

Digital Transformation and Smart Cold Chain Technologies for Improving Export Competitiveness in the Indian Seafood Industry

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Abstract: India is a leading exporter of marine products and exports its seafood products to many of the major destinations in the world. Consumers' demand for food safety, food traceability and food sustainability has raised a great demand for efficient supply chain management. It is in this scenario, the digital transformation and the smart cold chain technologies have emerged, proposing an improvement in the production chain, and also reducing losses by waste in the post-harvest production and guaranteeing compliance with international quality standards. The study focuses on the potential of digital technologies, such as the 'Internet of Things (IoT)', blockchain, AI, cloud-based logistics and automated cold storage, in boosting exports competitiveness of the seafood sector in India. The research design was mixed, where a structured survey was used for gathering data from 200 respondents, including operators of seafood export, seafood processing, aquaculture, logistics and cold stores companies and 20 semi structured interviews were conducted among the industry experts. The results indicate that the use of digital 10x affects the management of the inventory and buyer's confidence on international markets as well as improving the efficiency of the operations. However, the extent of infrastructure and technical skills of SMEs are not yet robust enough to facilitate the use of more technologies and implementation costs are still very high. The findings indicate three investments that can help to achieve the digital transformation challenges throughout the seafood supply chain: investment in digital infrastructure, workforce training, and government supportive policies. Extension of the smart, cold chain will contribute towards the competitiveness of Indian seafood exports and make their supply chains sustainable and resilient.

Keywords: Digital transformation, Smart cold chain, Seafood exports, IoT, Blockchain, Artificial Intelligence, Export competitiveness, India.

1. INTRODUCTION

India is one of the leading producers and exporters of marine products such as shrimp, fish, crab, squid and a lot more in the world markets, which supply the North American, European and Asian markets. It is an important contributor to export revenues, and is associated with millions of jobs in coastal areas. With the rapid growing demand from the international markets on safe and quality seafoods has compelled Seafood Exporters to update the seafood production, processing system and the logistics system. The demand for safe, quality seafood products in the international markets is compelling the seafood suppliers to upgrade seafood logistics and production & processing.

As a perishable commodity from its harvesting to storage, seafood transport to export, temperature control is very crucial. Breaks in cold chain lead to loss in product quality, added spoilage and possible rejection of products by importing countries. Efficient operation of the Cold Chain has become one of the business conditions in modern times as far as exporters are concerned.

Digital transformation has brought about a range of technologies that provide greater visibility and efficiency with supply chains. The sensors track temperature, humidity and upload this data in real-time to the internet; the GPS provides for

refreshed tracking on refrigerated transport vehicles. AI can be used to predict demand, optimise stock levels, and identify and forecast potential problems with refrigeration equipment. Blockchain returns transparency to the topic, something that's key when it comes to producers' responsiveness to international traceability requirements throughout the product's journey from the harvest to export.

However, these benefits may not always materialise and there is differential take up of technology. There are lots of small businesses that are not automated yet because of budgetary reasons and/or lack of digital facilities, etc, which are considered and are required as part of the automated processes are in place on a high level in the big exporters who have spent millions on high level logistics and automated processing systems. Government has stressed the significance of the technology development and fisheries modernisation, and it is hoped that they will become more popular in the future with even more cooperation between exporters, fisheries technology providers, policy makers and research institutions.

The analysis of the factors influencing the technology adoption, operational benefits, barriers to technology implementation and opportunities to apply smart cold chain technologies in a strategic manner provide insights into the potential of smart cold chain technologies and digital transformation in improving the export competitiveness of Indian seafood industry.'

2. LITERATURE REVIEW

On the global stage, the Digital transformation is one of the drivers of competitiveness in the Food value Chains. Companies will be able to better react to the market conditions with the centralization of coordination, decision making and entertainment of visibility of the supply chain with modern digital technologies.

In the management of a cold chain, seafood product is of special interest since product quality is closely related to maintaining the product at a stable temperature. Using IoT for monitoring, real-time information about storage and transport specifications can be obtained and several food safety requirements in international standards (Verdouw et al., 2016) could be met by ramping down the level of spoilage.

Other examples of how AI boosts the efficiency of supply chain management systems include demand forecasting, route optimization, and predictive maintenance. These functions are helping to reduce the costs and improve the reaction to disruption (Ivanov & Dolgui, 2020).

By implementing blockchain, it is proving to be a very important tool in addressing the issue of seafood traceability. It generates trustworthy electronic documents comprising all steps from the suppliers, leading to improved transparency and confidence in the purchasing process, and the prevention of documentation fraud (Kamilaris et al., 2019).

Digital technologies are also useful for meeting sustainability goals; these technologies can reduce waste, increase energy efficiency and optimize logistics processes (Ben-Daya et al., 2019). Companies that are able to provide a consistent product quality, provide accurate documentation and can communicate information about the supply chain generally perform better when exporting.

But, for many SMEs, going digital is still difficult. Today, the negative impact of high investment costs, lack of technical knowledge, insufficient infrastructure and organizational barriers are still a reality in terms of implementing technology (Kache & Seuring, 2017). These issues are especially prevalent in the smaller processors and in the local logistics network in the country's seafood business.

The earlier studies clearly provide insights into the benefits of implementing digital technologies, however, the evidence showing the cumulative benefits of combining more components of smart cold chain solutions in the seafood industry of India is weak.

Research Gap

Though these topics have been studied individually by various studies on blockchain, AI, cold chain and digital logistic, but no studies till now have analyzed their individual and combined impact on competitiveness of seafood exporters in India. The issues of small and medium enterprises have not been examined in the past studies which mainly focused on large exporters. These gaps are filled in by this study which provides an integrated evaluation on digital transformation for various stakeholders.

Research Objectives'

1. To examine the adoption of digital transformation and smart cold chain technologies in the Indian seafood supply chain.'
2. To evaluate the impact of digital transformation and smart cold chain technologies on export competitiveness in the Indian seafood industry.'

Research Hypotheses'

- H1:** Digital transformation positively influences export competitiveness.
- H2:** Smart cold chain technologies improve operational efficiency and product quality.
- H3:** Supply chain traceability strengthens international buyer confidence.
- H4:** Financial and technological barriers significantly influence technology adoption.

3. RESEARCH METHODOLOGY

A mixed method research design was used.' Primary data on the industry, representing exporters, processors, aquaculture companies, logistic firms and even cold storage facilities, were gathered from 200 respondents located in seafood exporting states. Twenty semi-structured interviews were also held with industry experts.

Involved purposive sampling, which guaranteed that the participants had some relevant experience in their profession. Data were gathered with a structured questionnaire survey based on 'five-point Likert scales' to measure the uptake of digital technology, smart cold chain, operational efficiency, traceability and competitiveness in exports.

Quantitative data analysed and descriptive statistics, correlation analysis, regression analysis, and themed analysis was for the interview data. 'Cronbach alpha' greater than 0.70 was used to determine instrument reliability with acceptable internal consistency.

4. DATA ANALYSIS

Table 1. 'Profile of Respondents (n = 200)'

Category	'Frequency'	(%)
Seafood Exporters	55	27.5
Seafood Processors	48	24.0
Aquaculture Firms	36	18.0
Logistics Providers	34	17.0
Cold Storage Operators	27	13.5
Total	200	100

The sample represents the major stakeholders involved in India's seafood export supply chain. Exporters and processors account for over half of the respondents, ensuring that the findings reflect practical industry perspectives.

Table 2. Adoption of Digital Technologies

Technology	Mean Score	Standard Deviation
IoT Temperature Monitoring	4.28	0.61
GPS Fleet Tracking	4.15	0.70
Cloud Inventory Management	3.96	0.73
Artificial Intelligence	3.74	0.81
Blockchain Traceability	3.58	0.88

Highest adoption rate was achieved with IoT temperature monitoring as product freshness is the main concern for the industry. The use of GPS for refrigerated tracking is extremely prevalent. Adoption of blockchain is comparatively low because of higher cost of adoption and technical complexity.

Table 3. Correlation Analysis

Variables	Digital Adoption	Operational Efficiency	Export Competitiveness
Digital Adoption	1.000	0.74**	0.71**
Operational Efficiency	0.74**	1.000	0.77**
Export Competitiveness	0.71**	0.77**	1.000

p < 0.01

The conclusions of this analysis point to positive and robust association between PT adoption, operational efficiency, and export competitiveness. In general, better logistics performance, product quality and export results are found in organisations that implement digital technologies.

Table 4. Regression Results

Dependent Variable: Export Competitiveness

Variable	Beta	t-value	p-value
Digital Transformation	0.46	7.12	<0.001
Smart Cold Chain	0.39	6.08	<0.001
Supply Chain Traceability	0.29	4.74	<0.001

R² = 0.62

Through the regression results, it is indicated that digital transformation has the greatest effect on export competitiveness followed by smart/smart cold chain systems and supply chain traceability. These variables, taken as a group, account for 62% of the variation in export competitiveness.

5. RESULTS AND DISCUSSION

The analysis shows that the digital transformation has a profound positive impact on operational efficiency and export competitiveness of Indian Seafood industry. The technology that had been studied and is most widely adopted is IoT based temperature monitoring that allows to keep a real-time check on the storage conditions, minimise product spoilage and maintain product quality prior to transportation. GPS sensor-based fleet management seemed to be something that is widely embraced as it had considerable impact on delivery scheduling and supply chain visibility.

AI solutions are increasingly gaining traction to forecast demand, manage inventory and also to predict maintenance issues, thereby enhancing the usage of resources. Even though it was not the most popular, respondents recognized the importance of traceability, transparency and buyer's confidence in global trade because of its potential application.

Correlation and regression analysis" results showed that export competitiveness had high positive correlation with the use of digital technology, which means that when the company uses the digital technology in an integrated form, the company's export competitiveness is high, and the effectiveness of regulatory compliance is also high. Interviews, however, did show a number of challenges with implementation including cost, lack of a robust digital infrastructure, limited technical expertise, and concerns about cyber security, primarily within small and medium enterprises.

Overall it may be inferred that increased awareness and adoption of digital transformation and smart cold chain could contribute to supply chain efficiency, quality of products and enhance the export competitiveness of Indian seafood products as predicted in all the hypotheses.

6. CONCLUSION

Digital transformation is shaping the Indian seafood export market, making the process more efficient, of better quality, and compliant with regulations, through the use of information, visibility and data insights. From the practical use of these technologies to prevent the loss of quality through contact with IoT, Artificial Intelligence, GPS tracking, inventories and databases in the cloud or blockchain can be included in the list of those that can help prevent spoilage, achieve real traceability and increase the trust in the international market by consumers. The study shows that the smart cold chain technologies have been proven to improve the logistic performance and export competitiveness of organizations. The monitoring and GPS tracking technologies are becoming commonplace as they are directly solving some of the problems

related to transporting highly perishable seafood products, and have already been widely accepted. Blockchain and AI technologies could offer much promise to boost transparency and decision-making in the long run. Without the advantages, there are still variations in technology use across the industry. A lack of funds, technical skills and digital infrastructures are still the barriers to SMEs. Infrastructure, financial instruments and digitalising of programs through courses and learning materials, as well as innovative joint programs, will thus be key pillars of support for the acceleration of digitalisation in industry.

Seafood exporters' competitiveness will depend more and more on their capacity to apply the advanced digital technology along with the efficient cold chain management system. If some organizations manage to do some modernization of the supply chain, they will be in a better situation to cope with the evolving global food policy and quality standards, reduce their operating costs, strengthen market entry and position India better in the international seafood market.

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