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Reducing Complexity in Exporting RMG Products Using Artificial Intelligence in Bangladesh

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Abstract

The Ready-Made Garments (RMG) sector in Bangladesh is one of the primary contributors to the nation's economy, holding the position as one of the world's largest garment exporters. The industry faces significant challenges in maintaining its competitive edge due to inefficiencies in supply chain management (SCM), logistical issues, and quality control inconsistencies. This study investigates the potential of integrating Artificial Intelligence (AI) and Internet of Things (IoT) into the RMG supply chain to address these challenges. The proposed approach focuses on optimizing shipping routes using AI-driven methods, enhancing real-time tracking and quality control with IoT devices, and leveraging predictive analytics to streamline operations. Through AI-based route optimization, cost and time reductions are achieved using advanced algorithms like A* search guided by Convolutional Neural Networks (CNNs). The study also highlights stakeholder attitudes toward AI adoption in the sector, with most respondents supporting its integration despite concerns regarding workforce adaptability and implementation costs. The findings suggest that incorporating AI and IoT into SCM could significantly enhance operational efficiency, improve product quality, and reduce export complexities. The study concludes with recommendations for strategic AI adoption, emphasizing workforce reskilling, data security, and ethical considerations for sustainable growth in Bangladesh's RMG sector.

Keywords: Ready-Made Garments (RMG), Supply Chain Management (SCM), Artificial Intelligence (AI), Internet of Things (IoT), Route Optimization, Convolutional Neural Networks (CNNs), Export Efficiency.

1. Introduction

In Bangladesh, the products of Ready-made Garments are listed as the top major export products of Bangladesh. Readymade garments (RMG) have significantly contributed to the economic growth of Bangladesh. The sector is the largest industry in Bangladesh and also the 2nd largest garment exporter worldwide (Government of Bangladesh, n.d.). According to the sustainable strategic vision 2030, the industry has set a target of porting apparel worth $100 billion by 2030 (BGMEA, n.d.). To reach this milestone and become the top of the RMG sector in the world, a proper supply chain management (SCM) strategy is needed, focusing on the integration of Artificial Intelligence (AI) into the supply chain to overcome the obstacles in exporting products from Bangladesh's RMG sector.

Lead time refers to the interval from the moment a customer places an order until the final product or service is delivered to them. It includes several critical phases: processing the order, procuring the necessary raw materials, converting those materials into finished goods through manufacturing, and then transporting the products through various stages of the supply chain until they reach the customer. Efficient management of lead time is essential for ensuring timely delivery, meeting customer expectations, and maintaining a competitive edge in the market.

Supply chain management plays a very important role in any industry. A supply chain consists of several key factions such as Raw Materials, Manufacturers, Distributors, Customers, and Consumers (Akhter et al., 2023). Bangladesh is currently the 2nd largest exporter in the world but still faces challenges while exporting products. In 2023, Bangladesh's garment sector faced challenges in the US market as exports of Bangladesh-made garments to the country decreased by $2.44 billion (Prothom Alo, n.d.; Shijua et al., 2023). The RMG sector in Bangladesh faces common challenges such as long lead times, financial and political issues, power and raw material crises, improper cost management, and declining quality (Chowdhury et al., 2014).

The major problems can be solved, and the efficiency of exporting products can be improved by integrating AI into SCM. In general, AI is referred to as the use of computers for reasoning, recognizing patterns, learning or understanding certain behaviors from experience, acquiring and retaining knowledge, and developing various forms of inference to solve problems in decision-making situations where optimal or exact solutions are either too expensive or difficult to produce (Nilsson 1980, Russell). Put simply, the main objectives of AI are to understand the phenomenon of human intelligence and to design computer systems that can mimic human behavioral patterns and create knowledge relevant to problem-solving. Thus, AI should have the ability to learn and comprehend new concepts, learn from experience ("on their own"), perform reasoning, draw conclusions, impute meaning, and interpret symbols in context. Due to such capabilities, AI has been successfully applied in areas such as game playing, semantic modeling, human performance modeling, robotics, machine learning, data mining, neural networks, genetic algorithms (GAs), and expert systems (Min, 2010; Tuser et al., 2023).

Implementing AI in the supply chain of RMG can be an excellent solution to improve the entire exporting system and increase efficiency by a large margin. For example, if we need to predict the route of a shipment, we can easily do so with AI by providing the required data. It will predict the route in a very optimal way, considering factors such as time, cost, fuel, and forecast (BGMEA, n.d.; Government of Bangladesh, n.d.; Prothom Alo, n.d.; The Daily Star, n.d.

2. Objectives

The main focus of this study is to identify and assess how artificial intelligence (AI) can be utilized to minimize the complexities in the supply chain management of the RMG (Ready-Made Garment) sector for export purposes, focusing on enhancing efficiency, reducing costs, ensuring sustainability, and maintaining a competitive advantage. The objectives of this study are:

- To identify complexities in the supply chain management of the RMG (Ready-Made Garment) sector for export purposes:
  - Analyze logistical and quality control factors to understand challenges.
- To develop AI-based solutions to enhance export processes:
  - Optimize shipping routes and schedules to minimize transit times and costs.
  - Implement automated quality control systems to ensure product consistency and compliance.
- To provide recommendations for AI adoption in RMG supply chains:
  - Utilize IoT (Internet of Things) devices for real-time tracking and data analysis to enhance visibility and decision-making.
  - Leverage AI to achieve competitive advantage by fostering agility, innovation, and market responsiveness in the RMG sector.
  - Enhance customer satisfaction through improved service levels and responsiveness, facilitated by AI-driven efficiencies.
  -

Literature Review

Bangladesh is the second-largest RMG manufacturing hub worldwide with a market share of USD 47 billion in 2022-23, rising from 2.5% in 2005 to 7.9% in 2022 (Wing, 2024). Recently, clothing exports for the July–February fiscal year 2023–2024 totaled $32.86 billion, representing a 4.77 percent increase from the previous year (The Daily Star, 2024). However, this growing sector has several challenges and particular problems that limit its potential to boost export performance and become more competitive. The major problems are longer lead time, heavy dependence on imported raw materials, inadequate infrastructure, utility disruption, inefficient use of technology, etc. (Hossain et al., 2019, Rahaman, 2022). This clearly indicates that this sector has a significant lack of supply chain management. Hossain Arnob et al. (2020) examine that to maintain its top spot in the global RMG industry, the nation needs to develop a sustainable supply chain management strategy that emphasizes lead time reduction, waste reduction, and efficiency maximization (Atik et al., 2020). Several essential components make up a supply chain, including raw materials, manufacturers, distributors, customers, and consumers. Other groups include the Clearing and Forwarding (C&F) agent, Customs, Export Promotion Bureau (EPB), Ports, and Transportation.

Das (2024) says that as technology advances, artificial intelligence (AI) will definitely become a part of the RMG business. AI has the ability to revolutionize numerous aspects of the industry, such as supply chain management, negotiation and communication processes, and production efficiency (Das, 2024). In supply chain management, AI can increase traceability and transparency by providing real-time tracking of the procurement of raw materials, the status of production, and the logistics of shipping. By reducing risks and spotting possible bottlenecks, this improved visibility helps to guarantee that orders are delivered to clients on time.

The application of AI-powered quality control systems is one actual instance of AI adoption in Bangladesh's RMG sector. In the past, quality control in the clothing industry has involved laborers manually inspecting garments to find problems such as uneven color, stitching, and fabric. However, this method can be subjective and time-consuming, which might result in inconsistent product quality.

Some Bangladeshi clothing factories have begun using AI-based quality control systems as a solution to these issues. These devices automatically check clothing for flaws faster and more accurately than human inspectors by using computer vision technology and machine learning algorithms. AI algorithms can identify even minute flaws and irregularities in stitching, fabric texture, and color by examining photos of clothing taken by high-resolution cameras (Das, 2024).

Nevertheless, there are issues in implementing AI in the Ready-made Garments industry. The collection and use of customer data are increasing, making data security and privacy more important (Sabuj et al., 2022). Additionally, some people may be reluctant to adopt AI because they fear losing their employment, particularly in labor-intensive industries like clothing manufacturing (Akseer et al., 2022). Strict quality control is necessary for fashion designs created by AI. Even though AI is powerful, it might still need to comprehend human sensibility, cultural context, and creative design (Ahmmed, 2023). It is also a matter of concern that while AI has many benefits, overreliance on it is risky. Participants stressed the importance of balancing AI and human talents. Relying too much on AI may expose businesses to unanticipated problems, disruptions in the system, and technological difficulties. Design and supply chain processes could flourish with human experience and decision-making (Ahmmed, 2023).

In order to overcome the challenges that the RMG industry faces when implementing AI, Ahmmed (2023) offers some policy recommendations: the government and industry should collaborate on skill development and training initiatives to address job displacement in the garment design industry. Ethical AI guidelines should be created to address ethical issues, including transparency, data handling, and preventing harmful preconceptions. Technology readiness efforts should be made to minimize AI overdependence and retain a diverse skill set. Public-private collaboration is essential for RMG innovation, and the government should provide forums and incentives for collaboration. Data privacy and security regulations should be implemented, and financial support for AI adoption could be offered. Awareness and education initiatives should be supported to educate industry stakeholders on AI integration's pros and cons, emphasizing garment design ethics and craftsmanship (Ahmmed, 2023).

In conclusion, the literature explains that AI has significant potential to minimize complexity in the RMG sector in Bangladesh by optimizing AI-based supply chain management. However, successful implementation requires a balanced strategy that takes workforce development, technological readiness, and ethical issues into account. In addition to protecting social and environmental obligations, this well-balanced strategy would ensure the future prosperity of Bangladesh's RMG industry (Ahmmed, 2023).

3. Proposed Methodology

3.1. Analyze Logistical and Quality Control Factors to Understand Challenges

The supply chain management (SCM) of the Ready-Made Garment (RMG) sector in Bangladesh faces a multitude of complexities that significantly impact its ability to compete in the global market. Analyzing logistical, regulatory, and quality control factors reveals several challenges that hinder the sector's efficiency and effectiveness.

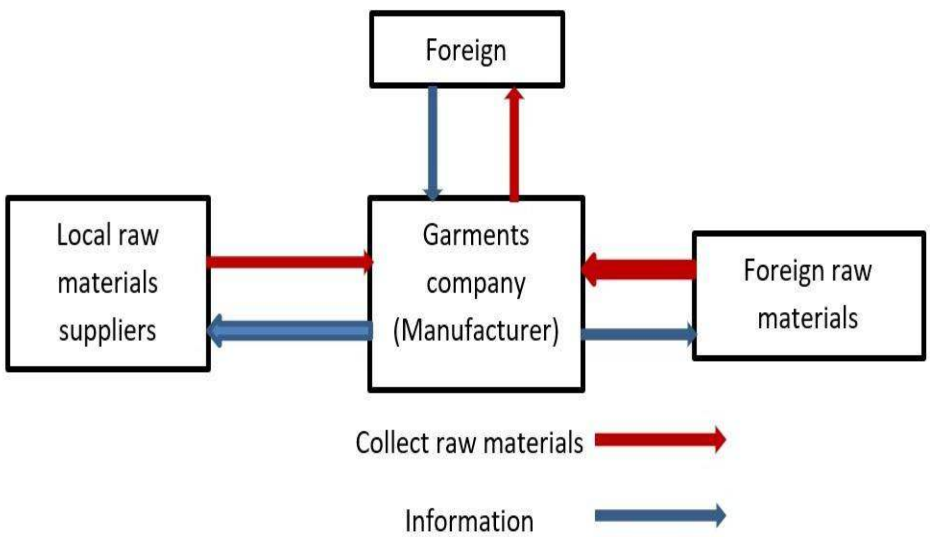

Figure 4.1: Business structure in Bangladesh RMG industries

*3.1.1. **Logistical Challenges***

Many factors affect a successful operation in RMG, logistics is one of them. Ensuring consistent productivity, utilizing high-quality resources, optimizing resource efficiency, and maintaining lead time are crucial factors. Among them, the most crucial is maintaining the lead time, which mostly depends on shipments. However, it is a matter of concern that port congestion is one of the most pressing logistical issues in Bangladesh, which leads to delays in shipments and increases costs("The Transportation Logistics in Supply Chain Management and RMG Sector in Bangladesh", 2024). Illustrations of the basic supply chain in the RMG sector and seaport below,

GoComet (n.d.) mentioned Bangladesh's sea ports, particularly Chittagong, are facing severe congestion due to increasing trade volumes and insufficient infrastructure. This is leading to delays, disrupting supply chains, and driving up costs for businesses. These delays are also negatively impacting the RMG sector, resulting in missed orders and a decline in product quality, ultimately resulting in customer dissatisfaction and potential

Figure 4.2: Ports of Bangladesh(“Ports of Bangladesh | Con- trainer Terminal Ports in Bangladesh Map Details”, n.d.)

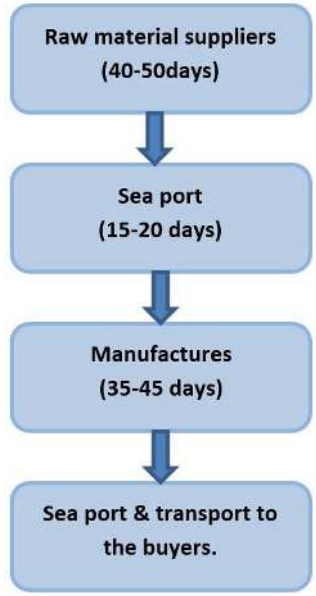

Figure 4.3: Basic supply chain of the RMG sector

3.1.2. ***Quality Control Issues***

Quality control is paramount in maintaining the reputation of Bangladesh’s RMG sector. Bangladeshi ready-made garments (RMG) use a total quality control approach to maintain the quality of their products, as specified by the buyers. Quality control is conducted systematically across different sections to ensure the production of 100% defect-free products. At each stage, from fabric inspection to cutting, sewing, washing, and finishing, quality checks are performed to identify and address any defects (Nahiyan et al., 2016).

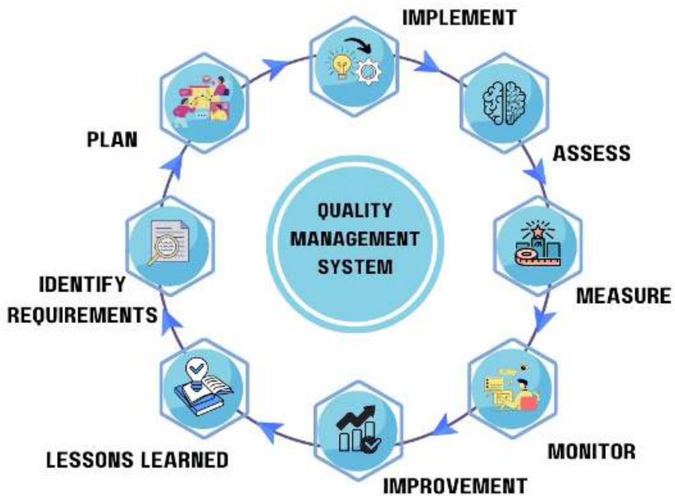

Figure 4.4: The cycle of quality management system for RMG ("Cycle of Quality Management System for Garments Industry", n.d.)

The process begins with fabric inspection, followed by quality checks during cutting. Any issues identified are resolved on the spot. This step-by-step approach continues through the sewing, washing, and finishing sections. As a result, high-quality products are consistently produced, meeting the buyer's standards and requirements.

However, quality control issues remain a major challenge for Bangladesh's RMG sector in competing within the international market. One of the main challenges is the inconsistency in raw materials supplied by various suppliers, which increases the risk of quality disparity. Failure to meet quality standards leads to rejected shipments, financial losses, and brand damage. Continuous investment in quality assurance processes and technologies is necessary, though it slightly increases operational costs. Smaller manufacturers may find it difficult to implement adequate quality control due to the financial burden. Maintaining a full network of suppliers and manufacturers is challenging enough to ensure consistent quality. In production, discrepancies can arise due to different machines or personnel, even within the same factory. This situation requires extensive monitoring and training to maintain consistent standards(Azim, 2023).

3.2. Time and Cost Minimization Through Route Optimization

This way is based on minimizing the total cost and delivery time for delivering ready-made garments from one place to another region, using a graph model.

- **Nodes and Edges**: Nodes indicate critical places like cities, ports, and junctions whereas edges show air, road train paths with link cost which considers both time consumption as well financial.
- **Objective**: The search is expected to locate the most economical path from Start, Country A to Destination, Country B. x
- **A* Search and CNN**: Our implementation is the A* search algorithm, which has a heuristic learned from Convolutional Neural Network (CNN) based on historical data.

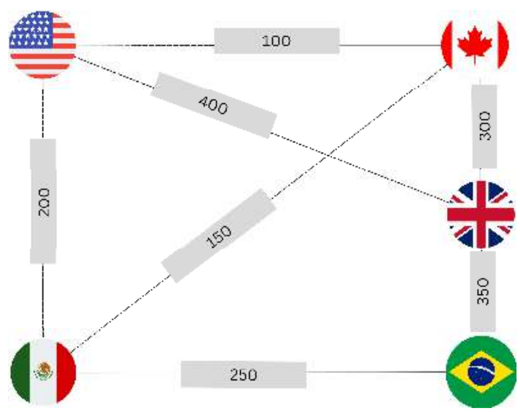

Figure 4.5: Simplified Graph Representation of Routes

Graph-Based Model for Shipping Products

To minimize the total cost of shipping products from Country A to Country B, we design a graph-based model.

Graph Representation

The graph comprises nodes and edges, where nodes represent locations such as cities, ports, and transit points. Example nodes include N_{A1} and N_{A2} for cities/ports in Country A, N_{B1} and N_{B2} for cities/ports in Country B, and $T1$ and $T2$ as transit points between the two countries.

Edges represent possible routes between these locations, with various transportation modes such as air ($N_{A1} \rightarrow T1$), road ($N_{A2} \rightarrow T2$), and ship ($T1 \rightarrow N_{B1}$). Mixed modes, such as road-ship-road combinations, are also considered. Cormen et al., 2009

Edge Attributes

Each edge has a cost function that incorporates time and various expense components. The general cost function is defined as:

$$C_{ij} = \alpha \cdot T_{ij} + \beta \cdot E_{ij} \tag{4.1}$$

where C_{ij} represents the total cost of the edge from node i to node j, T_{ij} is the transit time, and E_{ij} is the total expenses, including fuel costs (F_{ij}), manpower costs (M_{ij}), maintenance costs (Ma_{ij}), and other relevant expenses such as tolls and port fees (O_{ij}).

Objective

The objective is to minimize the total cost of shipping products from the starting node S in Country A to the destination node D in Country B. This is achieved by minimizing the sum of costs over all edges in the selected path from S to D:

$$\text{Minimize} \sum_{(i,j)\in\mathcal{P}} C_{ij} \qquad (4.2)$$

where P is the set of edges in the path.

Example Graph Representation

The nodes in the example graph include the starting node S in Country A, the destination node D in Country B, and transit nodes $T1$ and $T2$. Intermediate nodes represent cities and ports, such as N_{A1}, N_{A2}, N_{B1}, and N_{B2}. The edges include routes like $(S \to T1)$ via air with cost $C_{S,T1}$, $(S \to N_{A1})$ via road with cost $C_{S,N_{A1}}$, and others as described previously. Cormen et al., 2009

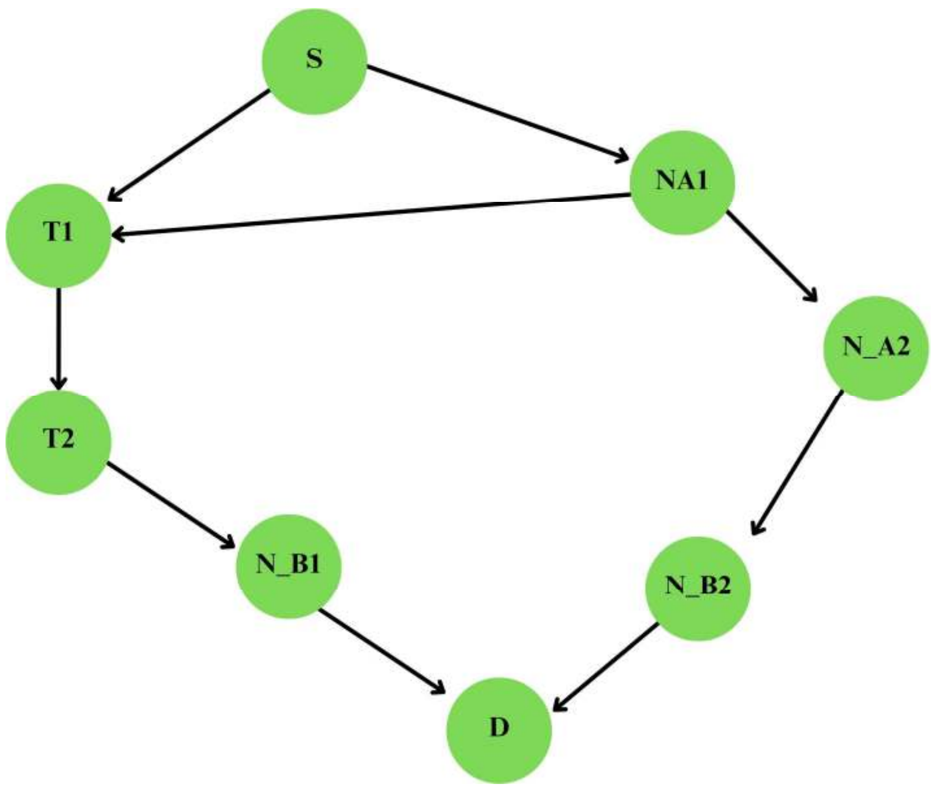

Figure 4.6: Graph-Based Model for Shipping Products

*3.2.1. **A* Search with Heuristic Determined by a Deep Learning Model***

A* search is an informed search algorithm used for path-finding and graph traversal. It combines the strengths of Dijkstra's algorithm and Best-First Search by using both the actual cost from the start node and the estimated cost to the goal to determine the most efficient path. The algorithm employs a priority queue to explore nodes, prioritizing those with the lowest combined cost, ensuring optimal and efficient route determination. Chandra, 2014; Russell and Norvig, 2016

Graph Construction

The nodes in the graph represent locations such as cities, ports, and transit points, while edges represent possible routes with transportation modes like air, road, and ship. Each edge has attributes that include a cost function combining transit time and various expenses.

Cost Function Definition

The cost function is defined as:

$$C_{ij} = \alpha \cdot T_{ij} + \beta \cdot E_{ij} \quad \textbf{(4.3)}$$

where the expense components E_{ij} consist of fuel costs (F_{ij}), manpower costs (M_{ij}), maintenance costs (Ma_{ij}), and other relevant expenses (O_{ij}).

Heuristic Function (Estimated Cost to Destination)

The heuristic function $h(n)$ estimates the cost from node n to the destination D. This estimation is provided by a deep learning model, such as a Convolutional Neural Network (CNN), which takes input features like historical transit times, costs, route distances, transportation modes, and seasonal factors, and outputs the estimated cost.Russell and Norvig, 2016

Data Preparation and Training for Heuristic Model

To prepare the data for the heuristic model, historical data on past shipments, transit times, costs, and routes is collected. Relevant features are then extracted and the data is normalized and preprocessed for model training.

The model architecture, typically a CNN or other suitable deep learning architecture, is designed based on the data. The training process involves splitting the data into training, validation, and test sets, training the model to minimize the error between predicted and actual costs, and validating and fine-tuning the model for accuracy.

Implementing A* Search Algorithm (Russell and Norvig, 2016**)**

The A* search algorithm is initialized by setting the start node S with $g(S) = 0$ (the actual cost from the start to the current node) and $f(S) = g(S)+h(S)$ (the total estimated cost). A priority queue is used to store nodes based on their f -f-value. The algorithm proceeds by exploring nodes, updating costs and paths, and using the deep learning model to predict heuristic values until the destination node is reached or the priority queue is empty.

The trained deep learning model is integrated to predict the heuristic $h(n)$ during the A* search. The model must be capable of performing real-time inference to provide heuristic estimates quickly.

Evaluation and Optimization

The performance of the A* algorithm with the heuristic is evaluated on different routes and scenarios. Metrics such as efficiency, cost savings, and accuracy of the predicted routes are measured. The heuristic model is continuously updated and refined with new data to improve performance.

3.2.2. *Using CNN to Predict Path Cost and Heuristic in Shipping Optimization*

Introduction

Convolutional Neural Networks (CNNs) offer powerful tools for optimizing shipping routes by predicting the cost and determining the most efficient paths in supply chain logistics. In the context of shipping ready-made garments from Country A to Country B, CNNs can be used to enhance the A* search algorithm, which finds the most cost-effective routes by estimating the cost from any location to the final destination. This capability is critical in minimizing transit times, reducing expenses, and improving overall shipping efficiency.Taye, 2023; Tijanić et al., 2020

Applications of CNNs in Supply Chain Management

- **Path Cost Prediction:** CNNs are adept at capturing complex spatial relationships within data, making them suitable for predicting path costs in shipping. By analyzing features such as historical transit times, fuel costs, manpower expenses, and distances between key locations, CNNs can accurately estimate the cost associated with different shipping routes. This information is used as a heuristic in the A* algorithm, guiding the search process towards the most efficient paths.
- **Real-Time Decision Making:** In dynamic environments like supply chain management, real-time decision-making is essential. CNNs can be integrated into systems that operate in real-time, allowing for continuous updates and adjustments based on the latest data. This ensures that the most current information is always being used to optimize routes, leading to more reliable and timely deliveries.

Impact on Supply Chain Efficiency

- **Cost Reduction:** By providing accurate estimates of shipping costs, CNNs help in selecting the most economical routes, significantly reducing transportation expenses. This not only lowers the overall cost of shipping but also enhances the profitability of the supply chain.
- **Improved Accuracy:** The ability of CNNs to learn from vast amounts of historical data ensures that predictions are not just based on surface-level trends but on deep, underlying patterns. This improves the accuracy of cost predictions, leading to better decision-making and fewer unexpected costs.
- **Enhanced Operational Efficiency:** The integration of CNNs into shipping logistics streamlines operations by automating the route selection process. This reduces the time spent on planning and allows for quicker responses to changes in the shipping environment, such as delays or route closures.

Conclusion

Utilizing CNNs in shipping optimization offers a strategic advantage in the competitive world of supply chain management. Their ability to predict path costs accurately and in real-time leads to significant reductions in transportation costs, more efficient route planning, and an overall enhancement in supply chain performance. As supply chains become more complex, the role of CNNs in optimizing these processes will continue to grow, driving further innovation and efficiency in the industry.

3.3. IoT and AI Integration in RMG Supply Chain

3.3.1. ***Introduction***

The evolution of Supply Chain Management (SCM) over the past century has transitioned from conventional practices to smart SCM, driven by advancements in sensor-based technologies and communication devices. Initially, SCM relied on manual, time-consuming methods for information gathering and tracking. However, the advent of technologies like Radio Frequency Identification (RFID) marked a shift towards more efficient and automated systems. Today, the Internet of Things (IoT) plays a critical role in SCM by enabling real-time tracking, intelligent situation prediction, and loss reduction, significantly enhancing supply chain monitoring and management. IoT infrastructure now heavily relies on data collection and communication to monitor the location, quality, and timeliness of deliveries, representing a substantial improvement over traditional methods (Sharma and Sahu, 2023; Stăncel and Dumitrescu, 2021).

The integration of IoT-based applications into supply chain operations has recently revolutionized the manufacturing and transportation industries. Despite its potential, IoT adoption in SCM remains limited due to challenges like a lack of comprehensive knowledge and implementation hurdles. Nonetheless, IoT technologies, particularly RFID, are increasingly recognized for their ability to track objects, monitor logistics, and ensure product quality throughout the supply chain, from production to inventory tracking. This integration has facilitated the digital transformation of SCM and introduced new approaches for traffic management and transport planning, underscoring IoT's growing importance in modern supply chain practices (Ahmed et al., 2023; Behl and Dhir, 2022; Ullah et al., 2023).

3.3.2. ***Utilizing IoT devices for Real-Time Tracking and Data Analysis***

Supply Chain Analysis: Ready-Made Garments Industry

The RMG industry's supply chain is a multi-stage process crucial for maintaining efficiency and competitiveness. It begins with sourcing raw materials like cotton and polyester from global suppliers, ensuring quality and timely delivery through strategic selection and logistics. These materials then enter the manufacturing phase, involving fabric processing, cutting, sewing, and quality checks to meet production standards (Hasan, 2017).

Once garments are produced, they are stored, managed, and shipped through optimized logistics, including warehousing, transportation, and customs clearance. The finished products reach consumers via retail outlets and online platforms, supported by after-sales services. Ultimately, consumer preferences drive demand and influence supply chain strategies, emphasizing the adaptive nature of this process.

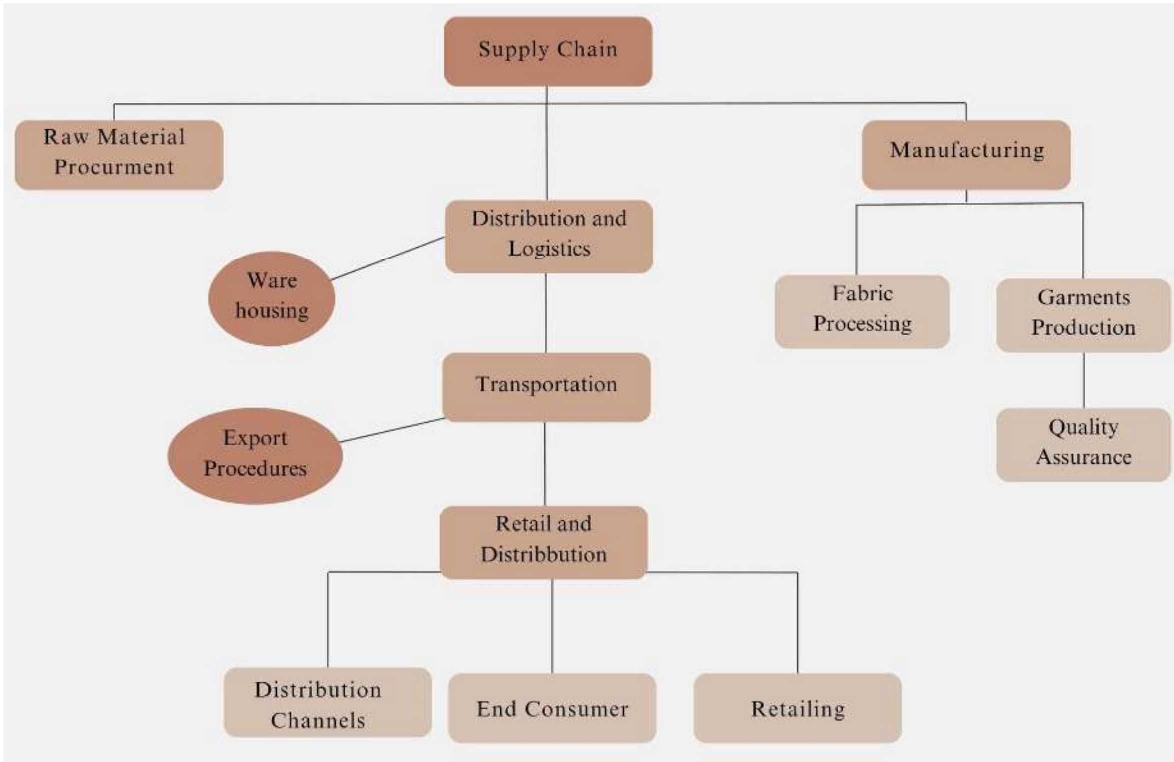

Figure 4.7: Supply Chain Process in RMG

IoT Integration in RMG Supply Chain

Integrating IoT into the RMG supply chain can significantly enhance efficiency, transparency, and responsiveness at every stage, from sourcing raw materials to delivering finished products to consumers. By incorporating IoT devices at critical points, companies can gather real-time data, optimize operations, and improve overall decision-making. Below are detailed ideas for IoT integration across the key stages of the RMG supply chain:

1. **Raw Material Procurement**

- **IoT-Enabled Supplier Tracking:** Implement IoT devices such as GPS trackers and quality sensors to monitor the real-time status, location, and quality of raw materials during transit from global suppliers. This ensures timely deliveries and maintains the quality standards of textiles like cotton and polyester.
- **Quality Assurance Sensors:** Deploy IoT sensors at supplier sites to assess the quality of raw materials

before they are shipped. These sensors can check parameters like fiber strength, moisture content, and fabric integrity, ensuring that only materials meeting the required standards are used in production.

- **Inventory Management:** Use IoT devices for real-time tracking of raw material inventory levels in warehouses. This allows for better forecasting, and timely reordering, and avoids production delays due to material shortages.

2. **Manufacturing**

- **Smart Factory Monitoring:** Integrate IoT sensors on manufacturing equipment to monitor the health and performance of machinery in real time. These sensors can predict when maintenance is needed, preventing unexpected breakdowns and reducing downtime, which is critical in high-volume production environments.
- **Real-Time Quality Control:** Utilize IoT-enabled quality control systems that continuously monitor the fabric processing, cutting, and sewing stages. These systems can detect defects or deviations from sign standards early, ensuring that only garments of the highest quality move forward in the production process.
- **Energy Efficiency Monitoring:** Implement IoT systems to monitor energy consumption across the manufacturing facility. By analyzing the data, companies can identify inefficiencies, reduce energy waste, and lower operational costs.

3. **Distribution and Logistics**

- **GPS-Enabled Shipment Tracking:** Equip shipments with IoT-enabled GPS devices to provide real-time tracking from the factory to warehouses and retail destinations. This not only ensures timely deliveries but also allows for proactive management of any delays or disruptions in the supply chain.
- **Environmental Monitoring:** Use IoT sensors to monitor and control environmental conditions, such as temperature and humidity, in warehouses and during transportation. This is crucial for maintaining the quality of garments, especially those sensitive to environmental changes.

4. **Retail and Distribution**

- **Smart Inventory Management:** Implement IoT-based RFID systems to track garment inventory levels in real time across retail outlets and warehouses. This enables better stock management, reduces the risk of stockouts, and improves overall supply chain efficiency.
- **Customer Behavior Analysis:** Use IoT sensors in retail environments to gather data on customer interactions with garments. This data can help optimize store layouts, improve product placement, and tailor marketing strategies to enhance customer experience and boost sales.

5. **End Consumer**

- **Smart Garment Tags:** Deploy IoT-enabled smart tags on garments that provide detailed product information, such as origin, material composition, and care instructions. These tags can also verify authenticity, enhancing consumer trust and reducing counterfeit risks.

- **Personalized After-Sales Service:** Use IoT data to offer personalized after-sales services, such as tailored recommendations for garment care or future purchases based on customer usage patterns. This can enhance customer satisfaction and encourage repeat business.
- **Feedback Loop:** Implement IoT systems that allow consumers to provide real-time feedback on garments, directly influencing supply chain strategies and helping companies quickly respond to market demands.

These detailed IoT integrations aim to create a more efficient, transparent, and customer-centric RMG supply chain, ultimately driving competitiveness and sustainability in the industry.

*3.3.3. **Integrating AI into the RMG Supply Chain***

The integration of Artificial Intelligence (AI) into the RMG supply chain leverages the vast amounts of data collected by IoT devices to enhance decision-making, optimize processes, and predict future trends. By applying AI techniques such as machine learning, predictive analytics, and data mining, the RMG industry can transform raw data into actionable insights, driving efficiency and competitiveness across the supply chain.

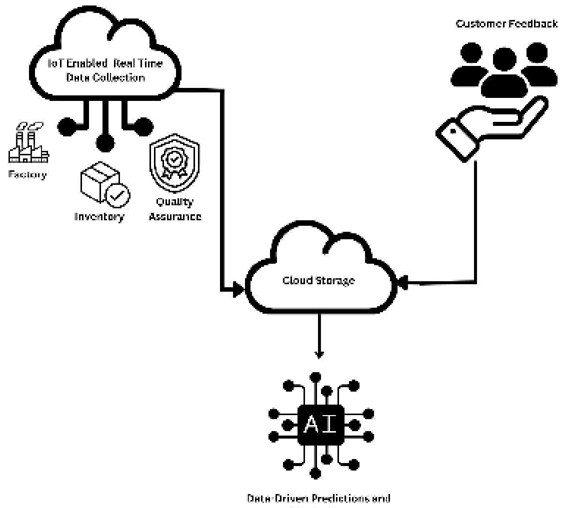

Figure 4.8: AI Integration in RMG Supply

Chain Data-Driven Predictions and Optimizations

IoT devices embedded throughout the RMG supply chain continuously gather real-time data on various parameters such as raw material quality, production line efficiency, inventory levels, and shipment conditions. AI algorithms can analyze this data to make accurate predictions and optimize different aspects of the supply chain:

1. **Demand Forecasting:**

- **Application:** AI can predict future demand for garments by analyzing historical sales data, market trends, and consumer behavior. This helps in optimizing inventory levels, reducing overproduction, and minimizing stockouts.
- **Impact:** Improved demand forecasting leads to better alignment between production and market needs, reducing waste and enhancing customer satisfaction.

2. **Supply Chain Optimization:**
   - **Application:** AI can analyze data collected from IoT devices to identify bottlenecks, inefficiencies, and opportunities for improvement in the supply chain. This includes optimizing production schedules, reducing lead times, and improving resource allocation.
   - **Impact:** Optimizing supply chain processes using AI leads to cost savings, faster time-to-market, and increased operational efficiency.
3. **Predictive Maintenance:**
   - **Application:** AI can use data from IoT sensors monitoring machinery and equipment to predict when maintenance is required, preventing unexpected breakdowns and reducing downtime.
   - **Impact:** Predictive maintenance ensures the continuous operation of production lines, reducing costs associated with equipment failure and improving overall productivity.
4. **Quality Control and Defect Prediction:**
   - **Application:** AI models can analyze data from IoT-enabled quality control systems to detect patterns that indicate potential defects in raw materials or finished garments. This allows for early intervention and quality assurance.
   - **Impact:** Enhancing quality control through AI reduces the risk of defective products reaching the market, protecting brand reputation and minimizing returns.

Integration with Route Optimization

The data collected by IoT devices and processed by AI algorithms also feeds directly into the route optimization methods discussed earlier in the paper. For instance, AI can refine the heuristics used in the A* search algorithm by continuously updating them with real-time data on shipping conditions, traffic patterns, and logistical constraints. This dynamic adjustment ensures that the most efficient and cost-effective routes are always selected, even in changing conditions.

- **Real-Time Adaptation:** AI allows the route optimization model to adapt in real time to unforeseen events such as delays, weather conditions, or supply chain disruptions, ensuring that shipments are rerouted optimally to minimize time and cost.
- **Enhanced Predictive Capabilities:** By incorporating AI-driven predictions, the route optimization model becomes more accurate over time, as it learns from historical data and adjusts its heuristics accordingly.

Conclusion

Integrating AI into the RMG supply chain, in conjunction with IoT data, creates a powerful system that not only monitors and controls operations in real time but also anticipates future needs and challenges. This synergy between AI and IoT not only improves operational efficiency but also drives innovation, agility, and competitiveness in the RMG sector.

Data Analysis

The survey conducted among stakeholders in the Ready-Made Garments (RMG) sector highlights several key challenges and provides insights into the industry's familiarity with and attitudes toward the integration of Artificial Intelligence (AI). The results are discussed in the following sections.

3.4. Challenges Faced by Exporters in the RMG Sector

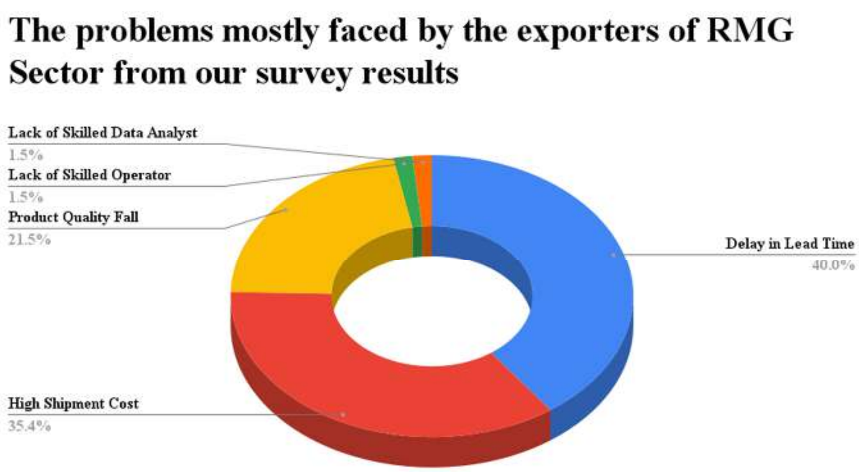

Figure 5.1: Challenges Faced by Exporters in the RMG Sector

The survey identified several critical challenges faced by exporters in the RMG sector. The most significant challenge reported by respondents is the delay in lead time, cited by 40.0% of participants. This prevalent issue within the supply chain and production processes has a substantial impact on the timely delivery of goods, which is a critical factor in maintaining competitiveness. High shipment costs are another major concern, affecting 35.4% of respondents. These logistical expenses are a significant barrier to cost-efficient exports, increasing the overall burden on manufacturers and exporters alike. Additionally, 21.5% of respondents highlighted a decline in product quality as a key challenge, reflecting the difficulties in maintaining consistent standards across large-scale production, which can adversely affect the global reputation and market positioning of RMG products. Although only 1.5% of respondents identified the lack of skilled data analysts as a problem, this gap in technical expertise is still noteworthy. The underrepresentation of skilled data professionals could limit the sector's ability to fully leverage data-driven decision-making and analytics, which are increasingly vital for modern supply chain optimization.

Familiarity with Artificial Intelligence (AI)

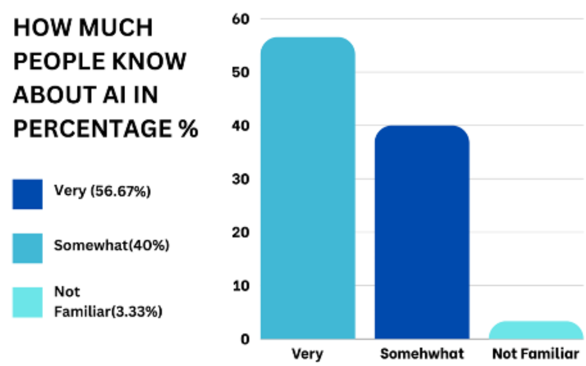

Figure 5.2: Familiarity with AI

The survey also explored the respondents' familiarity with the concept of Artificial Intelligence. A significant proportion of respondents (56.67%) reported being very familiar with AI, indicating a high level of awareness and understanding of AI technologies among stakeholders in the sector. This suggests that many in the industry recognize the potential applications and benefits of AI, even if they have yet to fully adopt such technologies. Additionally, approximately 40% of respondents indicated that they are somewhat familiar with AI, reflecting a moderate level of exposure to the technology. These respondents may have a basic understanding but could benefit from further education and hands-on experience to deepen their knowledge. On the other hand, a small percentage (3.33%) of respondents reported not being familiar with AI, indicating a need for targeted education and training programs to ensure that all stakeholders are adequately equipped to engage with and implement AI technologies effectively.

3.5. Attitudes Toward AI Integration in the RMG Sector

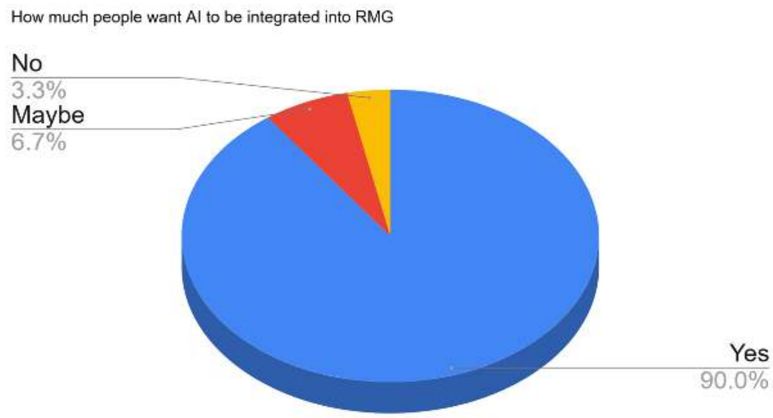

Figure 5.3: Attitudes Toward AI

The survey further assessed the respondents' attitudes toward the integration of AI into the RMG sector. An overwhelming majority of respondents (90.0%) expressed support for the integration of AI, reflecting a strong belief in its potential benefits, such as enhanced efficiency, improved quality control, and increased competitiveness. This positive outlook suggests that the industry is largely prepared to embrace AI as a key driver of innovation and growth. A smaller group (6.7%) expressed uncertainty regarding AI integration, likely due to concerns about the complexities of implementation, potential costs, or doubts about the sector's readiness to adopt new technologies. Only 3.3% of respondents were opposed to integrating AI into the sector, possibly due to concerns about job displacement, the complexity of managing AI systems, or perceived risks associated with the technology. This minority view highlights the importance of addressing the challenges and fears associated with AI adoption, particularly in terms of workforce impacts**,** and ensuring that the transition is smooth and inclusive for all stakeholders.

Results

This study delves into the effects of incorporating Artificial Intelligence (AI) and the Internet of Things (IoT) into supply chain management processes within the Ready-Made Garments (RMG) sector, particularly in the context of improving export operations. The key outcomes of this research are summarized below:

AI-Driven Route Optimization

The proposed approach leverages the A* search algorithm, which is enhanced through a Convolutional Neural Network (CNN) heuristic. This combination reveals significant potential in achieving more effective and efficient shipment planning. By taking into account real-time factors such as transit times, logistical costs, and fluctuating environmental conditions, this methodology facilitates dynamic route selection, optimizing both temporal and financial aspects of logistics.

IoT-Enabled Tracking and Quality Control

The integration of IoT devices across various stages of the RMG supply chain introduces a robust system for real-time data collection. This capability not only strengthens tracking mechanisms but also improves transparency and enables proactive management strategies. By continuously monitoring critical parameters during production, storage, and transport phases, this approach ensures consistent product quality and timely corrective actions when deviations are detected.

Stakeholder Support for AI Integration

Survey data gathered from industry stakeholders reflect a generally favorable attitude toward adopting AI technologies. The main drivers for this support include expectations of enhanced operational efficiency, reduced costs, and better quality control. Nevertheless, there remain concerns regarding potential challenges, such as implementation complexities, the adaptability of the workforce, and the risk of disruptions during the transition to AI-based systems. Addressing these concerns will be essential for successful integration.

Predictive Analytics for Enhanced Efficiency

AI-powered predictive models have demonstrated their ability to deliver more accurate demand forecasting, optimized inventory management, and predictive maintenance capabilities. These improvements play a vital role in streamlining overall operations, ensuring better alignment between production levels and market demands, and mitigating inefficiencies that can arise from misaligned resource allocation.

Challenges and Implementation Considerations

Despite the clear benefits, several obstacles to implementation have been identified. These include concerns related to data security, resistance to technology adoption within certain segments of the workforce, and the upfront costs associated with deploying these advanced systems. To overcome these challenges, a carefully crafted strategy that includes targeted reskilling initiatives, comprehensive planning, and supportive policies will be required to ensure a smooth and successful transition.

Discussion

We conducted a survey and gathered insights from industry experts to identify key challenges in the supply chain management of the RMG sector, particularly in the context of exporting products. The survey results reveal that delays in lead time and high shipment costs are the most significant issues faced by the sector. These are areas where AI can offer substantial improvements. Encouragingly, most respondents expressed a willingness to integrate AI into their operations.

Based on these findings, we propose several methodologies to reduce the complexity of exporting RMG products by leveraging AI solutions. Below are some key findings:

- **Supply Chain Complexity:** The RMG supply chain is inherently complex, involving multiple stakeholders from raw material suppliers to manufacturers and logistics providers. This complexity can lead to inefficiencies, increased lead times, and challenges in meeting global compliance standards

(Dragon Sourcing, 2024, Arnob et al., 2020).

- **Role of AI:** AI technologies, including advanced analytics and machine learning, have been identified as critical tools for optimizing various aspects of the supply chain. These technologies can enhance demand forecasting, inventory management, and production scheduling, ultimately leading to reduced operational complexities and improved responsiveness to market changes (The Textile Network, 2024).

- **Digitalization Benefits:** The digital transformation of the RMG sector has facilitated real-time tracking of materials and products, improving visibility across the supply chain. This transparency allows stakeholders to identify bottlenecks and inefficiencies quickly, enabling timely corrective actions (The Textile Network, 2024). Additionally, AI-driven algorithms can optimize production schedules and minimize overstock and understock situations, which are common issues in garment manufacturing (The Textile Network, 2024).

- **Training and Skill Development:** The shift towards AI and digital tools necessitates a workforce that is skilled in these technologies. Ongoing training and development programs are essential for workers to adapt to new systems and practices, ensuring that the benefits of digitalization are fully realized (The Textile Network, 2024).

The adoption of AI in the RMG sector's supply chain management has the potential to address some of the most critical challenges faced by exporters, particularly in reducing lead times, enhancing product quality, and lowering shipment costs. The positive awareness of AI among stakeholders is a strong indicator that these solutions can be successfully implemented with the right strategies and support.

However, the successful implementation of AI technologies requires a concerted effort from all stakeholders, including government support for infrastructure development and investment in technology. Furthermore, fostering a culture of innovation and continuous improvement within the industry will be crucial to adapting to the rapidly changing global market dynamics.

As the industry continues to evolve, embracing these technologies will be vital for sustaining growth and competitiveness in the international arena.

4. Conclusion

The RMG supply chain is complex, involving multiple stakeholders and causing inefficiencies. AI and IoT can optimize supply chain aspects, such as demand forecasting and inventory management, reducing operational complexities like delays in lead time and a decline in product quality. Digitalization benefits include real-time tracking of materials and products, enabling quick identification of bottlenecks, and minimizing overstock. However, a skilled workforce is needed for the shift. The adoption of AI and IoT in the RMG sector can address challenges like reducing lead times, improving product quality, and lowering costs.

The implications of these findings are profound, contributing to the existing body of knowledge on supply chain management and AI applications in the textile industry. This suggests that by implementing IoT and AI, Bangladeshi manufacturers can actually improve their operational effectiveness, experience cost savings, and gain a competitive edge in the global market.

The survey findings were encouraging. However, this study has several limitations. The study was mainly based on qualitative insights from industry experts, which might not have captured the complete extent of the quantitative impact caused by IoT and AI implementation among all RMG manufacturers. Additionally, AI technologies are advancing rapidly, and these discoveries may soon become outdated as new cutting-edge advancements emerge.

The scope for further research lies in quantitative analyses to quantify the specific economic impacts of AI integration within the RMG sector. Future work could include longitudinal studies that explore the long-term benefits and challenges of AI technologies. It would also be helpful to reflect on the social impact of AI, particularly the displacement of workers and the skill requirements needed for artificial intelligence. Furthermore, the research could investigate how government policies and support contribute to facilitating AI adoption, as well as the importance of these factors in fostering resilience and competitiveness more generally within the sector.

In conclusion, the research identified the potential of AI and IoT in enhancing supply chain management in the RMG sector, particularly for Bangladesh, highlighting the need for strategic integration, workforce development, and ethical considerations to ensure sustainable economic growth and improved working conditions.

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