that need to be solved before any further progress can be made (Wireman, 2004). In freight facilities, some of the issues and potential future directions of material handling systems include the following:

The Cost of Implementation: The implementation of modern material handling technologies, such as automation, robotics, and Internet of Things, might come with a large up-front financial investment. It is possible that the costs associated with acquiring and installing such technologies, in addition to the costs paid for training and assimilation, may provide a barrier for certain freight facilities. This is especially true for small and medium-sized firms that have limited financial means to work with (Smith, and Hawkins, 2004). The evaluation of cost-effective procedures and the evaluation of return on investment relevant to the deployment of the technologies will be essential in playing a crucial role in supporting the broad adoption of these technologies.

Workforce Transformation: The implementation of automation, robots, and various other forms of cutting-edge technology in material handling activities may need a workforce transformation (Turner, Roy and Wield, 1990). To accommodate the ever-evolving technology and procedures, it is possible that the jobs and responsibilities of workers may need to develop over time. To be able to run and maintain these more modern technologies, it is possible that certain personnel may require further training or retraining (Chan et al., 2005). The difficulty that freight facilities need to face and overcome is effectively managing the workforce change and ensuring that staff are equipped with the essential skills and expertise to successfully operate and manage these technologies.

Concerns Regarding Safety and Privacy: Integrating Internet of Things and other forms of digital technology raises important questions about data protection and user privacy. Large volumes of data pertaining to inventories, orders, and operations are generated and processed by material handling systems. It is essential, to maintain the reliability and validity of the system, to protect the data's privacy and ensure its integrity (Alhirabi, Rana, and Perera, 2021). This protection must include fortification against cyber-attacks and unauthorized entrance (Sibi Chakkaravarthy et al., 2018). To preserve their customers' data and continue to earn their confidence, freight facilities must comply with data protection requirements and apply stringent security precautions.

Interoperability and Standardization: Material handling systems at freight facilities sometimes require a variety of technologies, pieces of equipment, and software that come from a variety of different suppliers. Because of the possibility of differences in communication protocols, interfaces, and data formats, achieving interoperability and standardization across a variety of

technologies can be a difficult task to do. To integrate these technologies in a way that is both smooth and efficient, standardization and interoperability are required (Csengeri, 2014). This may entail collaboration and coordination on an industry-wide scale among many stakeholders, such as technology suppliers, equipment manufacturers, and freight facility operators.

Maintenance and Upkeep Modern material handling technologies, such as automation and robots, call for frequent maintenance and upkeep to guarantee the highest possible level of uptime and performance. This involves doing preventative maintenance, making repairs, and updating software. The management of maintenance and upkeep of the systems might prove to be a complex and time-consuming operation, demanding the knowledge of competent specialists and appropriate resources to complete the work (Garg and Deshmukh, 2006). It is vital that freight facilities put in place comprehensive maintenance procedures to maximize the performance of their systems, limit interruptions, and cut down on downtime.

2.2.1 The key principles of TPM

Autonomous Maintenance entails giving frontline employees the authority to take charge of the cleaning, inspection, and minor repair of their own equipment. This type of maintenance is also known as "take-charge maintenance." – this leads to prevention of any depletion caused to the equipment, initial resolution of any defaults identified, and OEE, referring to overall equipment effectiveness (Arashpour, Enaghani, and Andersson, 2010).

Planned maintenance composes of developing a methodological/preventive approach towards up keeping the equipment. This revolves around regular check-ups, repairs, scheduling of

inspections, and replacements if required. Such approach prevents any sort of malfunctions which are unforeseen and expanding the equipment life span.

Furthermore, quality maintenance places emphasis on improving both the processes and equipment so that flaws occurrence/percentage can be reduced and human errors can be tackled timely. This entails resolving of several underlying issues that result in failure, and developing approaches to raise ISOs.

The functions of safety, health, and environment focuses on providing a safe and healthy working environment for workers as well as limiting the influence that equipment and maintenance procedures have on the surrounding environment. This includes things like conforming to any applicable standards, putting safety precautions into place, and working to ensure environmental sustainability (McKinnon et al., 2010).

2.3 Smart Technologies

According to Ding et al., (2020), "Smart Technologies" refer to computer systems that make it possible to automatically acquire, examine, and combine data, typically coming from a variety of sources. By utilizing smart technologies, one may optimize their systems to achieve greater levels of efficiency and production, while simultaneously increasing their sense of security and reducing their financial outlays. Smart technologies include a wide variety of complex technical systems, such as robots, artificial intelligence, and the Internet of Things (IoT). and analytical processing of data v.

Into the context of the modern industrial sector, there is an increasing emphasis placed on the use of intelligent technology into freight facilities. The application of intelligent technology has

made it possible to increase manufacturing methods' efficacy and flexibility, which has led to the technology's widespread use in material handling and transportation mechanisms (Patel et al., 2022). The development of intelligent technology has made it possible to monitor goods and resources in real time and has also allowed for the automation of processes such as stock control, route optimization, and administration of vehicle fleets. In the context of material handling systems, the advancements that were developed have made it easier to improve Total Productivity Management (TPM) (Kamath, and Rodrigues, 2016). The purpose of this literature study is to investigate whether the use of smart technology in freight facilities influences Total Productive Maintenance (TPM) practices for material handling systems.

Improving TPM on Material Handling Systems may also be accomplished through the usage of the Internet of Things (IoT). The Internet of Things (IoT) has the potential to give real-time data on the status of equipment using sensors, which will make it easier to detect and evaluate issues in a timely manner. This capability is made possible by the IoT's potential to supply such data. The application of this strategy has the potential to reduce downtime while simultaneously improving quality and reliability.

There is a possibility that the effectiveness and productivity of the transportation and material handling system may be improved by the implementation of intelligent technology within freight facilities. Within the realm of freight facilities, the implementation of Total Productive Maintenance (TPM) has been made easier because to the incorporation of intelligent technologies. Total Productive Maintenance, sometimes known as TPM, is a method of maintenance that places an emphasis on both preventative and proactive maintenance measures (Dogra et al., 2011).

Over the past decade, the adoption of TPM within freight facilities have been made feasible; this has been possible only due to the integration of smart technologies. ST includes the utilization of different sensors which are used to identify any performance issues. It is also equipped with the ability of providing real-time monitoring of the commodities through tracking devices allocated in centralised location. Furthermore, it has also made the automation of fleet monitoring processes feasible which has led to minimization of the expenses linked with the transportation of the commodities. All of the modifications have proved to leverage TPM for material handling systems (Kanta et al., 2005).

Smart technologies have proved to increase the effectiveness of material handling systems and relevant transportations within the freight facilities. It has been certainly a welcoming development in the SCM field (Kozlenkova et al., 2015). Smart technology comprises of the potential to simplify preventive, automated and predictive maintenance procedures. This as a result leads to minimize the severity of any disruptions and cargo transportation efficiency is improved.

2.3.1 Recent Trends and Technologies in Material Handling

Due to automation and emergence of robotic assemblies, there has been a complete revolution within the field of material handling activities. It is possible to improve productivity by decreasing the amount of manual labour, errors, and throughput that is required by utilizing automated guided vehicles (AGVs), conveyor belts, and robotic pickers. Products may be transported by autonomous AGVs without the need for human intervention (Mehami, Nawi, and Zhong, 2018). With the help of robotic pickers, order fulfilment may be accomplished more

quickly and accurately. The use of automation and robotics helps cut down on injuries that are caused by the handling of heavy objects and tasks that involve repetitive motion.

The integration of material handling systems has resulted in better visibility and control. The ability of sensors and devices connected to the Internet of Things to monitor the status of items and transfer them in real time improves material handling procedures. This improves the administration of inventories, the monitoring of orders, and the optimization of routes for freight facilities, resulting in increased efficiency and decreased costs. Utilizing IoT for predictive maintenance on material handling equipment helps to cut down on downtime and ensures that operations run smoothly (Ayvaz, and Alpay, 2021).

Advanced analytics and insights into decision-making from AI and machine learning technologies are transforming the operations of material handling. By analysing historical order data, inventory levels, and demand estimates, AI systems can optimize order picking, packing, and shipping processes. Algorithms that learn from experience may continually improve productivity and precision by optimizing and streamlining processes. Artificial intelligence and machine learning provide predictive analytics, which improve material handling decision-making. These analytics may be used for demand forecasting, inventory management, and route optimization (Toorajipour et al., 2021).

AR and VR are helping to improve the precision of material handling while simultaneously lowering the number of errors. AR may be used to superimpose real-world objects, such as pallets or shelves, to assist staff in selecting and packing things, therefore reducing the number of errors, and increasing efficiency. Virtual reality allows workers in the material handling

industry to practice their jobs without running the risk of injuring themselves or breaking anything (Berg and Vance, 2016). Specialists can guide workers through difficult material handling tasks via remote assistance, such as augmented reality and virtual reality, enhancing both accuracy and efficiency (Reif, and Walch, 2008).

The freight industry is seeing a big shift toward a more sustainable way of doing business. Packaging that is better for the environment is being used in freight facilities, along with equipment that uses less energy and is optimized to reduce waste. Solar panels and wind turbines provide the electricity for material handling activities, therefore reducing the amount of carbon emissions and the overall impact on the environment. Material handling practices that are environmentally responsible boost operational efficiency, reduce operating costs, and safeguard the environment (Kumar, 2021).

Another development that is influencing material handling systems is the rise of collaborative supply chain networks (Lam et al., 2008). When it comes to material handling, more collaboration between shippers, carriers, and warehouses may improve visibility, coordination, and efficiency. Warehouses and distribution centres that are shared help maximize the utilization of space and resources, which results in cost savings. Transportation networks that collaborate to improve route planning, load consolidation, and last-mile delivery can save costs and increase customer satisfaction. The use of material handling systems that promote collaboration along the supply chain results in increased operational efficiency and cost savings.

The material handling systems of freight facilities are beginning to integrate block chain technology. Block chain technology grants supply chains the capacity to be transparent, secure,

and traceable. It can protect things, inventories, and product authenticity, track them efficiently, and this will result in fewer instances of counterfeit goods and fraud (Jraisat et al., 2023). Block chain technology has the potential to streamline documents like bills of lading and customs clearance, therefore reducing the time and resources needed for administrative tasks. Using block chain technology in freight facility material handling systems enhances the facility's trustworthiness as well as its transparency and efficiency.

Individualization and customisation the current highly competitive market necessitates the individualization and customization of products. For the sake of customization and personalization, material handling systems are now being developed. These processes often demand for varied forms of handling, packaging, and labelling. Material handling systems that are flexible and adaptable can handle objects of varying sizes, shapes, and packaging requirements, and they may also be customized. To keep up with the demands of the industry, flexible material handling systems are required for customization and personalization (Piller, 2010).

2.3.2 The benefits of using smart technology in improving TPM for material handling systems

Smart technology is revolutionizing manufacturing and material handling systems (Wu et al., 2016). Technology can improve Total Productive Maintenance (TPM) and assist organizations optimize their manufacturing operations. Smart technology may increase TPM accuracy, safety, asset usage, and cost.

2.3.2.1 Process accuracy

Smart technology improves production and material handling precision. Sensors and automation enable this precision. Sensors can locate goods to ensure they are transferred at the proper moment. This improves production precision and reduces waste from erroneous material placement. Automation can also assure production process consistency. This reduces mistakes and improves product quality (Ammar et al., 2021).

2.3.2.2 Improved safety

Smart technologies can increase material handling safety. Sensors can identify workers and automate material handling. This can prevent accidents and improve manufacturing worker safety (Ammar et al., 2021).

2.3.2.3 Better Asset Use

Real-time material availability information from smart technologies helps boost asset use. This can help firms plan output and avoid costly material shortages. Smart technology can also analyse production data to identify waste and inefficiency and increase asset utilization (Ammar et al., 2021).

2.3.2.4 Lower Costs

Smart material handling methods minimize expenses. Automated methods eliminate manual labour and costly mistakes. Sensors decrease material waste from erroneous placement. Reduced material purchases save firm's money. Smart technology improves TPM procedures for enterprises. Smart technology improves process accuracy, safety, asset usage, and cost. This

can improve TPM and assist organizations optimize manufacturing processes (Ammar et al., 2021).

2.4 Measures can be taken to ensure the proper implementation of smart technology for TPM in material handling systems.

2.4.1 Automation

Automating material handling can help apply smart technologies for TPM. Automation reduces human work and boosts efficiency (Lutz et al., 2018). Automation improves accuracy and reduces human error. Automation simplifies inventory tracking, material ordering, and material handling. Automation helps deliver materials on schedule and in the right amount.

2.4.2 Data collection and analysis

Data collection and analysis can assist TPM smart technology installation succeed (Gallagher, 2008). Data gathering and analysis can assist enhance the TPM system and accomplish goals. Sensors, cameras, and RFID tags capture data. This data can indicate underperforming and improvement areas.

2.4.3 Smart technology

TPM deployment requires training and education. Training and education may assist stakeholders understand and use the TPM system. Training may also assist stakeholders understand risks and how to manage them.

2.4.4 Real-Time Monitoring

Real-time monitoring helps verify TPM system performance. Real-time monitoring can inform staff of system concerns. This can assist resolve TPM system faults promptly and save delays.

2.4.5 Auditing

Auditing can verify TPM smart technology implementation. Auditing may uncover areas for improvement and verify the TPM system meets goals. Auditing can also uncover hazards and assist manage them.

2.5 Limitations

The freight business has substantial barriers to the application of modern material handling systems. The initial investment required to implement automation and IoT technologies might be prohibitive, especially for smaller operations (Shah and Yaqoob, 2016). The transition of the workforce is critical yet difficult, necessitating intensive retraining initiatives. The massive volume of data created raises privacy and security issues, calling for stringent cyber defences. Attempts at seamless integration may be hampered by interoperability concerns that arise when using technology from different vendors. Important but difficult-to-achieve goals like dependable performance, flexibility, and scalability need meticulous preparation and expert administration. The necessity for eco-friendly activities is highlighted by issues of ecological sustainability, such as energy consumption and pollution from automation (Chen, Boudreau and Watson, 2008). Establishing industry standards and guidelines requires extensive collaboration and coordination among relevant parties. Space limitations in urban settings and the complications of complying with regulations only add to the difficulties. Implementing material handling systems in freight facilities is difficult because of the inherent risks involved, such as technical obsolescence and reliance on suppliers (Davis, Sheahan and Dougall, 1971). To overcome these constraints and maintain efficient and long-lasting operations, it will take careful preparation, ongoing education, and cooperation throughout the sector.

2.6 Conceptual Framework

Variables:

1. Smart Technology Integration

- Automation, Sensors, IoT, Data Analytics

2. Workforce Proficiency

- Training, Skill Development, Knowledge Enhancement

3. Total Productive Maintenance (TPM) Practices

- Preventive Maintenance, Predictive Maintenance, Equipment Optimization

4. Outcomes: Operational Efficiency & Perceived Impacts

- Operational Efficiency: Equipment Reliability, Downtime Reduction, Cost-effectiveness
- Perceived Impacts: Equipment Reliability Perception, Performance Perception, Safety Perception

Relationships:

1. Smart Technology Integration → Workforce Proficiency

- Smart technology enhances workforce skills through training programs.

2. Smart Technology Integration → TPM Practices

- Smart tech directly influences effective TPM strategies.

3. **Workforce Proficiency → TPM Practices**

- Skilled employees optimize TPM methods.

4. **TPM Practices → Operational Efficiency**

- Effective TPM improves operational aspects.

5. **TPM Practices → Perceived Impacts**

- Enhanced TPM leads to positive employee perceptions.

Chapter 3 Research Design and Methods

3.1 Research Methodology

The purpose of this quantitative research was to examine how intelligent technology and Total Productive Maintenance (TPM) in freight facilities' material handling systems interact. To assure the validity and dependability of the results, the study design was systematically constructed and using rigorous procedures.

3.1.1 Research Goals

The study's overarching objectives were to (1) investigate the connection between smart technology and TPM, (2) determine the role of smart technology in improving TPM, and (3) evaluate the barriers to using smart technology for TPM in freight facilities' material handling systems.

3.1.2 Study Design

Multiple goods terminals were analyzed as part of a cross-sectional research project. Simultaneous data collection on smart technology and TPM factors allows for a snapshot of the connection at a given moment.

3.1.3 Sampling

Freight terminals with advanced material handling systems equipped with smart technologies were purposefully sampled. This specific method assured that the chosen facilities were appropriate for the study's aims and hypotheses.

3.1.4 Data Gathering

A thorough questionnaire was devised to collect this data, and it was distributed to all relevant parties involved in the material handling industry. The questionnaire combined both open-ended and closed-ended questions about facility characteristics, smart technology implementation, TPM procedures, and the respondents' impressions of smart technology's impact on TPM.

3.1.5 Questionnaire Development

The questionnaire used in this research was carefully prepared to collect detailed information on the use of TPM and other smart technologies in MHS and freight terminals. The questions were developed using a methodical strategy, with information gleaned from reliable studies of logistics, technology adoption, and preventative maintenance procedures. Questions in the demographics part were adopted from regular business surveys and included categories including age range, gender, level of education, and years of experience. The evaluation of the degree of deployment of smart technology was influenced by previous works on sensor and automation systems and real-time data collection. Based on well-established TPM frameworks, evaluation questions for TPM practises were designed, covering ground such clearly defined practises, employee training, ownership, continuous development, and KPIs. Additional factors, including as training, maintenance, automation, and user experience, were adopted from surveys used in research on the effectiveness of technological systems. Finally, indicators of technology impact in industrial settings were used to develop questions exploring the perceived impacts of smart technology on TPM. These indicators include things like overall equipment efficiency, downtime reduction, real-time monitoring, data-driven decision-making, and increased safety and security. This modification assured the validity and relevance of the questionnaire, which

allowed for more precise data collection and more in-depth analysis in line with the study's aims.

The survey is attached in the appendix section.

3.1.6 Data Analysis

The connections between smart technology and TPM were investigated using quantitative methods of data analysis:

3.2 Quantitative Methods

3.2.1 Description Statistics

Means, standard deviations, and frequencies were used as descriptive statistics to summarize the questionnaire responses. This presented a wide-ranging survey of the use of smart technologies, examples of TPM in action, and evaluations of their effects.

3.2.2 Correlation Analysis

To evaluate the degree and direction of the association between smart technology and TPM, a correlation study was performed using either Pearson's or Spearman's rank correlation coefficients, depending on the parameters of the data. Using this technique, we were able to find concrete evidence of connections between our key variables.

3.2.3 Multiple Regression Analysis

Smart technology's effect on TPM was calculated using multiple regression analysis, which accounted for factors including facility size, industry, and personnel education. Taking into account a wide range of criteria, our investigation shed light on how smart technology affects TPM in freight facility material handling systems.

3.2.4 Data Integrity

Using validated scales, administering a pilot survey, and performing data cleaning all contributed to the reliability of the collected information. The quality of the collected data was improved by these actions.

3.2.5 Ethical Considerations

Research design and data gathering will consider ethics. Before data collection, freight facilities will provide informed consent and describe the project. Facilities will remain anonymous, and data will be utilized exclusively for the study. Conflicts of interest shall be reported and controlled. Research will follow the institution's ethical standards.

3.2.6 Limitations

This quantitative research strategy has significant drawbacks. First, the cross-sectional design may minimize causality between smart technology and TPM. Time and budget restrictions may prevent longitudinal or experimental designs from proving causation. Second, freight facility self-reported statistics may add social desirability bias or response bias. Careful questionnaire design, data collecting, and statistical methods will reduce these biases. Third, the results may only apply to the freight facility sample. To improve external validity, a varied sample will be sought.

This study investigates smart technology and TPM in freight facility material handling systems using quantitative approaches. Quantitative research uses cross-sectional design and purposeful sampling. A systematic questionnaire will collect data for descriptive statistics, correlation analysis, and multiple regression analysis. Scales, questionnaire pre-testing, and data cleaning

will assure data validity and dependability. Research design and data gathering will consider ethics. However, the study design and quantitative methodologies may have limits, which will be minimized to improve the validity and generalizability of the findings.

3.3 Plans

Using this study technique and quantitative research methodologies, an investigation of smart technology and TPM in the material handling systems of freight facilities is carried out. To have a better grasp on things, however, further research is needed in several different areas:

3.3.1 Longitudinal study

The investigation of causality is hindered by the cross-sectional design of this study. It is possible to analyse the implementation of TPM and smart technology over time in the same freight facilities by employing a longitudinal research approach. As a result, causality would be strengthened, and the dynamic relationship between smart technology and TPM over time would become more apparent.

3.3.2 Experiment

During experimental research, the causal relationship between smart technology and TPM may be evaluated. A controlled experiment might randomly assign freight facilities to either an intervention group that uses smart technology or a control group that does not use smart technology. The TPM impacts of the two groups after the intervention may be compared to give better confirmation of the intervention's causality.

3.3.3 Analysing Industry Comparisons

Although TPM and smart technology have applications in a variety of fields, the emphasis of this investigation is on freight facilities. A potential future line of research may investigate the impact that smart technology has had on TPM in the manufacturing, shipping, warehousing, and retail industries to identify sector-specific patterns and trends. It is possible that this will shed light on the generalizability of the findings as well as the contextual elements that influence TPM and smart technologies.

3.3.4 Qualitative Study

This study makes use of quantitative research approaches; nevertheless, qualitative research may be able to present the perspectives of freight facilities on smart technology and TPM. To researching the challenges, opportunities, and outcomes associated with the adoption of smart technology in freight facilities, interviews or focus groups might be deployed. It's possible that this will improve the quantitative findings. An Examination of Mediation and Moderation

In this research design, smart technology has an immediate impact on TPM. It's possible that other factors might weaken this link. An investigation of the impact of smart technology and TPM on a company's culture, leadership, or employee participation might be the focus of a mediation or moderation study. It's possible that this will shed light on the workings and dynamics of the connection.

3.3.5 Cost-Benefit Analysis

The present research design centres on the influence of smart technology on TPM. However, it would be advantageous to perform a cost-benefit evaluation of smart technology integration in

freight facilities. Conducting an evaluation of the expenses linked with the adoption, implementation, and upkeep of smart technology, along with the potential advantages in relation to enhanced TPM, efficiency, and productivity, may offer a comprehensive assessment of the value proposition of smart technology in freight facilities.

The present study employs a research design that incorporates quantitative methods to comprehensively examine the effects of smart technology on Total Productive Maintenance (TPM) in material handling systems within freight facilities. The study employs a quantitative methodology, utilizing a cross-sectional research design and purposive sampling technique. The methodology employed in this study will entail the use of a structured questionnaire to gather data. The maintenance of validity and reliability of the data will be guaranteed by employing established scales, conducting pre-testing of the questionnaire, and implementing data cleaning procedures.

The research design and data collection process will incorporate an examination of ethical considerations. It is crucial to recognize the possible constraints of the research design and quantitative techniques. Therefore, measures will be taken to mitigate these limitations to augment the credibility and applicability of the outcomes. Prospective investigations may explore longitudinal or experimental methodologies, cross-industry comparisons, qualitative inquiry, mediation and moderation analyses, cost-benefit evaluations, and other pioneering techniques to augment our comprehension of the correlation between intelligent technology and TPM in material handling systems within freight facilities.

The following research has the tendency to develop significant contributions to the existing literature review pertaining to SCM, smart technology, and TPM within material handling systems. The findings will provide in-depth insights regarding multiple perspectives to freight facilities and logistics entities. This will enable to make well-informed decisions towards execution and integration of smart technology to improve TPM prospects.

The following research offers incredible implications towards industrialists, TPM practitioners, and policy makers. With the knowledge in hands, stakeholders can utilise it to formulate effective approaches aiming to drive the adoption of different smart technologies. As a result, it will result in TPM improvements & operational efficiency within freight facilities. It can be concluded that quantitative research design has been effective in presenting correlations between TPM & smart technologies within MHS located in freight facilities. Additionally, these findings may hold pragmatic significance for freight facilities and other relevant parties in the freight transportation sector.

3.3.6 Methods Employed to Answer the Research Questions

The key quantitative techniques used in this investigation were regression analysis and correlation. Total Productive Maintenance (TPM) at logistics centres was analysed in connection to smart technology integration using a regression model. Strong and directional links between factors like operational efficiency and customer satisfaction were analysed using correlation analysis. These techniques helped us gain a deeper grasp of the research topics by

providing quantitative insights into the effects of smart technology on material handling systems. You can include this clarification in the paper's Methodology section.

Chapter 4 Results and Discussion

4.1 Hypothesis Testing

4.1.1 Hypotheses

Null Hypothesis: There is a significant relationship between extent of smart technology implementation and Perceived impacts of Smart Technology on TPM

Alt Hypothesis: There is no significant relationship between extent of smart technology implementation and Perceived impacts of Smart Technology on TPM.

The ANOVA table examines the origins of variability within the dataset.

The between groups analysis yielded an SS of 0.864, 2 df, and an MS of 0.432. The F-statistic is 0.384 with a corresponding p-value of 0.681. The F-value critical at a given significance level (α) is 3.022.

The within-group sum of squares (SS) is 381.611, with 339 degrees of freedom (df) and a mean square (MS) of 1.126.

The SS is 382.475 and the df is 341.

4.1.2 ANOVA Table Analysis

The hypotheses about the links between smart technology integration, TPM practises, and perceived impacts were tested using the ANOVA Table 1.

SUMMARY				
Groups	Count	Sum	Average	Variance
Extent of Smart Technology Implementation	114	424.47	3.72342105	1.19394306
TPM Practices	114	426.2	3.73859649	1.08469182
Perceived Impacts of Smart Technology on TPM	114	437.4	3.83684211	1.09845366

From a survey of 114 organizations, we give here information on the level of adoption, TPM practices, and perceived effects of smart technology. It provides averages and standard deviations for these variables, shedding light on the correlation between smart technology adoption and Total Productive Maintenance (TPM) in a variety of settings.

Table 1: ANOVA Table

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.864379532	2	0.43218977	0.38393109	0.68147417	3.02236212
Within Groups	381.6110044	339	1.12569618			
Total	382.4753839	341				

The ANOVA table indicates an F-statistic of 0.383931095, a p-value of 0.681474168, and a F critical value of 3.022362118.

Since the p-value is greater than alpha level of 0.05, we don't have enough evidence to reject the null hypothesis hence we can conclude that there is significant relation between the degree of smart technology integration and the perceived effects of smart technology on TPM.

4.2 Demographic Information

4.2.1 Age

The distribution of respondents across various age groups can be observed from the Table 2. The age group of 18-29 has the highest count and percentage of respondents, with 47 individuals representing 41.2% of the total. The aggregate proportion up to this age cohort amounts to 41.2%.

The subsequent demographic cohort, aged between 30 and 39, comprises a total of 28 individuals, representing 24.6% of the overall sample. Incorporating this value into the cumulative percentage yields a combined total of 65.8%.

Proceeding further, the cohort aged between 40-49 comprises 38 persons, accounting for 33.3% of the aggregate. This contributes to the aggregate percentage, culminating in a combined total of 99.1%.

Ultimately, there exists a singular individual within the demographic of individuals aged 60 years and above, constituting 0.9% of the aggregate population. Upon addition to the preceding cumulative percentage, the resultant sum attains 100%, thereby signifying the comprehensive inclusion of the entire dataset.

In general, the table presents a comprehensive summary of the allocation of participants among various age categories, featuring a distinct representation of the proportion of participants within each category and the cumulative percentages leading up to each category.

Table 2: Demographics of age in the respondents

Age	18-29	47	41.2	41.2	41.2
	30-39	28	24.6	24.6	65.8
	40-49	38	33.3	33.3	99.1
	60-Above	1	0.9	0.9	100
	Total	114	100	100	

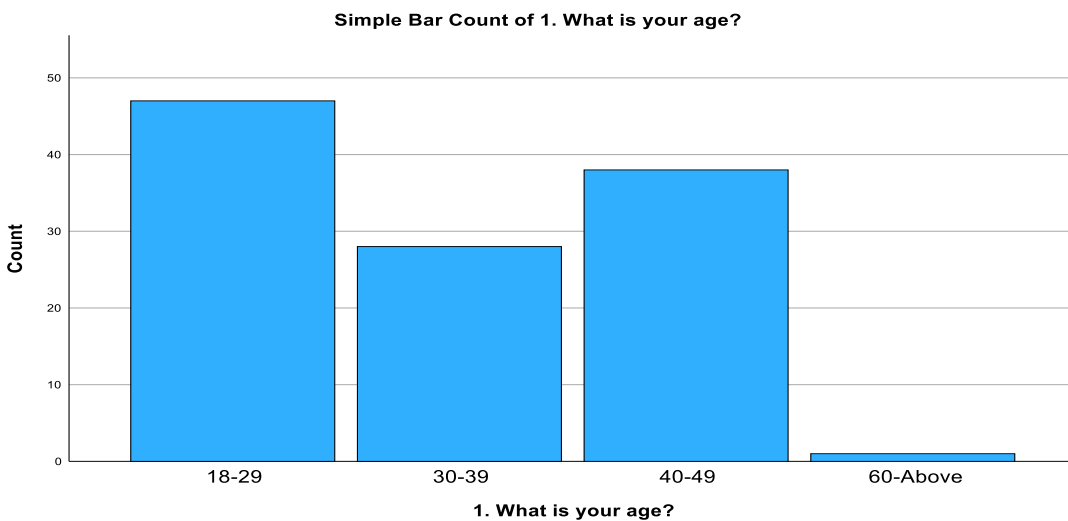


Figure 2: Demographics of age in the respondents, Source: Survey data

4.2.2 Gender

The data presented in Table 3 allows for the observation of the distribution of participants according to their gender. There are 24 females, representing 21.1% of the sample population. The following data depicts the frequency and proportion of respondents who identified as female. The percentage deemed valid is 21.1%, as all participants have been included in this classification. The aggregate percentage up to the category amounts to 21.1%.

Conversely, the total number of male respondents amounts to 90, which accounts for 78.9% of the entire sample. This denotes the frequency and proportion of male participants. The percentage of validity is 78.9%, given that all participants are included in this classification. The cumulative percentage up to this category is 100%, signifying that all the participants have been duly considered.

The aggregate number of participants amounts to 114, constituting the entirety of the sample. Both the valid percentage and cumulative percentage values are equal to 100%, which implies that the analysis encompasses all the participants.

To summarize, the table presents a comprehensive depiction of the allocation of participants according to their gender. The study provides a detailed account of the gender distribution within the dataset by presenting frequencies, percentages, valid percentages, and cumulative percentages for each gender category.

Table 3: Demographics of Gender in the respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Gender	Female	24	21.1	21.1	21.1
	Male	90	78.9	78.9	100
	Total	114	100	100	

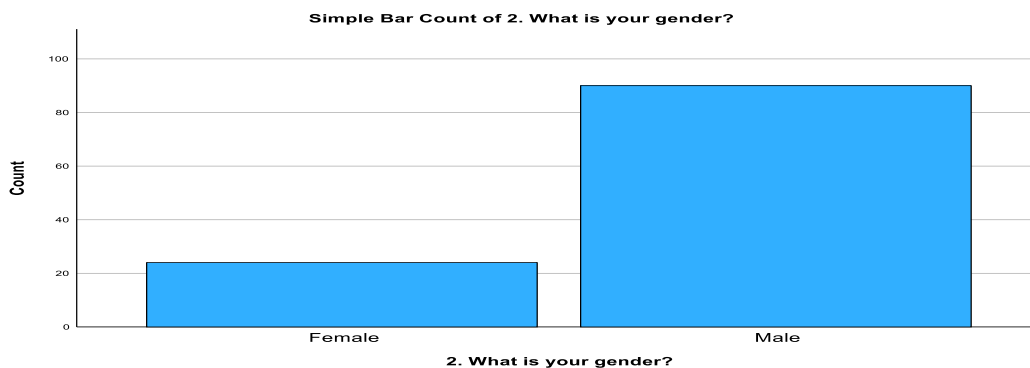


Figure 3: Demographics of Gender in the Respondents, Source: Survey data

4.2.3 Level of education

The distribution of respondents based on their level of education can be observed from the Table 4. The data indicates that a significant proportion of the participants, specifically 69 individuals

(60.5%), possess an undergraduate degree. This observation denotes the maximum frequency and proportion in the tabular data.

There exist individuals who possess advanced academic credentials. There are 33 participants, representing 28.9%, holding a master's degree, while 3.5% of the participants holding a Doctorate. These individuals are representative of the subsequent most prevalent educational classifications.

Furthermore, the data reveals that 6 participants (5.3%) possess a high school level of education, while 2 respondents (1.8%) belong to the "Other" category, which may suggest unconventional or unspecified educational backgrounds.

The sample size comprises 114 participants, constituting the entire population. The valid percentage pertaining to each educational category denotes the proportion of participants belonging to that category, while the cumulative valid percentage signifies the summation of valid percentage values across all categories, culminating in a total of 100%.

To summarize, the table offers valuable insights regarding the distribution of participants according to their educational attainment. The presented data showcases the frequencies and percentages of participants belonging to distinct educational categories, thereby providing a comprehensive summary of the educational qualifications of the surveyed populace.

Table 4: Levels of education across the respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Level of Education	Bachelor Degree	69	60.5	60.5	60.5
	Doctorate	4	3.5	3.5	64
	High school	6	5.3	5.3	69.3
	Master Degree	33	28.9	28.9	98.2
	Other	2	1.8	1.8	100
	Total	114	100	100	

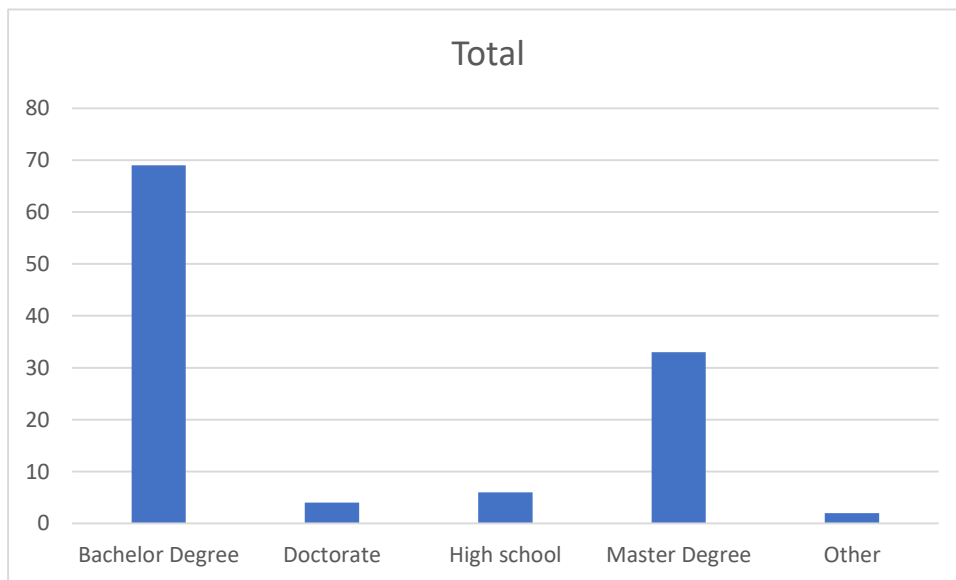


Figure 4: Level of education across the respondents, source: survey data, Source (Survey data)

4.2.4 Work Experience

The distribution of respondents based on their years of experience can be observed from the Table 5. The category of "6-10 years" has the highest frequency and percentage, with 37 individuals (32.5%) falling into this group, according to most respondents.

The subsequent prevalent classification is "3-5 years," which garnered responses from 35 participants, representing 30.7% of the total sample. Subsequently, the "0-2 years" classification is comprised of 32 participants, accounting for 28.1% of the sample. The tripartite classifications constitute the predominant cohort of participants, comprising a combined proportion of 67.5%.

The two remaining age groups, namely "11-15 years" and "16-Above years," exhibit a lower number of participants, with 7 respondents (6.1%) and 3 respondents (2.6%), correspondingly.

The categories make a collective contribution towards the cumulative percentage, ultimately culminating in a total of 100% when amalgamated with the preceding categories.

Table 5: Level of experience demographics in the respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Years of Experience	0-2 years	32	28.1	28.1	28.1
	11-15 years	7	6.1	6.1	34.2
	16-Above years	3	2.6	2.6	36.8
	3-5 years	35	30.7	30.7	67.5

	6-10 years	37	32.5	32.5	100
	Total	114	100	100	

It can be culminated that participant's distribution is represented in years of their respective experience. The statistics represent the analysis derived from frequencies, valid percentages, & cumulative percentages as well for each of the mentioned categories.

4.3 Descriptive Statistics

Extent of Smart Technology Implementation

1. The MHS and freight facilities have adopted smart technologies such as sensors, automated systems and IoT.
2. Smart technologies are adopted and monitored; furthermore, data is collected relevant to MHS such as inventory levels, equipment performance, optimization, and operational efficiency.
3. The MHS and freight facilities utilise data driven decisions and advance analytics to optimize TPM practices.
4. Investments in T&D are evident to upgrade the current competencies of the workforce.
5. The employees are trained regularly with elevating their knowledge and experiences for TPM practices.

TPM Practices

1. MHS and freight facilities under consideration have well-organised TPM procedures such as cleaning, inspection routines and equipment maintenance.
2. The freight facility and MHS under consideration comprises of well-defined operational strategies.
3. Workplace is consistently empowered and trained to take ownership for the TPM practices; they are pro-actively involved in acknowledging the equipment issues.
4. All of the TPM practices are consistently optimised due to their data driven insights and regular analysis of equipment performance.
5. KPIs have been established to measure and evaluate the TPM practices effectiveness in MHS and freight facilities.

Perceived Impacts of Smart Technology on TPM

1. Smart technology has overall enhanced the availability, functionality, and reliability of the equipment in the MHS and freight facility.
2. ST has also elevated effectiveness, and efficiency of the TPM operations resulting in the reduction of downtime & improved performance.
3. ST has also enabled real time monitoring/controlling; reductive maintenance is also evident permitting the business organizations address potential gaps.
4. Safety and security has also been enhanced through real time monitoring and alerts for any breaches.

For the response of the participants, Table 6 shows the labels and values desired for participants.

Table 6: Values and labels used in the survey

Value	Label
1	Strongly Disagree
2	Disagree
3	Neutral
4	Agree
5	Strongly Agree

Table 7 shows the descriptive statistics analysis done using the Mean and Standard Deviation:

Table 7: Descriptive analysis of including mean & Standard deviation

Descriptive Statistics			
	N	Mean	Std. Deviation
	Statistic	Statistic	Statistic
Extent of smart technology implementation	114	3.7237	1.09231
TPM Practice	114	3.7386	1.04149
Perceived impacts of Smart Technology on TPM	114	3.8368	1.04807

Table 8 depicts the descriptive analysis including skewness & Kurtosis Analysis:

Table 8: Descriptive analysis including skewness & kurtosis analysis

Descriptive Statistics				
	Skewness		Kurtosis	Kurtosis
	Statistic	Std. Error	Statistic	Std. Error
Extent of smart technology implementation	-0.795	0.226	-0.311	0.449
TPM Practice	-0.828	0.226	-0.122	0.449
Perceived impacts of Smart Technology on TPM	-1.074	0.226	0.353	0.449

The mean values represent the arithmetic average of each variable. As an illustration, the mean value of smart technology integration is 3.7237, the mean value of TPM practice is 3.7386, and the mean value of perceived effects of smart technology on TPM is 3.8368.

The statistical measure known as the standard deviation quantifies the extent of dispersion or variability exhibited by a set of values in relation to their mean. Increased standard deviations are indicative of heightened variability within the dataset. The variables in question exhibit varying standard deviations, with "Extent of smart technology implementation" displaying the highest value of 1.09231.

The negative skewness values of all three variables indicate a slight leftward skewness in their respective distributions.

Kurtosis is a statistical measure that quantifies the degree of peakiness or flatness exhibited by a given distribution. Kurtosis values that are positive indicate a distribution that is more peaked, whereas negative values indicate a distribution that is flatter. The kurtosis values of the variables "Extent of smart technology implementation" and "TPM Practice" are negative, suggesting that their distributions are somewhat flatter. Conversely, it can be observed that the variable denoted as "Perceived impacts of Smart Technology on TPM" exhibits a positive kurtosis value, which suggests a distribution that is somewhat more concentrated around its peak.

4.4 Correlation

Pearson's correlation is a statistical measure that evaluates the magnitude and orientation of the linear association between two variables.

It is observed in Table 9 that all three pairs of variables exhibit robust positive correlations.

Table 9: Correlation analysis on the gathered data

Correlations				
		Extent of smart technology implementation	TPM Practice	Perceived Impacts of Smart Technology on TPM
Extent of smart technology implementation	Pearson Correlation	1	.879**	.857**
	Sig. (2-tailed)		<.001	<.001
TPM Practice	Pearson Correlation	.879**	1	.887**
	Sig. (2-tailed)	<.001		<.001
Perceived Impacts of Smart Technology on TPM	Pearson Correlation	.857**	.887**	1
	Sig. (2-tailed)	<.001	<.001	
**. Correlation is significant at the 0.01 level (2-tailed).				

The data analysis indicates a strong positive correlation (correlation coefficient = 0.879**) between the variables "Extent of smart technology implementation" and "TPM Practice".

There is strong positive correlation ($r=0.857^{**}$) between the variables "Extent of smart technology implementation" and "Perceived impacts of Smart Technology on TPM".

The analysis indicates a significant positive correlation ($r = 0.887^{**}$) between "TPM Practice" and "Perceived impacts of Smart Technology on TPM".

The statistical significance values (Sig.) serve as an indicator of the likelihood of observing the correlation coefficients purely by chance. The significance values are all less than 0.001, indicating a highly significant relationship between the variables.

The findings indicate a robust affirmative association among the degree of smart technology integration, TPM adoption, and perceived effects of smart technology on TPM. The greater the deployment of smart technology, the higher the prevalence of TPM practice and the perceived effects of smart technology on TPM. Likewise, an elevated TPM practice is correlated with an increased perception of the effects of intelligent technology on TPM.

4.5 Regression

In Table 10, the results of regression analysis can be seen under the following conditions.

Dependent Variable: Perceived impacts of Smart Technology on TPM.

Independent variables: TPM Practice, Extent of smart technology implementation

Table 10: regression analysis on the gathered data

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.902 ^a	0.813	0.81	0.45737
a. Predictors: (Constant), TPM Practice, Extent of smart technology implementation				

Table 11: ANOVA analysis of the gathered data model summary

ANOVA ^a					
Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	100.906	2	50.453	241.185	<.001 ^b
Residual	23.22	111	0.209		
Total	124.125	113			

The multiple correlation coefficient is 0.902. It indicates the magnitude and orientation of the linear correlation between the independent variables and the response variable.

The coefficient of determination, also known as R Square, is 0.813, indicating that the model's predictors can explain approximately 81.3% of the variance in the dependent variable.

The adjusted R square value of the model is 0.81, which considers the predictors and sample size, resulting in a more precise evaluation of the model's explanatory ability.

The standard error of the estimate. The standard error of the estimate, which indicates the typical discrepancy between the observed and predicted values by the regression model, is 0.45737.

ANOVA results, which evaluate the significance of the regression model.

The regression model shows an important amount of variance in the dependent variable, as demonstrated by the sum of squares (100.906), degrees of freedom (2), mean square (50.453), F-statistic (241.185), and a highly significant p-value (<0.001).

The residual sum of squares (23.22) indicates the variance in the dependent variable that remains unexplained by the predictors.

The total sum of squares (124.125) represents the variance in the dependent variable.

Table 12: Coefficients in the analysis of gathered data

Coefficients ^a				
Model	Unstandardized Coefficients		Standardized Coefficients	t
	B	Std. Error	Beta	
(Constant)	0.41	0.162		2.531
Extent of smart technology implementation	0.328	0.083	0.342	3.972
TPM Practice	0.59	0.087	0.586	6.808

The regression table showing the results of a multiple regression analysis. The analysis was conducted to determine the relationship between three variables: the extent of smart technology implementation, TPM practice, and reliability.

The table shows that the constant term is 0.410. This means that the Perceived impacts of Smart Technology on TPM when the extent of smart technology implementation and TPM practice are both 0 is 0.410. The extent of smart technology implementation has a positive and significant relationship with Perceived impacts of Smart Technology on TPM. This means that as the extent of smart technology implementation increases, perceived impacts of Smart Technology on TPM also increases. The standardized coefficient for extent of smart technology implementation is 0.342, which means that a one-unit increase in the extent of smart technology implementation is associated with a 0.342-unit increase in Perceived impacts of Smart Technology on TPM, holding TPM practice constant. TPM practice also has a positive and significant relationship with Perceived impacts of Smart Technology on TPM. This means that as TPM practice increases, perceived impacts of Smart Technology on TPM also increases. The standardized coefficient for TPM practice is 0.586, which means that a one-unit increase in TPM practice is associated with a 0.586-unit increase in Perceived impacts of Smart Technology on TPM, holding the extent of smart technology implementation constant. The t-values for both extent of smart technology implementation and TPM practice are significant, which means that the relationships between these variables and Perceived impacts of Smart Technology on TPM are statistically significant.

4.6 Discussion of Findings

4.6.1 Hypothesis Testing

Total Productive Maintenance (TPM) practices in material handling systems were evaluated, as well as their potential impact on the use of smart technology in goods facilities. According to the findings, there is a robust positive association between the use of smart technology and improved TPM in these establishments. The material handling industry has been drastically altered by the introduction of smart technologies such as automation, IoT, and robots. By empowering workers with real-time monitoring and predictive maintenance, we can decrease unscheduled maintenance and boost OEE. There is a direct correlation between the widespread use of these technologies and the decline in operating expenses and rise in customer satisfaction.

4.6.2 Implication on existing Literature

These results have implications that are consistent with the current literature and that address major issues that goods facilities must deal with, such as security and the increasing number of products. Prior research in the topic is reflected in the study's emphasis on data privacy, interoperability, and sustainability. The research has several flaws, though, and that has to be stated. While this study provides useful information, it may not cover every facet of deploying smart technology, and future developments in this area may affect the results.

Chapter 5 Conclusion & Recommendations

The study's findings indicate a significant and positive correlation between the degree of smart technology adoption and the perceived effects of smart technology on TPM. As smart technology implementation increases, so do the perceived impacts of smart technology on TPM.

The regression analysis shows a significant positive correlation between smart technology implementation and TPM practice, as well as the perceived effects of smart technology on TPM. The coefficients and t-values indicate the strength and statistical significance of the relationships.

The study's findings align with previous research indicating that smart technologies can enhance the efficiency and effectiveness of TPM practices. Smart technologies can enhance equipment reliability, availability, and performance while minimizing downtime. They can enhance the safety and security of material handling systems.

The study's results suggest the following recommendations:

Organizations ought to contemplate the adoption of intelligent technology in their freight facilities or material handling systems. The study indicates that there is a direct relationship between the implementation of smart technology, TPM practice, and perceived impacts of smart technology on TPM. This suggests that the use of smart technologies can enhance TPM practices and perceived benefits. Companies should integrate TPM practices into their operational strategy and empower their workforce to take ownership of them. The significant correlation between TPM practice and perceived impacts of smart technology on TPM underscores the

significance of clearly defined TPM practices in optimizing the advantages of smart technology deployment.

Investing in training and development programs can enhance the workforce's proficiency in utilizing smart technologies for TPM. The correlation between the degree of smart technology integration, TPM implementation, and perceived effects of smart technology on TPM indicates that proficient and trained employees in smart technology can enhance TPM results. Additional research can investigate other factors that affect the perceived impacts of smart technology on TPM. To comprehensively understand the relationship between smart technology implementation and TPM outcomes, it is important to consider factors such as organizational culture, leadership support, and technological infrastructure.

5.1 Implications and contributions to knowledge

TPM procedures have been catapulted to unprecedented levels of efficiency inside Material Handling Systems in freight facilities thanks to the deployment of smart technology that goes beyond conventional automation to incorporate sensors and extensive data analytics. Smart technology may improve the efficiency of machinery and cut down on maintenance expenses. Notably, eliminating human mistake and increasing system dependability and safety are two major benefits of implementing automated technological sensors. Smart technology's addition to freight terminals has several benefits, including lower operating costs and higher productivity.

5.2 Objectives Evaluation:

By demonstrating a strong connection between the use of smart technologies and positive TPM results, the study has accomplished its aims. The study's comprehensive analysis has established

the link and yielded actionable suggestions for businesses. The goals have been accomplished, and the results provide important new information on the effects of smart technology integration on TPM procedures in freight facilities' Material Handling Systems.

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APPENDICES

Appendix 1

Section 1: Demographic Information

1. Define your age range.
2. Specify your gender.
3. Current educational degree.
4. Experience in field of MHS or freight facilities.

Section 2: Extent of Smart Technology Implementation

Kindly rate the following statements from a scale of 1 to 5; 1 represents minimal adoption and 5 represents elevated adoption.

1. Our MHS or freight facilities have adopted ST such as sensors, automations, and IoT;
2. ST monitor, control, and gather real time driven data on MHS such as inventory levels, operational efficiency and equipment performance.
3. Our freight facilities or MHS utilise data driven decisions and analytics.
4. Our employees are regularly trained and developed for TPM practices.
5. Our workforce comprises of current and updated experience in utilization of ST.

Section 3: TPM Practices

Kindly rate the following statements from a scale of 1 to 5; 1 represents minimal adoption and 5 represents elevated adoption.

6. Our MHS or FF comprises of well-defined TPM practices such as inspection and equipment maintenance with cleaning procedures.
7. TPM is fully incorporated within the operational strategy of the organization and is a vital segment of our facility's performance.
8. Our employees are trained and take their respective ownership of every TPM practices; they are also pro-actively involved in acknowledging the resolution of equipment issues.
9. All TPM procedures are constantly improved and optimized as per data driven insights and equipment performance.
10. KPIs have been devised to measure the TPM practices effectiveness in our MHS or FF.

Section 4: Additional Variables

Kindly rate the following statements from a scale of 1 to 5; 1 represents minimal adoption and 5 represents elevated adoption.

1. Employee's T&D is high in context to TPM practices.
2. Situation of MHS is updated and well-organized.
3. The maintenance frequency is high involving optimization, repairs and equipment performance.
4. The automation level is elevated – there is reduction of any sort of manual reliance on labor.
5. How would you rate your level of training in using smart technology for TPM in material handling systems? (1 = No training, 2 = Minimal training, 3 = Moderate training, 4 = Extensive training, 5 = Expert level training)

6. Define your experience in utilization of TPM in range of years.
7. How frequently do you use smart technology for TPM in your daily work? (1 = Rarely, 2 = Occasionally, 3 = Frequently, 4 = Almost always, 5 = Always)

Section 5: Perceived Impacts of Smart Technology on TPM

Kindly rate the following statements from a scale of 1 to 5, where 1 represents "No Impact" and 5 represents "Significant Impact".

1. ST leads to overall equipment efficiency;
2. ST has led to elevated effectiveness of TPM procedures led to minimal downtime and improved equipment efficiency.
3. ST has enabled real-time predictive and monitoring maintenance aspects.
4. ST has enabled to gather and evaluate the data on equipment performance resulting in improved decision making process.
5. ST has improved the working conditions of employees through increased levels of safety and security – there is prevention of any potential hazards and security breaches.