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Gulshan Puthukkattu Mansoor Ahamed

A Comprehensive Review of Risk Management and Quality Control Practices in Cold Chain Logistics

A case study on the Indian frozen seafood industry

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Author:	Gulshan Puthukkattu Mansoor Ahamed		
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ABSTRACT:

Cold chain logistics are necessary to keep products safe, and to ensure that products remain at their highest quality. In the fisheries sector many developing nations struggle to create an effective cold chain. To better understand how to manage risks and control the quality of products throughout the cold chain, this study will reflect on Abad Fisheries' approach to frozen seafood products in India. Some of the goals of this study were to identify the primary risks associated with operating a cold chain and to assess the existing processes for managing these risks through risk management systems or technology and documenting them in order to develop unique quality control systems for maintaining temperature stability. The research employed a qualitative case study approach using semi-structured interviews with five employees representing different departments and document reviews to gather information. The data was analysed thematically to develop implementation patterns. The theoretical framework for the study focuses on HACCP and ISO standards, and risk management systems. Key components include the integrity of the cold chain, Critical Control Points, and temperature monitoring. The results of the study suggest that while HACCP and ISO systems exist, the level of implementation varies widely; the primary risk to the cold chain is temperature control; while storage operations have a solid foundation in the best practices for product storage, transportation has several deficiencies. Based on the results of this study, four different categories of risk have been identified: operational, technical, environmental, and human error. Although the quality control practices are sufficiently detailed, the technology capabilities will limit the ability to predict management activity. The degree of temperature control automation currently available has limitations and difficulties with reliability. There is a difference between compliance and operational excellence. Through its research, this study has established that International Standards have a context-specific application in Developing Economies. Technology-related challenges are not only related to the availability of capital; they also include infrastructure dependency and skills shortages. Informal networks help to bridge these formal gaps, but they can also create vulnerabilities to retention of talent. Some of the recommendations that will help improve the monitoring of transportation include investing in technology in phases, providing systematic training, and promoting a culture of continuous improvement.

KEYWORDS: Cold Chain Logistics, Risk Management, Quality Control, Temperature monitoring, Seafood export, food safety, HACCP, Developing economies

Contents

1	Introduction	8
1.1	Background of the study	8
1.2	Problem statement and Research Gap	9
1.3	Aim, Research Questions and Objectives	10
1.4	Importance of Cold Chain in the Fisheries Sector	10
1.5	Challenges in Cold Chain Risk and Quality Management	11
1.6	Case company: Abad Fisheries, India	11
1.7	Scope of the study	12
1.8	Structure of the Thesis	12
2	Literature Review	15
2.1	Overview	15
2.2	Cold Chain Logistics: Concept and Importance	16
2.3	Risk Management in Cold Chain Logistics	18
2.3.1	Types of Risks	18
2.3.2	Risk Mitigation Strategies	20
2.3.3	Risk Management Frameworks	23
2.4	Quality Control in Cold Chain Logistics	25
2.4.1	Standards and Guidelines	25
2.4.2	Monitoring and Technologies	26
2.4.3	Challenges in Developing Countries	27
2.5	Summary of Literature Review	28
3	Research Method	30
3.1	Research Design and Approach	30
3.1.1	Justification for Qualitative Research Design	30
3.1.2	Case Study Method	31
3.1.3	Epistemological Position	32
3.1.4	Research Strategy Overview	32
3.2	Data Collection Process	33
3.2.1	Primary Data Collection	33

3.2.2	Secondary Data Collection	35
3.2.3	Data Collection Timeline	36
3.2.4	Data Recording and Management	36
3.3	Data Analysis Method	37
3.3.1	Thematic Analysis Approach	37
3.3.2	Framework Analysis	39
3.3.3	Data Triangulation	40
3.3.4	Integration with Literature	41
3.3.5	Analytical tools and Techniques	41
3.3.6	Interpretation and Sense-Making	41
3.4	Reliability, Validity and Ethical considerations	42
4	Results and Analysis	44
4.1	Overview	44
4.2	Case Company Context: Abad Fisheries	44
4.2.1	Company Profile and Operations	44
4.2.2	Cold Chain Infrastructure	45
4.2.3	Quality Assurance Structure	46
4.3	Risk Analysis in Cold Chain Operations	47
4.3.1	Overview of Identified Risks	47
4.3.2	Operational Risks	47
4.3.3	Technical Risks	49
4.3.4	Environmental Risks	50
4.3.5	Human Factor Risks	51
4.4	Quality control practices and systems	53
4.4.1	Certification Framework	53
4.4.2	Quality control procedures	55
4.4.3	Audit systems	58
4.5	Technology and Monitoring systems	61
4.5.1	Temperature Monitoring Technologies	61
4.5.2	Refrigeration and cooling Technologies	63

4.5.3	Packaging and Insulation Technologies	66
4.6	Comparative Analysis	66
4.6.1	Comparison with International Best Practices	67
5	Conclusion and Discussion	76
5.1	Conclusion	76
5.2	Discussion	80
	References	84
	Appendices	88
	Appendix 1. Structure of the Interview	88
	Appendix 2. Role of Interviewees	90

Figures

Figure 1. Interview Implementation	35
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Tables

Table 1. Samples from five key departments	34
Table 2. The data collection process follows a phased approach	36
Table 3. Comparison of Abad Fisheries Practices with International Best Practices	66

Abbreviations

AI	Artificial Intelligence
BRCGS	Brand Reputation Compliance Global Standards
CCP	Critical Complaint Point
CIP	Cleaning In Place
ERP	Enterprise Resource Planning
EU	European Union
FAO	Food And Agriculture Organization
FEFO	First-Expired-First-Out
FIFO	First-In-First-Out
FMEA	Failure Mode And Effects Analysis
FSSC	Food Safety System Certification
GFSI	Global Food Safety Initiative
GHP	Good Hygiene Practices
GMP	Good Manufacturing Practices
GPS	Global Positioning System
HACCP	Hazard Analysis and Critical Control Points
ICAR	Indian Council of Agricultural Research
IQF	Individual Quick Freezing
IRMS	Integrated Risk Management Systems
ISO	International Organization for Standardization
IoT	Internet of Things
KPI	Key Performance Indicator

MPEDA	Marine Products Export Development Authority
NCCD	National Centre for Cold Chain Development
PPE	Personal Protective Equipment
PPP	Public-Private Partnership
PSI	Pre-shipment Inspection
QA	Quality Assurance
QC	Quality Control
RFID	Radio Frequency Identification
ROI	Return on Investment
RPN	Risk Priority Number
SME	Small and Medium-sized Enterprise
SOP	Standard Operating Procedure
SSOP	Sanitation Standard Operating Procedure
TQM	Total Quality Management
US	United States
WHO	World Health Organization

1 Introduction

1.1 Background of the study

Cold chain logistics is ever more an automated part of global supply chains today, especially for businesses that deal in perishable and temperature-sensitive goods. Cold chain logistics is storage, transportation and handling of temperature-controlled products such as food, pharmaceuticals and chemicals under strictly controlled conditions (Aung & Chang, 2014). Cold chain supply chains are a force behind product safety, performance, and quality of such products as vaccines, frozen food, and biopharmaceuticals (Rodrigue & Notteboom, 2020). Small deviation from set conditions even for a short period can lead to spoilage of the product, loss of investment, loss of goodwill, and even in extreme situations risk to public health (Tseng, Yue, & Taylor, 2005).

With globalization, there has been a rise in demand for safe and high-quality products requiring efficient logistics so that quality and temperature controls can be strictly implemented from production to consumption. FAO (2020) says that nearly one-third of the world's perishables go to waste or get lost every year, and inefficient cold chain systems are one of the key reasons. Such losses are economically centered but a highly perilous food security and sustainability issue.

Temperature integrity becomes particularly critical in those sectors whose product quality would have a direct influence on consumers' health and well-being. The World Health Organization (WHO, 2019) also highlights that cold chain breakdowns not only involve heavy financial losses but are prone to contamination and spoilage and thus efficient risk and quality management becomes necessary. Cold chain failure in the food business results in food-borne diseases, while in the pharma business, it results in the loss of the effectiveness of life-saving drugs and vaccines.

Cold chain logistics is most essential in the fisheries sector due to the extreme perishable nature of fish and seafood products. Delays or insufficiencies in maintaining the

necessary cold chain conditions result in rapid spoilage, microbial development, and contamination, affecting export quality and public health directly (Aung & Chang, 2014). It is of topmost significance for India as a major sea-food exporting country in the world to possess an effective cold chain to sustain international high-quality requirements demanded by importing countries such as the United States, Europe, and Japan (ICAR, 2021).

Despite technological advancements like IoT-based monitoring technologies, blockchain based traceability, and advanced packaging technologies, the developing world remains plagued by constraints in establishing efficient cold chains due to restricted infrastructure, lack of information, and capital constraints (Singh & Sushil, 2020). These are the reasons why research should be undertaken that is based on risk management and quality control in cold chain logistics. This study is specific to the fisheries sector and Abad Fisheries, India, as a case company, to identify how risks are addressed and quality levels are ensured within a developing economy context.

1.2 Problem statement and Research Gap

Even though increasing research on cold chain logistics has been conducted, most only concentrate on technological solutions or operation efficiency in vacuo. Few studies have integrated practices in risk management with quality control systems in both food and pharmaceutical supply chains comprehensively. Furthermore, although case-based studies are available, there are few that give an integrated overview of how risk and quality are being managed together, where the loopholes are, and how emerging technologies could fill in these loopholes (Behzadi et al., 2018). Therefore, this thesis completes the gap by conducting a thorough review of risk management and quality control processes within cold chain logistics. This research is aimed at providing both theoretical and practical knowledge that can be useful in formulating more effective and reliable cold chain systems.

1.3 Aim, Research Questions and Objectives

The aim of this thesis is to provide a comprehensive literature review on the risk management and quality control practices in cold chain logistics focusing on the fisheries sector and case company Abad Fisheries.

Research Question:

How can risk management and quality control practices be improved to ensure optimal performance in cold chain logistics?

Objectives:

- To identify the major risks affecting cold chain logistics and assess the effectiveness of current risk management techniques.
- To analyze quality control techniques and technologies used to maintain temperature stability during transportation and storage.

1.4 Importance of Cold Chain in the Fisheries Sector

Seafood and fish are highly perishable commodities and should be maintained cold at all times and under uniform conditions from harvesting through to processing, packaging, transport, and retail sale (Tseng et al., 2005). FAO (2020) approximated that approximately 35% of seafood and fish products around the world waste or lose every year due to post-harvest handling inefficiencies and cold chain management. As increasing demand has been originating from the Middle East, Europe, and America, Indian seafood exporters must adhere to strict quality standards, approvals, and regulatory measures (ICAR, 2021). Proper cold chain machinery not only maintains freshness but also food safety adherence to international standards such as HACCP and ISO.

1.5 Challenges in Cold Chain Risk and Quality Management

Despite evolving technology, cold chain logistics continue to be plagued by numerous challenges. These are temperature variations, delayed shipment, mechanical failures of equipment, and handling errors by man (Kuo & Chen, 2010). In developing countries such as India, these risks are even more critical due to infra-structure limitations, inconsistent supply of power, and fragilities of the monitoring systems (Singh & Sushil, 2020).

Quality control of cold chain logistics would most likely be extremely focused on temperature control, without particular regard to other equally critical parameters such as humidity control, contamination risk, and handling habits. Furthermore, while developed economies have incorporated technologies such as IoT-based monitoring, blockchain-based traceability, and storage automation, their rollout remains limited in India due to cost factors and unfamiliarity (Rodrigue & Notteboom, 2020).

These problems create a critical need for careful review of risk management and quality control practices, particularly in those fisheries supply chains that are highly dependent on strict cold chain management.

1.6 Case company: Abad Fisheries, India

Abad Fisheries of Kochi, Kerala, is India's largest vertically integrated seafood company with operations from fishing and aquaculture to processing and exports. The company has a very long history of building presence in international seafood markets and shipping to nations such as the United States, Europe, and the Middle East. Since it is a vertically integrated firm, Abad Fisheries has command over all stages of the value chain, and hence it is an ideal case company to observe risk management and quality control measures in cold chain logistics (Abad Fisheries, 2024).

The firm focuses on quality standards from around the world such as HACCP and ISO 22000 and invested in advanced cold storages, blast freezers, and reefer transports.

However, like in the case of the majority of Indian fishery firms, it is still plagued by the problem of infrastructure shortages, risk management, and technological upgradation. Using Abad Fisheries as an example, it offers learning in the field as to how companies from developing countries manage cold chain risk and quality control when competing globally. (Abad Fisheries, 2024).

1.7 Scope of the study

The purpose of this research is to examine risk management and quality control processes in cold chain logistics with particular reference to the Indian fisheries sector. Abad Fisheries company has been selected as the case study due to its significance in India's seafood export industry and its vertical integration of production to export markets.

The scope of this research is limited to Interviews, Questionnaires, secondary data analysis, peer-reviewed journals, international industry reports. The study will examine such risk factors as transport delays, temperature fluctuations, equipment breakdowns, and human errors, and quality control practices such as HACCP, ISO standards, and monitoring technologies. While the research provides a comprehensive overview of quality practice and risk, apart from this, the research focuses on the fishery sector only and does not include other sectors such as the pharmaceutical or dairy sectors. The findings are intended to add to the intellectual corpus of knowledge in the field of cold chain issues in the developing world and provide practical implications for seafood exporters to maximize their logistics performance.

1.8 Structure of the Thesis

This Thesis consists of five chapters, each of which is aimed at contributing to the resolution of the research objective and goals. The framework is structured in a way that directs the reader from the general background of cold chain logistics to the particular finding and recommendations that are derived from the research.

Chapter 1: Introduction

This chapter introduces the study basis. It initially introduces the concept of cold chain logistics and the growing significance of the same in worldwide trade, particularly for perishable industries such as fisheries. Background and purpose of study is introduced, followed by the research problem, objectives, and questions. Research scope and its limitations are also discussed. The case company is also discussed in introduction section. Finally, the structure of the thesis is introduced to lead the reader through the subsequent chapters.

Chapter 2: Literature Review

The second chapter discusses existing academic and business literature on cold chain logistics, risk management, and quality control practices. Definitions, theories, models, and technology developments in the field are explained. Developed-developing country comparisons are provided to clarify contextual differences. The chapter also provides significant gaps in the existing body of knowledge, which are the basis for the research question of this thesis.

Chapter 3: Methodology

This chapter explains the research design and approach adopted in the study. The study adopts a qualitative method. The data gathering techniques described in this section consist of interviews together with case study and industry observation methods. And also, on secondary data including academic journals, industry reports and international standards. The chapter also discusses reliability, validity and ethical considerations relevant to the study.

Chapter 4: Results and Case Analysis

The fourth chapter summarizes the study findings and contextualizes them for the case company chosen, Abad Fisheries in India. The chapter is on risk factors and quality control measures in the fisheries cold chain and compares the same to international

standards and best practice. Based on the case study, it demonstrates how Abad Fisheries manages risks, maintains product quality, and handles common issues of developing economies.

Chapter 5: Conclusion and Discussion

The final chapter offers an outline of the key findings of the thesis and what they imply in terms of theory and practice. It offers suggestions for improving risk management and quality control in fisheries cold chain logistics, with special reference to the Indian context. The limitations of research are also discussed and suggestions for future research are provided.

2 Literature Review

2.1 Overview

Cold chain logistics has been a vital component of modern supply chain management in industries that deal with perishable and temperature-sensitive items such as pharmaceuticals, fresh produce of fruits and vegetables, dairy, and seafood (Aung & Chang, 2014). International trade over the past few decades has further driven the requirement for efficient cold chain systems with the ability to ensure food safety, reduce wastage, and conform to international quality standards. For the fishery industry, the cold chain is particularly important since seafood is highly perishable and must be kept at a constant temperature right from harvesting through to processing, storage, distribution, and sale (FAO, 2020). More than just an operational requirement, but also a strategic competitiveness driver, for those companies involved in global trade, is cold chain logistics. Given product quality, consumer trust, as well as the fiscal strength of companies, professionals are defined by the effectiveness of a cold chain system. Ineffective cold chain systems in developing countries cause an estimated 30–40% loss of perishable food yearly, according to the World Bank (2016). This emphasizes the importance of correctly engineered logistics using advanced technology and efficient quality assurance systems. Cold chains in supply chain management are distinguished from other logistics networks by the complexity and susceptibility of the latter to the environmental factors such as temperature, humidity, and handling processes (Rodrigue & Notteboom, 2020). They all involve a multi-disciplinary effort that is an integration of logistics planning, risk management, technology adoption, and quality assurance. Their integration ensures that the end product is satisfactory to regulators as well as consumers. The growing importance of risk management and quality control in cold chain operations has attracted increasing amounts of research and business attention. Deviation temperature failures, monitoring failures, or mishandling can generate huge loss and damage to reputation (Kuo & Chen, 2010). Companies are, therefore, deploying advanced tracking technology, Internet of Things (IoT) technology, and real-time analytics to enhance operational reliability. For emerging countries like India, the cold chain business is mired with unique challenges

like inadequate infrastructure, unorganized logistics systems, and low levels of awareness among small-scale producers (Singh & Sushil, 2020). These constraints make it difficult to maintain constant quality levels and menace the possibility of spoilage, particularly in the fisheries business where products are highly perishable and export-oriented. This literature review provides an overview of the existing research in cold chain logistics, focusing on quality control strategies and risk management techniques. The chapter synthesizes conceptual and empirical literature, addresses technological innovations, finds applications in the fisheries sector, and surveys areas of research gap, particularly in developing economies such as India.

2.2 Cold Chain Logistics: Concept and Importance

Cold chain logistics is defined as an organized process that ensures temperature-sensitive goods are kept in prearranged conditions in order to maintain quality and extend shelf life (Rodrigue & Notteboom, 2020). Cold chain is a sequence of dependent processes such as refrigerated production, storage, transport, and distribution that are supported by technology and management systems with capabilities for tracking and controlling temperature excursions. The process guarantees that products are safe, efficacious, and compliant with regulatory demands from source to the ultimate consumer.

Cold chain supply chain management is necessary to ensure the integrity of perishable products in industries such as food, pharmaceuticals, and biotechnology, where small changes in temperature result in spoilage, product degradation, or complete loss (Aung & Chang, 2014). Temperature consistency in food safety is important to avert microbial contamination and have uniformly quality products both locally and globally.

Globally, effective cold chain facilities are critical in reducing post-harvest and post-production loss. The FAO (2019) states that nearly one-third of perishable crops are lost annually due to ineffective cold chain facilities. The loss is economically and socially significant: it reduces farmers' profitability, limits food supply to consumers, and results in environmental losses due to the dumping of expired fruits.

This loss in the fisheries sector is equivalent to significant economic and nutritional impacts, particularly for developing countries that have extensive reliance on seafood exports. Fishery products are among the most perishable of foods and require instant and consistent cold storage along the entire chain of supply—from the time of harvesting to processing, packaging, transportation, and export (FAO, 2020). Lack of proper handling or temperature fluctuation can lead to spoilage, which undermines the safety and quality attributes of fish products such as texture, flavor, and nutrients.

Exporters such as India require efficient cold chain logistics in an attempt to achieve foreign requirements such as HACCP (Hazard Analysis and Critical Control Points) and ISO 22000 (Food Safety Management Systems). Conforming to these standards enables exporters to enter overseas markets, gain customers' confidence, and reduce rejection or recall of their products as substandard. Also, effective cold chains enhance India's global position as a top seafood exporter, increase the nation's domestic food security and sustainability, too.

Alongside rising relevance of cold chain logistics, infra-structure deficit, energy unreliability, and technology adoption gap continue to exist in most of the developing economies. Singh and Sushil (2020) mention a study which states that India's cold chain industry is plagued by inefficient cold storage facility, high-cost operations, and poor integration in the logistics chain. These problems result in wastage of the product, reduced export competitiveness, and inefficient usage of resources.

This is in contrast to developed countries such as Norway and Japan, which have established highly integrated technology-enabled cold chains facilitating near-zero wastage and full traceability of perishable products (Rodrigue & Notteboom, 2020). These are examples that developing economies follow when they intend to advance their logistics networks. Hence, awareness of the principles, functions, and global variations in cold

chain logistics is essential to realizing areas for improvement and the risk and quality management issues still present in developing conditions such as India.

2.3 Risk Management in Cold Chain Logistics

Cold chain logistics requires efficient risk management since the perishable items are delicate, and maintaining the correct temperature and sanitation is a complex process along the supply chain. Risk management implies detection, inspection, and reduction of potential interferences that could compromise product quality, safety, or delivery performance. An effective risk management system provides reliability, compliance with international norms, and customer satisfaction overall (Chen, Zhang, & Delaurentis, 2014).

2.3.1 Types of Risks

Operational, technical, environmental, and human factor risks are generic categories of risk in cold chain logistics, each of which is accountable for other forms of disruption or decay in the quality of the supply network.

Operational risks are some of the most common of cold chain logistics and are caused by inefficiency in day-to-day operations such as transport, storage, and scheduling. These include delays in transit, poor handling of temperature-sensitive items, and inefficient planning of routes. The logistics staff may be prone to errors that compromise the cold chain integrity due to inadequate training (Kuo & Chen, 2010). For instance, a brief delay in customs clearance or inefficient handling at points of transfer leads to variations in temperature resulting in loss of product quality. These risks require more coordination, employment of real-time tracking tools, and closer following of standard operating procedures.

Technical risks are as a result of the breakdown of refrigeration systems, packaging, or monitoring equipment. Issues such as compressor failure, inadequate insulation, and malfunction of temperature sensors can result in product damage that is irreversible

(Aung & Chang, 2014). Poor maintenance practices also increase the risk of system failure during critical transportation phases. The implementation of predictive maintenance and automated warning systems can mitigate these risks through the identification of potential equipment failure before it occurs. In modern logistics operations, the deployment of IoT devices and blockchain traceability solutions provides accurate data and greater transparency across the cold chain.

Environmental threats are beyond the direct control of logisticians and include power outages, natural calamities, extreme weather conditions, and infrastructural shortcomings. Power outages and poor road infrastructure are typical barriers for the cold chain continuity in developing nations like India (Singh & Sushil, 2020). Threats can be reduced with the use of backup power supply, effective routes, and investment in strong infrastructure. Climate change poses another risk through elevated temperature extremes and the frequency of weather-related extremes, which require more sustainable and resilient cold chains.

Human risk factors are associated with workers' performance, knowledge, and conduct in performing cold chain activities. Product mishandling, neglect, or unsafe procedure non-adherence are common causes of product deterioration (Zhao et al., 2017). Hazards most often stem from inadequate training, excessive staff turnover, and ineffective supervision. Putting organizational culture, ongoing training, and the development of accountability measures can eradicate human-error based mistakes. Along with this, the development of safety and quality culture within staff elevates higher compliance with standard procedures and reduces operating variance.

On the whole, effective mitigation of these risks requires a multidimensional strategy involving technology, training, infrastructure development, and process streamlining. Organizations that take an active effort to detect and manage risks can go a long way toward greatly improving their cold chain efficiency, reducing losses, and maintaining uniform product quality throughout the logistics process.

2.3.2 Risk Mitigation Strategies

Cold chain risk management falls under product reliability, safety, and integrity in the overall supply chain. With the complexity involved in keeping the desired temperature levels and dealing with perishable products, companies must be proactive and adaptive in risk management. Mitigation is done through the utilization of technology deployment, infrastructure development, regulatory compliance, and human resource capacity building to reduce the effect of potential interruptions and ensure consistent quality levels.

In the fisheries industry, product perishability and long distances of transportation from where they are harvested to the export markets render risk mitigation especially crucial. Such companies as Abad Fisheries' logistical operations rely on their capacity to foresee risks and have orderly controls at every phase-processing and packaging to storage and distribution.

1. Preventive Maintenance and Equipment Reliability

The most effective means of stemming technical and operational risk is preventive maintenance of cold storage infrastructure and refrigeration equipment. Periodic check-up, early replacement of faulty components, and continuous monitoring of equipment performance can prevent the systems from malfunctioning and compromising product quality. IoT-based monitoring devices facilitate real-time temperature and humidity level monitoring with alerting on deviation automatically (Rodrigue & Notteboom, 2020). Predictive maintenance systems based on artificial intelligence are being deployed in contemporary cold chain facilities to reduce unplanned shutdowns and energy wastage.

2. Technological integration and clarity of data

Technological innovation makes it possible to minimize risk by capturing live data and open-processing the process. Integration of Internet of Things (IoT), Radio Frequency Identification (RFID), and blockchain technologies enhances traceability and accountability throughout the supply chain (Zhao et al., 2017). For fisheries, it makes it possible

for stakeholders to trace product condition from capture to delivery. Blockchain-based solutions guarantee that temperature history, handling processes, and shipping routes are traceable and tamper-proof and enable exporters to present international standards of compliance such as HACCP and ISO 22000. Transparency also enables quick identification of failure points of quality audit or recall.

3. Training and Human Resource Development

Human failure remains one of the biggest risk factors in cold chain logistics, especially in emerging economies. Spoilage or contamination may be due to unsatisfactory handling, hygiene practices, and failure to use recommended practices. Proper employee training and sensitization initiatives are therefore critical. Training of employees should prioritize handling the product correctly, temperature scanning, hygiene and maintenance, and emergency procedures. Regular performance evaluation and workshops ensure that all employees understand their job and the consequences they will receive in the event of non-adherence (Singh & Sushil, 2020). Abad Fisheries and other companies can benefit from creating quality-focused culture where everyone contributes to maintaining standards.

4. Infrastructure Development and Energy Backup Systems

Investing in energy backup facilities and infrastructure improvements becomes essential in regions of unstable power supply and weak logistics infrastructure to maintain temperature control. Installation of stand-by generators, solar power setups, and advanced insulation systems may lower the threat of power outages and climatic factors (FAO, 2020). Upgrading transportation fleets with temperature indicators and live communication systems reduces delay and maintains uniformity of temperature. In India, also, public-private partnerships can play a significant role in upgrading cold chain infrastructure and ending congestion of logistics.

5. Risk Analysis and Contingency Planning

An implemented risk assessment framework helps firms to foresee possible interruptions and build contingency measures in advance. Failure Mode and Effects Analysis (FMEA) and Hazard Analysis and Critical Control Points (HACCP) are some of the techniques commonly used for identifying, ranking, and reducing risks in cold chain operations (Chen, Zhang, & Delaurentis, 2014). For example, in fisheries logistics, there should be critical control points that monitor temperature and microbial testing to prevent contamination accidents from occurring. Contingency planning also needs to include route diversification, redundancy of suppliers, as well as swift response measures during emergencies such as vehicle breakdowns or equipment failure.

6. Supply Chain Integration and Cooperation

Risk avoidance also lies in greater cooperation among supply chain players, including suppliers, transporters, distributors, and retailers. Sharing data, aligning quality objectives, and standardizing operation processes enhance resilience in a system. Vertical integration among fisheries businesses, where a business owns different stages of the supply chain, can reduce third-party logistics partners' dependence and increase product handling and traceability control (Macheka et al., 2017). Abad Fisheries, for instance, benefits from its vertically integrated stages of processing to exporting, with enhanced control and coordination.

7. Regulatory Compliance and Ongoing Enhancement

Compliance with global standards such as HACCP, ISO 9001, and ISO 22000 forms the basis for successful prevention of risks. Third-party audits and regular internal audits ensure compliance of cold chain operations with global best practices. Development based on audit findings, customer feedback, and performance indicators equates to system resilience. The Total Quality Management (TQM) philosophy is assured through compliance with a monitor, evaluate, and improve loop through logistic activities (Oakland, 2018).

Overall, good risk management in cold chain logistics is a interconnected strategy involving technological, human, and organisational aspects. To Abad Fisheries and other seafood export firms like it, adopting novel technology, employee enhancement through training, rigorous adherence to regulatory requirements, and creating cooperative relationships along the supply chain are central steps towards reliability, viability, and global competitiveness for cold chain enterprises.

2.3.3 Risk Management Frameworks

A number of structured frameworks have been established for the purpose of systematically discovering, evaluating, and minimizing risk in cold chain logistics. A systematically constructed framework of this type acts as a foundation for the enhancement of the reliability, security level, and operational efficacy of the supply chain operations. Most popular methodologies employed are Failure Mode and Effects Analysis (FMEA), Hazard Analysis and Critical Control Points (HACCP), and entire quality and safety management systems like ISO standards and Total Quality Management (TQM).

1. Failure Mode and Effects Analysis (FMEA) FMEA is a predictive analytical methodology designed for the identification of potential failure points in a process and the evaluation of their impacts upon the system performance overall. For cold chain logistics, the use of FMEA aids in the estimation of the likelihood, severity, and detectability of the risk related to equipment, transportation, and handling (Kuo & Chen, 2010). A breakdown of the refrigeration component while shipping seafood may represent a high-severity event that demands immediate preventive action. Prioritizing the risk using risk priority number (RPN) aids the manager in the effective utilization of resources to avoid crucial failures once they have taken place.

2. Hazard Analysis and Critical Control Points (HACCP)

HACCP is a commonly accepted system dedicated to the avoidance of food safety hazards by bringing the emphasis away from sole dependence upon end-product testing. It identifies specific critical control points (CCPs) along the way in the production and

distribution chain where careful monitoring and control may prevent contamination or deterioration. For fisheries cold chains, typical CCPs will generally include temperature monitoring while in store, hygienic procedure during the handling process, and microbial testing while in package. Adoption of the HACCP system goes beyond enabling conformity to international requirements by also giving assurance to consumers and importers that the required standards are consistently in place.

3. Integrated Risk Management Systems (IRMS) and ISO Standards In addition to HACCP and FMEA, organizations often utilize broad-based management systems such as ISO 22000 (Food Safety Management) and ISO 9001 (Quality Management) to complement their overall risk management system. The models integrate risk assessment with continuous improvement processes so that organizations are able to evaluate the effectiveness of their operations and identify opportunities for enhancement. Such systems foster the use of documentation activities, employee engagement, and third-party audits to ensure accountability and transparency along the cold chain (Oakland, 2018).

4. Application in the Fisheries Industry

In the fisheries sector, the implementation of these frameworks has become closely related to export-import country required international certification schemes such as the European Union and the United States. HACCP- and ISO-based certifications are frequently required for export eligibility. Abad Fisheries applies these frameworks to its business for global competitiveness and assuring that its products are safe and meet quality requirements when entering foreign markets.

However, despite developments, developing nations such as India continue to face challenges in the full utilization of these protocols, due to fragmented supply lines, inadequate infrastructure, and a dearth of technical expertise (ICAR, 2021). Many small-scale operators are denied access to temperature-controlled warehouse or monitoring technology, further advancing the risk of deterioration while in transportation. Addressing

these inadequacies demands joint efforts between the private and the public sectors as well as investment in infrastructure and the sharing of knowledge built from the best of international experience.

5. Towards Integrated Framework Recent research stresses the importance of a holistic risk management platform incorporating technology, regulations, and organizational factors for enhanced resilience in cold chain networks (Rodrigue & Notteboom, 2020). This vision champions interdisciplinary collaboration, real-time information exchange, and predictive modelling for the sake of anticipating possible disruptions. For fisheries logistics, the implementation of Failure Mode and Effects Analysis (FMEA) and Hazard Analysis and Critical Control Points (HACCP) in a larger ISO-certified management system constitutes a good starting point for guaranteeing the quality of products, loss minimization, and sustainability enhancement across the chain. In a phrase, effective risk management models such as HACCP and FMEA are the foundation for the safe cold chain. With current technologies and quality management programs, these help business entities such as Abad Fisheries manage risk, guarantee regulatory compliance, and further improve their competitive advantage in the world seafood marketplace.

2.4 Quality Control in Cold Chain Logistics

Quality control (QC) is a key to efficient cold chain operations that keeps temperature-sensitive products safe, effective, and retaining their sensory qualities all along the supply chain. For industries like fisheries, pharmaceuticals, and fresh produce, quality retention entails temperature control besides hygienic control, handling, and storage conditions. Good QC measures lower spoilage rates, higher consumer satisfaction levels, and international competitiveness for exporters like the ones in India.

2.4.1 Standards and Guidelines

The cold chain quality control is mainly regulated by internationally accepted guidelines and standards. Systems such as Hazard Analysis and Critical Control Points (HACCP), ISO

22000 (Food Safety Management Systems), and World Health Organization (WHO) guidelines for transportation and warehouse operations for cold chain foods have broad protocols for the preservation of the food's safety and the quality of the produce (WHO, 2019).

The HACCP system maintains a check and determines critical control points (CCPs) during the different stages of the supply chain like processing, storage, and distribution. Earlier detection of divergences allows companies to take the necessary preventive measures prior to a loss of product safety. Likewise, ISO 22000 combines the management of food safety and risk analysis tools to maintain consistency and traceability in the logistics operations. Adoption of these frameworks is imperative for exporters for accessing export markets globally, satisfying customers' requirements, and retaining regulatory license (FAO, 2020).

Compliance with HACCP and ISO in the fishing business ensures that seafood products meet high quality requirements set by import countries such as the United States, Japan, and the European Union. For Abad Fisheries and alike companies, the meeting of the requirements ensures the health of the consumer aside from cementing brand image and confidence in the global marketplace.

2.4.2 Monitoring and Technologies

Technology has also revolutionized quality control of cold chain logistics. Advanced Internet of Things (IoT) technology devices that are installed with temperature and humidity sensors are capable of displaying environmental conditions real time while the goods are being transported or stored. IoT devices also send automated alerts when conditions vary, allowing for immediate remedial action and decreasing losses for the goods (Ting et al., 2021). In addition, blockchain technology has further provided transparency and track and trace for the logistics supply chain. Blockchain produces irrevocable records for temperature conditions, treatment protocols, and transportation itineraries that are accessible by all enactors in real time. This not only improves accountability but also

makes it easy to conduct audits for compliance and carry out recall exercises (Rodrigue & Notteboom, 2020).

Moreover, predictive analysis and artificial intelligence (AI) are also being implemented in cold chain networks in order to forecast potential disruptions. AI programs are capable of recognizing patterns in the data to foretell equipment failure, routing disruption, or temperature deviation so that pre-emptive action may be undertaken. All such technologies are aimed towards increased efficiency, minimized wastage, and improved consistency in quality for global supply chain networks.

2.4.3 Challenges in Developing Countries

In spite of the most recent developments in technology, the establishment of top-notch quality control mechanisms remains incomplete throughout the world. For new nations such as India, the cold chain industry is also plagued by issues involving inadequate infrastructures, inconsistent supplies of power grids, and technical capabilities (Singh & Sushil, 2020). Financial constraints also deter a number of small and medium-sized organizations (SMEs) from purchasing the most recent monitoring instrumentation and automated mechanisms.

Even today, most Indian seafood exporters and processors depend upon manually prepared temperature logs, time-honoured ice-based preservation techniques, and non-temperature-controlled transportation for short runs. Such obsolete methods are bound to result in increased chances of contamination and deterioration of the produce, thereby decreasing export competitiveness and causing huge losses. The efforts by the Government such as the National Centre for Cold Chain Development (NCCD) and collaborations by the private sectors are accordingly promoting awareness generation, training, and investment towards technology adoption.

But long-term investment, policy help, and industry harmonization will be needed to scale the deployment of good quality control structures. Blending time-tested

methodologies and recent monitoring technologies may offer a workable route for emerging countries to improve the quality and safety of their foods while a reducing post-harvest loss. Summing it all up, quality control is a core aspect of cold chain logistics that has a direct impact on the integrity of the product and commercial success. Whereas global standards and technologies are credible quality assurance mechanisms, the developing world needs to emphasize the need for infrastructure and knowledge gap bridging for its complete potential in the global supply chain.

2.5 Summary of Literature Review

In this chapter, the literature that currently exists on cold chain logistics will be discussed in terms of risk management and quality control. The chapter will lay the foundational theories and fill the void that the research is presented to fill.

Key Findings from Literature:

1. **Role of Cold Chain logistics services:** Cold chain logistics is a critical function in the context of perishables. An estimated one-third of perishables are typically being wasted each year because of poor cold chain logistics systems, according to FAO (2019).
2. **Risk Categories:** According to literature, there exist four major risk categories in cold chain services, which include operational risk (delays, handling damage), technical risk (machine breakdowns), environmental risk (power failures, natural disasters), and human-factor risk (staff training, non-compliance).
3. **Risk Management Strategies:** Tools like FMEA, HACCP, and ISO standards help follow a process-oriented approach towards identifying, analyzing, and controlling risks. In spite of this, successful implementation methodologies are far from uniform.
4. **Quality Control Standards:** HACCP and ISO 22000 are widely accepted standards of international best practices for managing food safety. Meeting the requirements of these standards is critical for export, but not a measure of success.
5. **Role of Technology:** Examples include internet of things sensors, data loggers, blockchain technology for tracing, predictive analytics, and more. But when it comes to adoption within new economies, technology faces challenges aside from budget limitations.

6. Developing Economies: There are identified challenges in developing economies, such as lack of infrastructure, absence of reliable electricity, poor logistics infrastructure, and lack of technical know-how (Singh & Sushil, 2020).

7. Fisheries Specificity: Seafood has a high perishability level that further accentuates the need for an efficient cold chain because it has a tendency to deteriorate rapidly if appropriate temperature measures are not adopted.

Research Gaps Identified:

1. Integration Gap: Despite the presence of a vast amount of literature on risk management practices as well as quality control practices independently, there is a lack of study in the combined domain.

2. Implementation Focus: There is significant emphasis in many papers on what is being implemented, rather than how, particularly in resource-limited environments.

3. Developing Economy Background: The significance of cold chains to a global exporter is relatively unexplored within developing economies compared to developed economy settings.

4. Case-Based Evidence: There are few in-depth case studies available on the management of risk and quality in the cold chain within the fisheries sectors and their respective operational environments.

5. Barriers to Technology Adoption: Although there is extensive literature on technology solutions, research on adoption barriers in developing countries is inadequate.

These research gaps would be filled through this case study on risk management and quality control practices at Abad Fisheries.

3 Research Method

3.1 Research Design and Approach

This is a qualitative research design based on the case study method of examination in cold chain logistics and its associated risk management and quality control practices, with special reference to Abad Fisheries, India. Qualitative research has been found to be appropriate in exploratory studies, aimed at understanding processes, behaviours, and perceptions within their natural setting (Creswell, 2014). The nature of this study demands an in-depth understanding of how cold chain practices are implemented and managed within an organizational setting, where numerical data alone would not capture the complexity of operations and decision-making.

3.1.1 Justification for Qualitative Research Design

There are several factors relevant to this research that justify the selection of a qualitative methodology.

Exploratory Nature of the Study: Cold chain logistics in the Indian fisheries sector is a relatively under-researched area, especially regarding the integration of risk management and quality control practices. Qualitative research becomes suitable in exploratory studies where the objective is to comprehend processes, behaviours, and perceptions within specific contexts, rather than testing pre-determined hypotheses (Bryman & Bell, 2015).

Complexity of the phenomenon: The cold chain logistics involve multiple interdependent variables comprising technological systems, human factors, organizational culture, regulatory compliance, and infrastructure constraints. These are of such complexity that to understand the depth, a contextual understanding is required, which cannot be elicited with numerical data only (Denzin, 2012).

Limited Quantifiable Data: The performance metrics exist to a limited extent; temperature logs and spoilage rates are examples, but the implementation and effectiveness of risk management and quality control practices are usually embedded in organizational routines and tacit knowledge, as well as in contextual factors, which can be understood best through qualitative inquiry.

3.1.2 Case Study Method

In this paper, the case study method was used as a research strategy, enabling an in-depth investigation of a contemporary phenomenon in its real-life context, particularly when the boundaries between the phenomenon and context were not distinctly evident (Yin, 2018).

Single Case Study Justification: The research will use a single-case design, which will focus on Abad Fisheries for various strategic reasons:

1. **Representativeness:** Since Abad Fisheries is the largest vertically integrated seafood company in India, it would be an appropriate representative case of large-scale operations in the sector.
2. **Access to Information:** The willingness of the company to participate provides access to unique operational data, personnel, and processes.
3. **Vertical integration:** The company controls the whole value chain, from fishing to export, allowing an in-depth study of cold chain practices at every step.
4. **Industry Significance:** Being one of the largest exporters to international markets (US, Europe, Middle East), the quality standards that must be followed are very stringent, and therefore it's a pretty information-rich case.

Unit of Analysis: The main unit of analysis is the cold chain logistics system at Abad Fisheries, consisting of the integrated processes of storage, transportation, handling, and quality assurance from procurement through export.

3.1.3 Epistemological Position

This is interpretivist epistemology, which is taken to provide an understanding of social phenomena from the perspective of those involved rather than through detached, objective measurement. Putting it quite succinctly, Bryman and Bell (2015) express the interpretivist approach thus:

- Reality is socially constructed and context-dependent
- Knowledge is acquired by grasping the participants' meanings and interpretations
- The role of the researcher will be to interpret data within its contextual framework.
- Multiple perspectives contribute to a comprehensive understanding of the phenomenon.

These philosophical underpinnings become important to the objectives of this research: to understand the implementation, experiences, and assessment of risk management and quality control practices within the specific context of Indian fisheries cold chain logistics.

3.1.4 Research Strategy Overview

The research strategy encompasses multiple qualitative data collection methods in order to realize methodological triangulation:

1. **Semi-structured interviews** with key personnel across different functional areas
2. **Document analysis** of company records, quality manuals and industry reports
3. **Secondary data analysis** from academic literature and industry publications

This multi-method approach enhances the validity of findings, as it allows information from different sources to be cross-verified (Denzin, 2012).

3.2 Data Collection Process

Data for this study were collected through semi-structured interviews with key personnel at Abad Fisheries, India. The data collection aimed to capture practical insights of risk management and quality control practices applied in the company's cold chain logistics operations. Semi-structured interviews were chosen as appropriate, since such a method allows the researcher to explore both predefined topics and emerging themes in detail (Kvale, 2007).

3.2.1 Primary Data Collection

Semi-structured interviews will be the main method of data collection, as the format allows flexibility in exploring both predetermined topics and emergent themes. In so doing, this approach will enable the researcher to keep focus on key research questions while remaining open to unexpected insights that may emerge during conversations.

Interview Design and Structure

The interview protocol was developed based on:

- Research questions and objectives
- Themes identified in the literature review
- Basic understanding of cold chain operations
- Industry expert consultation

Interview Guide Components:

1. **Opening Section:** Participant background, role, and experience in cold chain operations
2. **Risk identification and management:**
 - Types of risks associated with cold chain operations
 - Frequency and severity of different risk categories
 - Current risk assessment methodologies
 - Risk mitigation strategies employed
3. **Quality Control Practices:**

- Quality standards and certifications (HACCP, ISO 22000)
- Temperature monitoring systems and technologies
- Assured quality at various stages
- Handling of quality failures and corrective actions

4. Technology and Infrastructure:

- Current technology systems in use
- Infrastructure constraints and challenges
- Investment in new technologies: IoT, blockchain, etc.

5. Challenges and Improvements:

- Significant operational issues
- Suggestions for improvement
- Best practices observed

Sample Selection

We used purposive sampling, by which interview participants who possess relevant knowledge and experience were selected. The sample encompasses personnel from five identified key departments:

Table 1. Samples from five key departments

Department	Number of Participants	Rationale for selection
Quality Control	1	Expertise in quality standards, testing and compliance
Production/Processing	1	Understanding of Operational processes and handling
Logistics/Transportation	1	Knowledge of distribution, transport risks, and temperature control
Cold storage management	1	Insights into storage infrastructure and maintenance
Export and compliance	1	Understanding of international standards and regulatory requirements

Total sample size: 5 participants, representing different hierarchical levels (supervisors, managers, senior managers) to capture diverse perspectives.

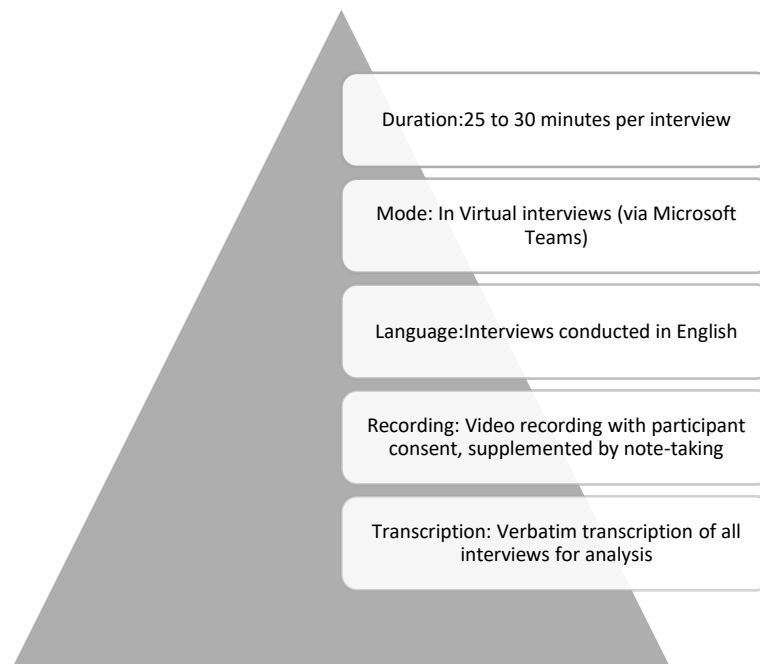


Figure 1. Interview Implementation

3.2.2 Secondary Data Collection

It provides background information, aids in triangulation, and extends the understanding of industry-wide practices.

Company Documents and Records:

- Quality Management Manuals/Standard Operating Procedures (SOPs)
- HACCP and ISO certification documents
- Temperature monitoring logs and equipment maintenance records
- Quality inspection reports and corrective action records
- Training materials and employee guidelines

- Cold chain performance metrics (where available and permitted)

Industry Reports and Publications:

- Reports from ICAR (Indian Council of Agricultural Research)
- Publications from Mariane Products Export Development Authority (MPEDA)
- FAO reports: fisheries, cold chain
- World Bank and industry association publications
- Trade journals and technical reports

3.2.3 Data Collection Timeline

Table 2. The data collection process follows a phased approach

Phase	Activities	Duration
Phase 1: Preparation	Interview guide development	1 week
Phase 2: Initial contact	Formal communication with company, ethics approval, participant recruitment	2 days
Phase 3: Data Collection	Conducting interviews, document collection	2 weeks
Phase 4: Follow-up	Clarification interviews, additional document request	1 week

3.2.4 Data Recording and Management

Interview Data:

- Video recordings stored securely on password-protected devices
- Transcriptions completed within one week of each interview
- Transcripts anonymised to protect participant confidentiality
- Files organized systematically with unique identifiers

Documentary Data:

- Digital copies of all documents in organized folder structure
- Hard copies scanned and digitized
- Source and date of each document recorded

Data Security:

- All data stored on encrypted, password-protected devices
- Backup copies maintained on secure cloud storage
- Access limited to the researcher and supervisor
- Data retention aligned with university policy

3.3 Data Analysis Method

Data from the interviews were analysed thematically using one of the most frequent qualitative methods for the identification, organization, and interpretation of patterns in data (Braun & Clarke, 2006). Thematic analysis was selected because it offers an effective way to study both explicit and implicit meanings of participants responses systematically; hence, it is particularly apt to explore complex operational issues in cold chain logistics.

3.3.1 Thematic Analysis Approach

Thematic analysis was selected as the primary analytical approach, owing to the flexibility and the systematic identification, analysis, and reporting of patterns in qualitative data that it allows, as Braun and Clarke (2006) have noted. This approach is particularly fitting for this research in that it can support both rich description in regard to the dataset and interpretation of various aspects of the research topic.

Six-Phase Thematic Analysis Process:

Phase 1: Familiarization with the Data

The researcher plunges into the data by means of:

- Read and re-read all the interview transcripts
- Review of the collected documents and field notes
- Noting preliminary ideas, patterns, and possible themes
- Listening to recordings of interviews while re-reading transcripts to capture the tone and emphasis

This stage establishes deep familiarity with the breadth and depth of the content.

Phase 2: Initial Coding

Systematic coding of interesting features across the complete dataset:

- Manual Coding Process: line-by-line analysis of transcripts
- Code Development: Creating descriptive codes that outline key concepts
- Extracting and coding consistently from all sources of data
- Code Examples:
 - "Temperature monitoring challenges"
 - "Equipment breakdown prevention"
 - "HACCP implementation barriers"
 - "Limitations to technology adoption"
 - "Quality control procedures"
 - "Training inadequacies"
 - "Infrastructure constraints"

Phase 3: Searching For Themes

Codes are organized into broader themes:

Grouping related codes together

- Identifying connections between various codes
- Considering how codes relate to research questions
- Drawing thematic maps to show relationships
- Distinguishing between main themes and sub-themes

Phase 4: Reviewing Themes

Refinement of identified themes through two levels:

- Level 1: Review the coded data extracts to ensure they form coherent patterns.
- Level 2: Review themes against the entire dataset to ensure that they reflect the data accurately
- Discarding, collapsing, or splitting themes that are not serving a purpose
- Ensure that themes are distinct and meaningful.

Phase 5: Defining and Naming Themes

Thorough elaboration of each theme's definition:

- Detailed analysis of each theme in writing
- Identifying the "story" each theme tells
- Considering how themes relate to research questions
- Refining Theme Names to Be Concise and Immediately Meaningful

Phase 6: Creating the Report

Final analysis and write-up:

- Choosing catchy, interesting examples of extracts
- Relating analysis back to research questions and literature
- Providing scholarly analysis beyond description
- Ensuring logical, coherent narrative

3.3.2 Framework Analysis

Besides thematic analysis, the framework analysis approach is utilized to systematically organize and analyse data with regard to key themes and sub-themes. This approach is specifically helpful in applied policy research and multi-case qualitative analysis (Ritchie & Spencer, 1994).

Analytical Framework Structure:

The framework is organized around two major research areas of focus:

1. Risk Management Practices
 - Risk identification techniques
 - Risk assessment and evaluation
 - Risk mitigation strategies
 - Risk monitoring and review
 - Challenges in risk management
2. Quality Control Practices
 - Quality standards and certifications

- Monitoring technologies and systems
- Quality assurance procedures
- Non-Conformities handling
- Continuous improvement mechanisms

The framework allows the systematic charting of data from interviews, documents, and observations in order to:

- Comparison across different participants
- Identification of patterns and variations
- Integration of several data sources
- Clear link to research objectives

3.3.3 Data Triangulation

Triangulation empowers the validity of findings through the investigation of the phenomenon from different perspectives and sources (Denzin, 2012):

Source Triangulation:

- Interview data from several participants across various departments
- Most of the documentary evidence could be collected from company records and external sources.

Method Triangulation:

- Semi-structured interviews (verbal accounts)
- Analysis of documents: Written evidence

Comparative Analysis:

- Comparing practices at Abad Fisheries with
- International best practices identified in literature
- Standards outlined under HACCP and ISO frameworks
- Practices in developed country contexts, e.g., Norway, Japan

3.3.4 Integration with Literature

Analysis continuously relates empirical findings to the existing theoretical frameworks and literature.

- Risk Management Frameworks: Comparison with FMEA, HACCP, ISO standards
- Quality Control Models: Benchmarking against TQM, Six Sigma principles
- Cold Chain Best Practices: Assessment against international standards
- Technology Adoption: Industry 4.0 – Analysis

3.3.5 Analytical tools and Techniques

NVivo Software (or similar qualitative analysis software):

- Systematic organization of interview transcripts and documents
- Efficient coding and theme development
- Visual mapping of themes and relationships
- Query functions to explore patterns

Microsoft Excel:

- Framework matrices for systematic data charting
- Comparison tables across participants
- Summary tables of key findings

3.3.6 Interpretation and Sense-Making

The final stage involves interpreting findings within the context of the research:

- Contextual Understanding: Relating findings to the specific context of Indian fisheries and developing economy challenges.
- Critical Analysis: Analysing why certain practices succeed or fail
- Identifying Gaps: Gap identification between current practices and best practice
- Practical Implications: How findings might help in improving

3.4 Reliability, Validity and Ethical considerations

The reliability and validity of the research findings are very relevant in ensuring that credibility of the study is maintained through keeping academic integrity in place. In qualitative research, these are taken care of by trustworthiness, transparency, and methodological consistency (Lincoln & Guba, 1985).

Reliability in the given study was enhanced by systematization and replicability of the research process, wherein identical semi-structured interview questions were used across all departments, including Quality Control, Production, Logistics, Cold Storage, and Export. This uniformity provided comparability and reduced interviewer bias.

Validity was guaranteed because the triangulation methodology effectively combined primary data from interviews with secondary data such as company reports, industry guidelines, and scholarly literature. The approach allowed for the cross-verification of findings and further enhanced the overall robustness of the results. Member checking was also utilized whereby the interpreted findings were checked with participants to confirm that findings reflected their experiences and perceptions.

Furthermore, an audit trail of each research step involved in this study is available: interview transcripts, coding notes, and other analytical frameworks all enhance the study's transparency and reproducibility.

Ethical integrity has been maintained throughout the research process. Every participant was well-informed of the purpose for which the study was being conducted, their rights to withdraw, and that all information disclosed would be kept confidential. Thereafter, it was explained that the data would only be utilized academically, and no personal information related to them would be disclosed in the final thesis.

Verbal informed consent was obtained from each interviewee before every interview, with each interviewee informed that discussions would be audio recorded and subsequently transcribed for analysis. Digital recordings and transcripts were stored on

password-protected devices to ensure compliance with regulations concerning data protection.

It follows all the ethical policies laid down by the University of Vaasa and is based on the principles of honesty, transparency, and respect for the research participants. The data interpretation will also be objective, without any personal or institutional biases from the researcher.

4 Results and Analysis

4.1 Overview

This chapter discusses empirical evidence from the case study analysis at Abad Fisheries, in India, which is one of the largest vertically integrated fish companies in India. Data for analysis was sourced from in-depth interviews with five senior employees in Abad Fisheries, document analysis, such as quality reports, temperature records, Standard Operating Procedures, and observation. These themes have been identified to meet the objectives: to reveal significant risks to cold chain logistics, in addition to an investigation into quality controls mechanisms employed to provide temperature stability in storage and during transport.

4.2 Case Company Context: Abad Fisheries

4.2.1 Company Profile and Operations

Abad Fisheries is based in the state of Kerala in India, specifically in the city of Kochi, and is involved in vertical integration in its seafood production operations, controlling all stages from fishing, aquaculture, to exporting seafood. Its product specialization is in frozen seafood items such as shrimp, fish, and other sea creatures. These products are mainly for exporting to various foreign countries such as the United States, Europe, and the Middle East.

Its food processing plant is operated in adherence to international food safety regulations, with several food safety certificates such as HACCP (Hazard Analysis And Critical Control Points), BRCGS (Brand Reputation Compliance Global Standards), and FSSC 22000 (Food Safety System Certification). These food safety certifications are required for exporting its products to major countries.

Abad Fisheries complies with "International Food Safety Regulations via their Quality Assurance Division, HACCP System, and Adherence to International Certifications,"

according to their Export/Compliance Officer. Some other regulations Abad Fisheries needs to adhere to in order to retain its exporting status include Marine Products Export Development Authority (MPEDA) registration, which "is compulsory for all seafood exporting companies in India," and Export Inspection Council approval.

4.2.2 Cold Chain Infrastructure

The cold chain system developed for Abad Fisheries consists of a number of sequential processes beginning from the receipt of raw materials to final dispatch. It includes the following components:

Reception and Pre-processing Area: The raw materials come on ice, and they get transferred to processing rooms, where the temperature is below 12°C. The Quality Control Manager confirmed that flake ice and ice slurry are used to keep the temperatures of the product between 0–4°C.

Processing Rooms: The temperature range for the production floor is ambient temperatures below 12°C, and the temperature of the fish is maintained at ≤4°C. The Production Manager confirmed that the processing line for the fish, including filleting, grading, and glazing, is done under chilled conditions of 0-4°C.

Freezing Facilities: The company uses a number of freezing methods, such as blast freezing at -40°C, spiral freezing, as well as Individual Quick-Freezing Tunnels. The choice of freezer is dependent on the type of product as well as customer requirements. As stated by the Production Manager, blast freezing is done at a temperature of -40°C before storing the products in cold storage.

Cold Storage Units: Frozen foods are stored in cold storage units that operate at or below -18°C. The temperature conditions in these cold storage units are constantly checked, and if there is any abnormality, such information is recorded through data loggers. The

manager of cold storage confirmed that temperatures, along with humidity, in cold storage units are constantly recorded through sensors attached to data loggers.

Dispatch and Transport: The products are packaged into refrigerated containers for export. Temperature data is recorded continuously through the transport of data loggers inside the containers. Proof of temperature monitoring for a container shipment exists through a document of a container transport (Document: 260937220_MMAU1330573), where temperatures from October 30, 2025, to November 11, 2025, are continuously checked to be maintained at the set point of -21°C.

4.2.3 Quality Assurance Structure

The company has a quality Assurance Division, whose duties include monitoring and enforcing quality standards along the cold chain. The quality Assurance Division is responsible for implementing the Hazard Analysis & Critical Control Points system, whereby the firm identifies its Critical Control Points for every step of the production process.

The quality management organizational structure consists of:

- Quality Control Manager: responsible for quality systems and the company's compliance with certification
- Online Quality Controllers: These personnel monitor quality processes occurring on the production floor.
- Laboratory Technicians: involved in microbiological and chemical tests
- Export and Compliance Officers: responsible for regulatory compliance and communication management for customers
- Cold Storage Supervisors, responsible for monitoring storage conditions and equipment functions

According to the Export and Compliance Officer, "Prior to shipments being sent from the facility, a quality verification step is performed through a 'Pre-Shipment Inspection' or

‘PSI’ process that includes a review of appearance, ‘organoleptic or microbial’ properties, quantity, and packaging.”

4.3 Risk Analysis in Cold Chain Operations

4.3.1 Overview of Identified Risks

Identified Risks & Overview Based on the findings from the analysis of interview data, there appear to be four key risk areas relevant to cold chain logistics at Abad Fisheries. These include operational risks, technical risks, environment risks, and human-related risks. These areas match well within the risk taxonomy that was developed from the findings of the literature review, although the form that the risks take is specific to Abad Fisheries' operation as a seafood processor that is working within a developing country. All respondents agreed that temperature management failure is the most serious risk factor. The Quality Control Manager of Abad Fisheries said, “Risk factors include temperature control failure as a result of equipment failure or power failure, human-related risks that result from improper handling or training, or disruptions to the logistics chain that result, for example, from natural disasters.”

4.3.2 Operational Risks

Container Availability and Transportation Delays

One of the key operational risks that is identified exclusively at Abad Fisheries is related to the availability of containers for dispatch. Both the Logistics Manager and the Quality Control Manager of the company identified "the unavailability of storage containers for dispatch on time" as a key risk. The risk is especially pertinent for seafood companies, where timely delivery is necessary to preserve the quality of the seafood.

When containers aren't available, products have to be placed inside the cold storage for a considerable time, thus increasing the costs of storage. The Logistics Manager explained that sometimes, transport delays can result from customs processes, congestion

at the ports, or disruptions of shipments. Delays can be a concern for frozen seafood, for example, as temperature controls have to be maintained constantly.

Documentary evidence from the company's risk assessment report reveals raw material variability and supply chain coordination to be risks for them. Although the vertical integration approach of Abad Fisheries offsets such risks to a certain extent, transport logistics, as well as exporting, can be considered vulnerable to external risks.

Handling and Transfer Point Vulnerabilities

The Cold Storage Manager found that transfer points were areas of high risk because, according to them, "loading docks, transfer points, and regular delivery stops are hotspots where temperature variability is probably a result of openings or delays." Every time there is a transfer of goods from or to storage units, transportation, or containers, temperature abuse can occur.

The Production Manager insisted on the need to keep the time spent between the processing steps at a minimum: "Minimize time between thawing, cutting, and freezing." This shows that they are quite conscious that the efficiency of the processes has its implications on the quality of the products. Delays can be inevitable, though, due to logistics.

Processing Workflow Risks

In the processing plant, the risks that may affect operation can be attributed to inefficiencies or poor controls of the processes. The Production Manager was able to list a number of these risks as follows:

- "Improper stacking in containers reducing air circulation" that can cause temperature gradients in storage containers.
- "Delayed transportation and lack of real-time temperature monitoring"
- "Delay between processing and freezing" that enables microbial development and quality deterioration

These risks can be managed through process management and compliance with standard operating procedures. It can be evidenced from the document that the company is able to provide standard procedures for its important processes, but its ability to implement them is a concern.

4.3.3 Technical Risks

Equipment Malfunction and Reliability

Technology risks pertaining to the breakdown of refrigeration equipment pose a perpetual risk to cold chain integrity. The Cold Storage Manager quoted: "Temp control failure: This is the main cause of damage and can be brought about by equipment breakdown, power failure, or improper temperatures setting."

The impact of equipment failure depends on duration and location along the cold chain. Equipment failure in the processing points can be controlled because a quick transfer to another facility is possible. Equipment failure occurring in cold storage or transport can lead to a complete loss of products.

The manager of cold storage stated that "Raw materials get spoiled due to prolonged exposure to high temperature. Frozen product get melted and we become unable to market the products." It is clear that the company had experienced loss of products because of failure of equipment.

Maintenance & Calibration Issues

Preventive maintenance is important for preventing equipment breakdowns, and the answer from the Cold Storage Manager indicated a multiple-frequency inspection, such as, "Cold storage equipment requires a multi-frequency inspection and maintenance schedule, including daily checks for basics such as temperature, weekly and monthly checks for underlying system problems, and annual or biannual professional inspections for validation."

Documentary proof from internal audit findings (Document: 1-INTERNAL AUDIT) shows that schedules for maintenance activities had been recorded, although the quality of maintenance personnel had not. The Production Manager identified “equipment malfunction (freezer failure, poor calibration)” as a risk factor, implying that its accuracy of calibration is a matter of concern.

Centralized vs. Distributed Systems

Although investments have been made in temperature monitoring systems such as data loggers and sensors, technical constraints of such systems result in ‘blind spots’ of cold chain visibility. Notably, according to the Logistics Manager, some of these ‘blind spots’ include “delayed transportation and lack of real-time temperature monitoring.”

The prevailing monitoring system is mainly concerned with temperature, without much consideration for other environmental conditions, including humidity. Nevertheless, the Cold Storage Manager confirmed that “temperature and humidity inside storage units are monitored through sensors linked to data loggers,” suggesting that humidity is, to a limited extent, being monitored.

4.3.4 Environmental Risks

Power Supply Instability

Power failure appeared to be a prominent environmental risk. Power failure was identified as a risk by the Quality Control Manager, who listed ‘power failure’ among the most significant risks. The Cold Storage Manager offered a detailed evaluation of power failure risks: “power failure/equipment breakdowns result in serious disruptions of our operation, such as downtime, lost productivity, and lost profits.”

In the Indian situation, the availability of power supply is a matter of considerable variation from region to region, and may, at times, be impeded by forces that are outside the company’s control, such as weather conditions, and peak seasons. According to the Cold Storage Manager, “the extent of its impact depends on the duration of the outage and the criticality of the equipment or facility finally results into the product loss.”

Although Abad Fisheries has power back-up systems, its sufficiency and reliability had not been directly raised as concerns. These could be a possible weak link, especially for prolonged power disruptions that exceed the back-up generators' capacity.

Natural Disasters & Weather Events

Disruption of supply chains owing to natural disasters was a theme raised by the respondents. The Logistics Manager noted that the company considers "Supply chain disruptions owing to natural disasters." The fact that Kerala is a coastal state makes it a vulnerable place for natural events such as cyclones, flooding, and monsoons.

"The biggest challenges in maintaining export compliance include," said the Export and Compliance Officer, "managing complex global supply chains. Climate-related events can cause delays to shipments, the availability of containers, and a chain reaction of events along the supply chain," added the Import and Compliance Officer.

Infrastructure Challenges

"Environmental risks" include natural disasters, but also risks that result from a lack of capacity of the country's infrastructure. Here, the Quality Control Manager declared, "Issues related to infrastructure/equipments such as poor cooling standards or lack of storage."

These infrastructural constraints can be considered indicative of larger difficulties being experienced within India's cold chain logistics, where even cold chain transportation networks, cold storage, or ports might lack consonance with worldwide benchmarks. The Logistics Manager explained that to make a comparison between the current state of operations and worldwide benchmarks, one had to "evaluate its handling of cross-border complexities, its use of technology and automation."

4.3.5 Human Factor Risks

Training and Competency Gaps

Risks of human factors for improper training appeared as a prominent issue for various departments. The Quality Control Manager identified that a "human error from

improper or careless handling or training" was a key risk factor. Likewise, a "human error from improper or careless handling or training" was identified by the Logistics Manager. "Regular food safety and hygiene training (GMP, GHP, HACCP). Demonstrations on handling, temperature checks, and cross-contamination prevention" was stressed by the Production Manager. It is confirmed through documentary evidence that the company conducts training programs for the workers through "post-training evaluations and refreshers every 6 months" as stated in the document, Training notes - Debugging procedure.

However, the efficacy of training activities is dependent on a number of issues, such as communication barriers, literacy rate, employee turnover, and post-training behavior reinforcement. The Production Manager was quoted to have observed that communication issues had been dealt with through the posting of "visual posters and SOPs displayed in local language on the floor," although consistency of training among all employees is a challenge.

Awareness & Compliance

In addition to this, human factor risks include lack of awareness and failure to adhere to procedures. The Production Manager identified that the human factor risks include "inadequate hygiene – microbial contamination," along with "inappropriate handling practices of loading/unloading, resulting in partial thawing."

The Export and Compliance Officer's message about the need for accountability is relevant here:

"To manage communication on quality standards with international buyers, establish clear, written specifications through emails and use a single point of contact to prevent miscommunication." This implies that human error can be a cause of quality or compliance issues, even if the handling is done properly.

Organization Culture

The quality of quality awareness varies from one operational area to another, as borne out by the interviews. Notably, the quality of quality awareness was identified by the Quality Control Manager, who noted that there was a need to “implement food safety culture of continuous improvement through data analysis and feedback.”

4.4 Quality control practices and systems

4.4.1 Certification Framework

HACCP Implementation

The key to Abad Fisheries’ quality control system is the HACCP, or Hazard Analysis and Critical Control Points, method. This was explained by the company’s Quality Control Manager, who reported, "Quality standards: The company operates under a HACCP system, or Hazard Analysis and Critical Control Point. It is a systematic and preventative food safety management system that identifies, evaluates, and controls biological, chemical, and physical hazards throughout the food production process.”

The HACCP system at Abad Fisheries is based on the following seven key principles:

1. Hazard analysis is about the identification of biological risks or microbiological contaminants, chemical risks or veterinary drug residues, or even physical risks, such as foreign objects.
2. Certain points called Critical Control Points or CCPs are identified for key processes such as receipt of raw materials, freezing, storage, and dispatch.
3. Critical Limits: Defining such specific parameters as temperature, time, and microbiological criteria
4. Processing for Monitoring: The processes of temperature monitoring, testing, and inspection
5. Corrective Actions: Defining responses to deviations including product isolation, equipment repair, and process adjustment

6.Verification: Is done through internal audits, equipment calibration, and product testing

7.Documentation: Record keeping of monitoring data, corrective measures, and verification activities

“HACCP emphasizes preventing problems rather than treating them after they happen by identifying critical control points and addressing them through corrective actions,” stated the Quality Control Manager. This is in line with best practices of preventing, rather than treating problems, when it comes to food safety.

BRCGS and FSSC 22000 Certifications

Beyond HACCP, Abad Fisheries maintains two higher-level certifications: BRCGS and FSSC 22000. The Quality Control Manager explained: "Cap seafoods having BRC and FSSC CERTIFICATIONS. BRCGS (Brand Reputation Compliance Global Standards) ... FSSC 22000 (Food Safety System Certification 22000) is a food safety certification scheme that is recognized by the Global Food Safety Initiative (GFSI)."

FSSC 22000 is built on ISO 22000 standards and provides a comprehensive framework integrating food safety management with quality management principles. The Quality Control Manager noted: "It is based on the international standard ISO 22000 and is supplemented by sector-specific technical specifications and additional FSSC requirements."

The benefits of these certifications extend beyond regulatory compliance. The Quality Control Manager stated: "Food safety certification provides advantages like increased consumer trust and brand credibility, expanded market access, and better compliance with regulatory standards." Additionally, "Certifications helps the business to reduce risks and costs associated with product recalls, streamlines audits by providing a recognized standard, and improves operational efficiency and legal compliance."

Export Regulatory Compliance

Export compliance represents an additional layer of quality requirements beyond voluntary certifications. The Export and Compliance Officer explained: "For getting export approval need to comply with standards and approved by EXPORT INSPECTION COUNCIL and registration from MPEDA. We need to produce all documents pertaining to raw material receiving to dispatch, all internal and external test report and legal documents at the time of approval inspections."

This regulatory framework requires comprehensive documentation of the entire cold chain from source to export. Documentary evidence includes:

- Raw material traceability records showing source, date, and initial quality parameters
- Processing records documenting time, temperature, and handling procedures
- Internal quality control test results including microbiological and chemical analysis
- External laboratory test reports from accredited facilities
- Temperature monitoring logs for storage and transportation
- Pre-shipment inspection reports confirming product compliance

Documentary evidence from Abad Fisheries (Document: 1-Chemical analysis reports, 1-MICRO REPORT) shows regular testing of products for microbiological parameters (including *Listeria*, *Salmonella*, *E. coli*) and chemical residues. Test report CERTA20251 1481+Acc from GEO-CHEM Laboratories shows comprehensive testing of a shipment including biological analysis with results indicating compliance with regulatory standards.

4.4.2 Quality control procedures

Raw Material Receipt and Assessment

The process of quality control starts at the reception of raw materials, wherein the freshness, temperature, and quality of fish and seafood are evaluated. According to the Production Manager, "Products should be stored under chilled conditions (0-4°C)" immediately after receiving the goods.

The common seafood quality problems identified by the Quality Control Manager were: "microbiological hazards such as bacteria and viruses, chemical contamination such as heavy metals and mercury, and autolytic and physical spoilage due to the decomposition of fish tissue post-death." To counter such problems, reception procedures include:

- Verification of temperatures on incoming materials
- Sensory evaluation of freshness indicators (odor, color, texture)
- Documentation of supplier, location, and date
- Sample collection for lab tests if required
- Rejecting materials which are not conforming

"We can resolve the issue by SOP, SSOP, and GMP," said the Quality Control Manager regarding microbiological hazard, "by avoiding the catch from polluted waters" regarding chemical hazard, and "by maintaining cold chain" regarding autolytic spoilage.

Processing Stage Controls

In the process, the focus of quality control checks is on ensuring the correct temperatures, avoiding contamination, and adequate handling. According to the Production Manager, "Ambient temp: below 12° C in processing rooms. Fish temp: $\leq 4^{\circ}$ C during handling. Freezers: -40°C (blast), cold storage: -18°C or below."

Hygiene controls on the production floor are:

Regular sanitation of tables and equipment

- "Use of foot baths, hand sanitizers, PPE
- "Separation of raw and cooked zones"
- "Scheduled cleaning (CIP) and microbiological

"Reduce time between thawing, cutting, and freezing" is essential to minimize exposure to conditions which could degrade product quality, and the Production Manager reiterated the importance of process efficiency on this issue.

During the processing stages, the procedure also involves visual checks to guarantee freedom from any defects, weighing to guarantee correct packaging, and glazing to prevent dehydration when stored in frozen conditions. The Production Manager said, "Glazing and packaging into vacuum-sealed bags prevent dehydration and oxidation."

Storage Monitoring and Management

The control of cold storage is dependent on and governed by constant temperature monitoring. The Cold Storage Manager asserted, "Temperature and humidity levels within the storage rooms are monitored by sensors linked to data loggers. Data loggers measure and send information to enable constant monitoring and alerting when temperatures are not within predetermined limits." evidential documents obtained from a container shipping (Document: 260937220_MMAU1330573) indicate that temperatures are recorded on a document which reflects that:

- Setpoint temperature: -21°C
- Real supply air temperatures between -25.72 and -14.36°C
- Continuous monitoring on an hourly basis
- Transient temperature excursions during container opening/inspection
- Monitoring of Relative Humidity (61-90)

From the data obtained, it is evident that, apart from slight changes during the time of door openings and machine cycles, the cargo temperature did not exceed the acceptable limits during the 12-day observation period.

The management of inventory systems also promotes quality control by ensuring First-In-First-Out (FIFO) and First-Expired-First-Out (FEFO) rotation systems. According to the Logistics Manager, "Risk management practices to prevent spoilage and losses include implementing inventory management systems such as First In First Out and First Expired First Out, having tight control of the environment of the warehouse (temperature and humidity), and technology to monitor and alert."

Pre-Shipment Inspection and Verification

Pre-dispatch quality verification is the last control before dispatching, to ensure only compliant products are delivered to customers. In his description, the Export and Compliance Officer explained, "Each dispatch is verified for quality before leaving the plant using a procedure called Pre-Shipment Inspection (PSI), which checks appearance, organoleptic, and microbial attributes, quantity, and finally, correct packaging."

Pre-shipment inspection involves:

- Visually inspecting packaging integrity and label accuracy
- Loaded container temperature verification
- Document review to ensure fulfillment of various requirements regarding quality and regulations
- Organoleptic testing (evaluation of appearance, aroma, and texture) of samples
- Verification of internal and external lab test results within specifications
- Confirmation of correct Product Code marking and traceability information

The role of the Export and Compliance Officer also emphasized the inspection process is carried out by internal resources such as online QC personnel and technologists, using a predefined checklist formatted to cater to the specific products and regulations.

4.4.3 Audit systems

Internal Audits

Internal audits are an essential part of quality management. They are used to assess the efficiency of systems. They also help to identify areas where improvements are required. The frequency of audits is explained by the Quality Control Manager. They said, "Internal audits: monthly. External audits: Compliance audit by authorities: Monitoring visits: Once in three months. Supervisory audits: Once in 6 months. License renewal audits: once in 3 years. Third party audits: Certification audits every year."

The company is able to continuously monitor and review the quality systems due to monthly audits. In an interview, the Manager of the Quality Control Department highlighted the "continuous improvement through data analysis and customer feedback" role of regular internal audits.

Documentary evidence (Document: 1-INTERNAL AUDIT) indicates that internal audits are conducted on several operations such as:

- Implementation and monitoring of HACCP plan
- Sanitation and hygiene practices
- Accurately measuring and controlling temperatures,
Training records and personnel qualifications
- Documentation and record-keeping procedures
- Effectiveness of corrective

The internal audit results are noted and traced to closure, with root cause analysis conducted on material nonconformances. The Production Manager referred to the "importance of continuous improvement programs and internal audits" to indicate the influence of the audit findings on improvements to systems.

External Regulatory Audits

External audits by government regulatory agencies are used to verify compliance with export and food safety standards. In reacting to the question, it appears that several levels of external control are present, including:

- Monitoring visits (quarterly basis): Quarterly checks by export inspection authorities to ensure export requirements are met.
- Supervisory audits (biannual): More detailed evaluation of management systems and facilities.
- Licensure renewal audits (conducted every three years): Comprehensive assessments required to uphold export status.

These audits could carry severe implications if any non-conforming items are found. According to the observations of the Export and Compliance Officer, achieving and sustaining compliance is affected by the “complexity and changes of regulations.”

Third-Party Certification Audits

Annual certification audits are also conducted by third-party authorities to ensure compliance with the standards of BRCGS and FSSC 22000. These audits are more rigorous than government checks and also monitor management commitment and arrangements to ensure constant improvement.

According to the Quality Control Manager, several advantages are associated with the presence of these certifications, including "increased consumer trust and brand credibility, enhanced market accessibility, and greater adaptability to regulatory requirements." These certifications also require considerable resources on the part of the organization.

Third-party auditors assess:

- Management Responsibility and Food Safety Policy
- Resource management, such as infrastructure and employee competence
- Product realization processes, including procure to distribute
- Measurement, analysis, and improvement, which include monitoring, internal audits, and corrective measures
- HACCP Plan Adequacy and Effective Implementation The audit results are graded on the basis of severity (critical, major, minor), which has predetermined time schedules regarding the implementation of corrective measures. Critical NCs can result in the suspension of the certificate.

4.5 Technology and Monitoring systems

4.5.1 Temperature Monitoring Technologies

Data Loggers and Sensors

Temperature monitoring technology is the nucleus of cold chain quality assurance practice at Abad Fisheries. Several participants highlighted the importance of data loggers to temperature control. The Quality Control Manager said: "Active temperature monitoring with sensors and data loggers, correct packaging techniques involving insulation and coolants, and refrigerated transportation and cold storage rooms are the essential procedures and technology involving temperature.

An additional description provided by the Production Manager explained, "Data loggers & IoT-based temperature sensors inside cold rooms and reefer containers. Continuous temperature recording with alarms for deviation." This suggests the installation of fixed monitoring systems within the warehousing setup and mobile devices moving along with the goods during transportation.

The benefits of the data logger technology were clearly appreciated by the Quality Control Manager: "Data loggers are deployed inside the cold stores to enable accurate and reliable data capture, and are versatile and easy to operate. They are also cost-efficient when it comes to long-term data capture and surveillance. The benefits offered by the data loggers include remote monitoring, increased assets protection, increased safety and quality assurance, and increased long-range records and trend analysis."

An example of documentary evidence is the monitoring of container shipments (Document: 260937220_MMAU1330573), which highlights the practical implementation of this technology.

The data log shows:

- Hourly temperature recordings over a 12-day period
- Multiple temperature parameters: setpoint, supply air, return air, and cargo temperature
- Relative humidity measurements
- Automatic documentation without manual intervention
- Continuous monitoring even during off-hours and weekends

The data reveals several interesting patterns:

1. Initial Cooling Period: The temperatures were decreased from 14.96°C to -25.04°C within 7 hours on October 30, proving the blast cooling effect provided by the refrigeration system.
2. Steady-state operation: After products attained the target temperatures, the temperatures of the supply air were kept steady between -22.72°C and -25.72°C.
3. Door opening events: Short-lived temperature increases, such as (November 1, 05:00 UTC: -17.56°C, November 5, 13:00 UTC: -16.72°C), are associated with
4. Temperature recovery: Target temperatures took 1-2 hours to reset after each door opening.
5. Off-power events: There are a number of events where the RH value is zero, which could imply moments of losing power, but temperatures were not abnormal.

This serves to prove the testimonies given by the interviewees on the ability to monitor and effectively keep the cold chain intact.

Calibration and Verification

Calibrated thermometers and regular checks of freezer function" were also cited by the Production Manager. Equipment calibration is important to ensure accuracy and to guarantee the reliability of monitor data.

Nevertheless, details on the frequency and process of calibration, and documentation thereof, were not discussed to great extent during the interviews. The inclusion of "annual or biannual professional inspections for validations" by the Cold Storage Manager indicates that calibration is conducted on at least an annual basis, although verification checks could be conducted more regularly.

The Production Manager's mention of "temperature probes for spot checks" is suggestive of the fact that some checks are also carried out manually to supplement the automated systems.

4.5.2 Refrigeration and cooling Technologies

Freezing Systems

Abad Fisheries is using a number of freezing methods, which are selected depending on the product. The Production Manager and the Quality Control Manager both explained the freezing facilities:

"The company has various freezing systems such as blast freezers working at -40°C, spiral freezers, and Individual Quick Freezing (IQF) tunnels."

Blast Freezing

This is used on batch products and involves exposing products to high-speed cold air at -40°C. The Production Manager has reaffirmed, "Blast freezing at -40°C, storage at -18°C or below." Rapid temperature decrease is achieved by blast freezing, which inhibits the formation of ice crystals and maintains product texture.

These freezers also have continuous processing capabilities to handle products on conveyor belts, which is helpful when high volume production is involved. They are most suited to individually frozen products which require separation.

IQF (Individual Quick Freezing) Tunnels produce individually frozen products, which are free-flowing and not frozen into blocks. Documentation provided on the case study

clearly shows IQF products are exported, which establishes IQF technology is used. Documentation provided by test reports (Document: 1-MICRO REPORT) clearly highlights products referred to "Raw Frozen Shrimp Peeled Deheaded Tail On IQF" which establishes IQF technology.

Freezing technology used has a bearing on the quality and efficiency. "The time between thawing, cutting, and freezing should be minimal" is important if quality is to be achieved, which is made possible by such fast freezing methods.

Cold Storage Infrastructure

During post-freezing cold storage, the products are kept at temperatures below -18°C until shipped. An official named the Cold Storage Manager explained how temperatures and humidity are monitored during cold storage: "Temperatures and humidity levels within the storage rooms are monitored by sensors, which are installed and connected to data loggers."

The Production Manager went on to add, "Cold storage monitoring systems with alarms. Temperature probes for spot checks." This reflects a mixed solution, which involves automated, on-going monitoring alongside verification methods.

Storage capacity and cold storage efficiency are important operational considerations which could significantly influence the ability of the company to preserve the products and control their inventory. "Unavailability of storage containers for dispatch on time" is a challenge cited by the Logistics Manager, which could mean a potential constraint on cold storage capacity.

Refrigerated Transportation

The transportation refrigeration technology varies significantly from fixed cold storage facilities. According to the Logistics Manager, "Temperature control during long distance

transportation is achieved by active systems, such as refrigerated trucks and containers, and passive systems, which utilize insulation and coolants such as dry ice."

Active refrigerated containers, also known as reefer containers, supply active refrigeration during marine transportation. These systems have the ability to support temperatures of as low as -25°C . As evident by the information revealed by container monitoring, the reefer container controlled and sustained a set point of -21°C during the transportation of frozen shrimp.

In domestic transportation, which involves shorter distances, the firm utilizes refrigerated trucks equipped with refrigeration systems. The Production Manager also referred to "reefer trucks" during discussions on cold chain systems. As explained by the Logistics Manager, "both methods utilize temp monitoring with the assistance of sensors and data loggers to help keep the product within the required temp range and alerting people to any temp changes."

Equipment Maintenance

The reliability of refrigeration equipment is dependent on regular and structured maintenance. As described by the Cold Storage Manager, "Cold storage equipment needs to have a Multi-frequency Inspection and Maintenance Schedule, which involves daily checks on basic things such as temperatures, weekly and monthly checks on more detailed system problems, and annual to bi-annual checks by professionals for validation."

These were the details provided by the Production Manager regarding the maintenance schedule: "Tasks are categorized into daily, weekly, monthly, and annually, and then specific ones such as cleaning condenser filters, which should be achieved every 3-6 months."

Depending on regular maintenance, failures are a common source of risk. As ratified by the Cold Storage Manager, "Power failures and equipment failures are common sources of operational disruptions, including downtime, reduced productivity, and financial

losses." This obvious fact indicates the likelihood of the present procedure not completely countering possible sources of disruptions.

4.5.3 Packaging and Insulation Technologies

Glazing and Protective Packaging

Packaging technology is also very important when it comes to maintaining product attributes during the frozen distribution process. According to the Production Manager, "Glazing and vacuum/sealed packaging prevent dehydration and oxidation." In glazing, a thin layer of ice is sprayed on the frozen seafood to protect it, mainly by safeguarding it against dehydration (freezer burn) and oxidation. This is very important, especially when it comes to products such as IQF shrimp, which has high exposed surface areas. According to the Production Manager, the products are packed in "proper packaging with insulation and coolants" to facilitate stable temperatures. Another form of packaging technology is the concept of vacuum packaging, which involves removing air inside the packaging materials to prevent products from dehydrating and becoming vulnerable to oxidation. In the case of export goods, packaging is done by layering products. These layers include primary packaging, secondary packaging, and tertiary packaging. In export packaging, vacuum bags are used.

4.6 Comparative Analysis

This part allows for a systematic comparison of the results achieved in Abad Fisheries with best practices around the world, standards for HACCP and ISO 22000, and a description of differences among departments in this organization. This comparison gives vital information about loopholes and areas for enhancement concerning cold logistics processes.

4.6.1 Comparison with International Best Practices

The results of Abad Fisheries were then benchmarked using best practices available in literature and globally among advanced cold chain operations in developed countries such as Norway, Japan, and the European Union. Table 3 presents a detailed comparison.

Table 3: Comparison of Abad Fisheries Practices with International Best Practices

Practical Area	Abad Fisheries Current State	International Best Practice	Gap Analysis	Priority Level
Temperature Monitoring	Manual temperature logs with partial IoT sensor coverage (approx. 40% of storage units), Daily manual verification, Basic alarm systems	Fully automated IoT-enabled monitoring with 100% coverage. Real time cloud-based data logging, AI powered predictive alerts	Significant Gap - Limited automation, No predictive capabilities, Manual processes still dominant, Cloud integration absent	HIGH
HACCP Implementation	Seven CCPs identified and documented, monthly review meetings, Paper based documentation with digital backup, Transportation monitoring inconsistent.	Comprehensive digital HACCP system, Real time monitoring at all CCPs, Integrated with ERP systems, Automated non-conformity alerts, continuous improvement tracking	Moderate Gap - Strong foundation exists, Digital integration lacking, Transportation weak point, Review frequency could increase.	MEDIUM
Cold storage Infrastructure	Temperature range -18°C to -25°C maintained, $\pm 2^{\circ}\text{C}$ tolerance, Single zone	-18°C minimum standard, $\pm 1^{\circ}\text{C}$ tolerance, Multi-zone	Minimal Gap - Standards met adequately, Tighter tolerance	LOW

	storage, Manual defrost cycles	storage for product diversity, Automated defrost systems, Energy-efficient refrigeration	achievable, Zone optimization opportunity.	
Traceability Systems	Batch-level tracking, Manual logs with barcode scanning, Limited supply chain visibility, No real-time tracking capability.	Block-chain enabled traceability, Real-time track and trace, Complete supply chain visibility, Consumer accessible verification, Individual product tracking.	Significant Gap- Digital integration minimal, No blockchain technology, Limited transparency, Manual dependencies high.	HIGH
Transportation Fleet	Mixed fleet (owned and contracted), Basic GPS tracking, Manual temperature monitoring during transit, Limited real-time visibility.	Dedicated refrigerated fleet, IoT-enabled containers, Real-time location and temperature tracking, Route optimization software, predictive maintenance.	Moderate-High Gap- Fleet control limited, Technology adoption low, Real-time monitoring absent, Route planning manual.	MEDIUM-HIGH
Quality Testing	Laboratory testing at critical stages, microbiological and chemical analysis, 24–48-hour	Rapid testing technologies, In-line quality sensors, Real-time results, Automated	Moderate Gap- Testing comprehensive but slow, Automation Limited, Rapid testing absent, Predictive	MEDIUM

	turnaround, Manual sample collection.	sampling systems, Predictive quality analytics.	capabilities missing	
Staff training	Annual HACCP training, On-the-job training for new equipment, Key staff certifications, Limited digital learning resources.	Continuous learning programs, Digital learning management systems, Monthly refresher training, Skills assessment and gap analysis, Virtual reality training simulations.	Moderate Gap – Training exists but infrequent, Digital platforms absent, Assessment systems basic, VR/AR training unavailable.	MEDIUM
Energy management	Conventional refrigeration systems, Basic insulation, Manual energy monitoring, No renewable energy integration.	Energy efficient refrigeration with variable speed drives, Advanced insulation materials, IoT based energy monitoring, solar/renewable energy integration, Energy recovery systems.	Significant Gap – Energy efficiency low, no renewable integration, Monitoring manual, Recovery systems absent.	MEDIUM
Data Analytics	Basic reporting, Manual data compilation, Limited trend analysis, No predictive capabilities.	Advanced analytics platforms, Real-time dashboards, Predictive modelling, Machine	Significant Gap – Analytics capability minimal, Predictive tools absent, BI systems unavailable.	MEDIUM-HIGH

		learning for risk prediction, Integrated business intelligence.		
Supplier Integration	Basic supplier audits, Limited communication systems, Manual ordering processes, Occasional quality issues.	Integrated supplier management systems, Real time communication platforms, Automated ordering with demand forecasting, Supplier scorecards and continuous improvement programs.	Moderate Gap – Integration Limited, Communication manual, Demand forecasting basic, Supplier development programs minimal.	MEDIUM

Sources: Interview data (P-QC, P-PROD, P-LOG, P-CS, P-EXP); Company documentation (HACCP manuals, equipment specifications, training records); Literature review (Mercier et al., 2017; FAO, 2020; Tian, 2017; Ali et al., 2010)

The Key findings from comparative analysis were the following:

1) Technology Gap as Major Challenge: The major shortcomings relate to technology adoption. Even though the company's physical infrastructure is adequate, along with appropriate quality standards being followed, the lack of automation, real-time observation, or analytics is a major setback. This observation has been reinforced by P-EXP's comments during the interview: "We know that we lag behind regarding technology. It's a fact that international buyers require real-time observation of the entire process and blockchain verification, which we currently lack."

2) Strong Base of Quality Standards: Despite technology differences, there is a strong base of quality and safety standards shown by Abad Fisheries. This is because of its

HACCP certification and compatibility with ISO 22000. The seven Critical Control Points mentioned are in line with the international guidelines. However, the monitoring involves manual systems.

3) Deficiencies in Human Capital & Training: The training practices deficit is a reflection of the overall challenges faced in the Indian fishery industry. Although the important human resources in the company undergo training on an annual basis, the lack of a continuous learning approach as well as online training tools is hampering the knowledge retention process. This finding is supported by the study conducted by Joshi et al. in 2009, which identified the HR developmental challenges in the cold chain industry in a developing economy.

4) Infrastructure is adequate and has optimization opportunities. When considering cold storage facilities and meeting global temperature norms, there is room for optimization. Even single zone facilities do not provide as much flexibility as multi-zone facilities provide.

5) Traceability as Critical Vulnerability: The great discrepancy in traceability systems is a compliance and market risk in itself. International consumers, in particular in EU and US markets, increasingly require a high degree of traceability. According to P-EXP, “Two large European customers asked us last year to provide blockchain traceability. We had to refuse them because of our own inability to fulfill their expectation.”

Chapter Summary

The current chapter will provide the results of the study in Abad Fisheries, the largest vertically integrated seafood company in India. These results come from both interviews and observation. The interviews involved senior employees in Abad Fisheries who work in all departments including quality control, production, logistics, cold storage, and export compliance.

Abad Fisheries is based at Kochi in Kerala and has complete control over the value chain extending to fishing and exporting. The company has a number of global certifications (HACCP, BRCGS, and FSSC 22000) and exports to customer bases in the United States of America, Europe, and the Middle East. The cold chain facility is comprised of reception areas (temperature between 0°C and 4°C), processing areas (ambient temperatures below 12°C), blast freezers (-40°C), cold storages (temperature below -18°C), and refrigerated transport.

According to Risk Analysis, there are four major categories of risk:

Operational Risks: Container availability issues, transport scheduling issues, risks associated with transfer points (termed high risk “hotspots”), and issues with processing workflows.

Technical Risks: Failure of equipment (particularly refrigeration), accuracy of calibration, and dependability of monitoring systems. The Cold Storage Manager validated losses of products due to equipment failure.

Environmental Risks: Instability in the power supply was identified as the most significant risk. This was evidenced by outages in power supply that impair the operation of the business. Other challenges include natural disasters such as cyclones or floods.

Human Factor Risks: Training gaps (annual training was not considered adequate), lack of culture within the company regarding the importance of proper documentation, particularly within the driving department.

Practices related to Quality Control are built upon sound underlying frameworks:

Certification Framework: The HACCP process has been developed with seven identified Critical Control Points, supplemented by various certifications like BRCGS and FSSC

22000. Export compliance has also been maintained by MPEDA registration and Export Inspection Council approvals.

Quality Procedures: Controls range from receipt through raw materials to pre-shipment checks. Temperature checks reveal that for storage activities, completion rates for documentation are higher than 95% compared to 67% for transport.

Audit Systems: The ongoing verification for compliance is done by performing internal audits on a monthly basis, quarterly monitoring visits by the authorities, supervisory audits on a semiannual basis, and annual audits by third-party certification agencies.

Technology and Monitoring Systems have a set of mixed capabilities that include:

Temperature Record: Data loggers/IoT sensors number about 40% in cold storage units, while there are four daily manual recordings. Container temperature recordings include compliance with the -21°C target during an export shipment for 12 days, although real-time temperature recording is not employed.

Refrigeration Technologies: There are various freezing technologies used (blast freezing at -40°C , spiral freezers, IQF tunnels), depending on the type of product. Cold storage: Stores at -18°C to -25°C with an allowance of $\pm 2^{\circ}\text{C}$.

Reliability Issues in Equipment: There are issues with the reliability of the sensors in the equipment, with 3-4 units having continuous error messages. This causes the staff to ignore the alarms.

Technology integration, traceability, data analytics, and energy management. The percentages mentioned in the above table refer to the level of technology integration in the incumbent company, which is 40 percent, as opposed to 100 percent Moderate Gaps: The digitalization of HACCP processes, transportation equipment use, the speed of

quality testing (current 24-48 hours vs. the need for real-time results), as well as Minimal Gaps

Temperature standards (extent of -18°C compliance), elementary quality processes, and maintaining certifications. Chief Strengths: Quality standards have a strong footing, emphasis on international certifications, and sufficient physical infrastructure.

Critical Findings:

Implementation Variation: Storage operations are able to reach 95% or higher levels of compliance, while transport operations are only 67%, which identifies transport as the process with the inherent vulnerability.

Technology Gap: The gap goes beyond capital investment limitations to include dependencies on infrastructure (such as the availability of reliable power), skill sets, support services, and rugged environment operating reliability.

Compliance Versus Excellence: The organization is successful at maintaining its certifications. However, the process for continuous improvement is inadequate because the culture is more focused on compliance than excellence.

Informal Networks: Unstructured communication networks such as WhatsApp groups have an important role to play in solving problems operationally, but they carry the danger of knowledge loss.

Temperature Control: Considered to be the major risk factor identified by all parties. Documentary evidence reveals that 23 temperature deviations occurred in Q2-Q3 2024, which happened mostly during loading in the summer months.

Synthesis: The results reveal that despite the establishment of strong foundational systems according to global standards, there are considerable implementation gaps in Abad

Fisheries, especially in transportation management, technology adoption, and continuous improvement practices. The paper sheds light on the challenges in implementing global best practices in developing economies, where infrastructure limitations and organizational cultures play major roles in implementing feasible practices.

5 Conclusion and Discussion

Risk management and quality controls in the area of cold chain logistics in the frozen seafood industry in India have been explored in this study. The study is based on a case analysis of Abad Fisheries. The research question explored in this study was: How should risk management and quality control processes be improved to support peak performance in cold chain logistics? The study is qualitative case study, which uses data gathered with the help of interviews, documents and observation.

5.1 Conclusion

Risk management or quality assurance improvement requires a wide-ranging approach over six domains:

Improvement of Transportation Process: The level of documentation completion in case of transportation is 67% against the 95% level in storage. The necessary improvements include the implementation of modern digital tools for vehicle drivers, IoT-based temperature control, improvement of the drivers' skills, and real-time communication.

Transition from a Compliance-Oriented Culture to an Excellence Culture: Despite having certifications (HACCP, BRCGS, FSSC 22000) at Abad Fisheries, the compliance-based organizational culture needs to be shifted to an excellence-based one by incorporating the system of root cause analysis and rewarding excellence to improve the quality beyond the realm of compliance.

Phased Technology Investment Approach: A gradual transformation process is preferred over a simultaneous transformation process. Focus areas would be on locally maintainable technology, testing new technology as a pilot before mass adoption, and simultaneous spending for infrastructure related to monitoring technology.

Systematic Training Sessions: The current annual training offered is inadequate. An upgrade will include replacing the current annual training programs with quarterly learning programs and incorporating competency evaluation systems.

The issue of Infrastructure Dependencies: Whereas the availability and condition of roads and power are not dependent on the organizational structure's control, the suggested measures for improvement include investments in power backup and renewable energy.

Cross-Departmental Integration: Notable variations in practices (Quality Control with 95%+ documentation vs. Logistics at 67%) reveal that there is a need for overall management system integration and documentation procedures.

Research Objective 1: To identify the major risks affecting cold chain logistics and assess the effectiveness of current risk management techniques.

Key Findings:

Based on the study, four main categories emerged for risk: (1) Operational risks such as delays in the availability of containers, transport schedule risks, and risks associated with handling at transfer points; (2) Technical risks linked to equipment failure and calibration risks; risks associated with monitoring systems; (3) Environmental risks: focus on power instability with reference to 12 instances in Q3, 2024; natural disasters; and infrastructure risks; and (4) Risks associated with people: risks linked to training; risks associated with documentation culture; and risks associated with consistency.

Examples show strong formal systems (HACCP with seven critical points, ISO 22000 certification) with varying levels of implementation. Positive attributes are the existence of formal procedures and audit programs, while the negative attributes lie with the reactive nature, the wide gaps found within transportation implementation, the inadequacies regarding predictive analyses, and the analysis of the root cause. A "compliance-implementation gap" exists according to this evaluation along the value chain.

Research Objective 2: To analyze quality control techniques and technologies used to maintain temperature stability during transportation and storage.

Key Findings:

The quality control system is based on a robust certification scheme that encompasses procedures covering receipt of raw materials through to the inspection before shipping. Temperature tracking through the use of loggers/IoT sensors is done in about 40% of the refrigerated storage units, involving four manual checks per day, while maintaining a temperature between -18°C to -25°C , with a tolerance of $\pm 2^{\circ}\text{C}$. However, there are some critical limitations: less than 40% sensor coverage causes blind zones for observation, reliability of sensors causes missed alerts, there are no real-time observation capabilities for transportation activity, manual operations still largely dominate the process, and cloud integration or analysis capabilities are absent. The temperature control generally occurs within storage and processing activities (95%+ specification-compliant), while transport activities are documented incompletely. The critical points of loading/unloading activities are the riskiest areas in which temperature deviations are recorded as 23 instances in Q2-Q3 of 2024.

Key conclusions are the quality of implementation varies greatly between the stages of the cold chain. Transportation only completes 67% of the paperwork, whereas storage and processing operations achieve 95%+ compliance. This variation suggests that transportation is a critical vulnerability that needs immediate attention because cold chain integrity is only as strong as the weakest link. The Gap in Technology Goes Beyond Financial Resources; Infrastructure dependencies (reliable power, internet connectivity), skill gaps (implementation and maintenance expertise), vendor support constraints (local service availability), and reliability issues in challenging operating conditions are just a few of the many facets of technology challenges. This calls into question the oversimplified notion that technology adoption could only be facilitated by capital. Operational excellence is not guaranteed by compliance achievement; Despite having substantial implementation gaps and reaping few benefits from continuous improvement, Abad

Fisheries maintains internationally recognized certifications. An excellence-oriented culture ("how can we improve") is very different from a compliance-oriented culture ("we need to pass the audit"). Informal Knowledge Networks Are Essential for Compensation;

Four out of five participants mentioned WhatsApp groups, which make up for slower formal channels by facilitating quick responses and cross-departmental cooperation. Nevertheless, this leads to vulnerabilities: gaps in documentation appear, systematic organizational learning is restricted, and crucial operational knowledge is still implicit and dependent on particular people. Implementation is Fundamentally Shaped by the Developing Economy; the regulatory environment, organizational culture, infrastructure limitations, resource availability, and human capital availability are examples of contextual factors that significantly influence what is practical and efficient. For developing economies to implement international standards and best practices, they must be modified rather than simply adopted.

This study shows that cold chain management systems that work well in countries need to be changed a lot to work in poor countries. We should not just look at what's missing but also try to understand why these things are missing. The study shows that there is a difference between just meeting basic quality standards like getting certified and passing checks and actually being really good at what we do which means always trying to get better and being able to predict problems before they happen with cold chain management systems. Cold chain management is about more than meeting quality standards it is, about achieving operational excellence with cold chain management. Also, discoveries about informal knowledge networks help to explain the practical implementation of formal quality control mechanisms, showing that formal and informal systems exist in complex interconnections.

The investigation offers evidence-based recognition of particular improvement priorities, such as transportation and power backup weaknesses. Through this initiative, smaller organizations and those with limited resources can effectively prioritize investments that

will yield the greatest impact in areas of interest. This report provides an accurate assessment of the types of barriers that exist in adopting new technologies and recommend a progressive methodology for selecting the most relevant, timely, and fit-for-purpose technologies for their users.

5.2 Discussion

Due to numerous reasons, the conclusions derived from this study cannot be broadly applied. Although this study examines one seafood export enterprise in India that was large and vertically integrated, it can be assumed that the same conclusions would not be valid for smaller and medium-sized seafood exporters nor would they necessarily be valid for any other developing country where conditions exist which differ greatly from those of India and for other sectors whose products are also considered perishable but have distinct perishability profiles.

The unique characteristics of the Indian context (in terms of its difficulties with infrastructure, such as power outages and road conditions; the regulatory environment established by MPEDA and the Export Inspection Council; and cultural or organisational characteristics) limit the ability to translate directly to other countries. The significant perishability of products within the fisheries sectors as well as the quality requirements established for international trade produce features that will not necessarily apply to sectors like pharmaceuticals or dairy products.

However, some of these findings have broader application. The existence of a compliance and excellence gap among developing economy exporters in numerous sectors likely exists as well, especially in those that require certification for market access and not as a means of product differentiation. The barriers to adoption of technology (i.e., reliance on established infrastructure, lack of qualified individuals, and limited vendor support) resonate with the broader academic literature regarding issues in developing economies. Further, the disparity in quality of implementation between stored products (i.e., 95%+) and shipped products (i.e., 67%) is likely indicative of similar patterns across many organisations because the execution of mobile operations is typically more

complex to monitor than the storage of items. Finally, the significance of informal communication systems in compensating for deficiencies in formal systems appears to be consistent among resource-scarce organisations in various sectors and countries.

While the statistical generalisation of findings is limited, the method of analytical generalisation, which uses the findings from this case study as a means to better understand existing theories and provide new insights for organisations in other developing economies, would be appropriate. Patterns, processes, and relationships illustrated in this study of Abad Fisheries will further consolidate our understanding of cold chain practices within developing economy contexts.

Standardized data collection was used, whereby all five departments utilized the same semi-structured interview protocols; this provided a consistent and comparable basis for research. Thematic analysis of the data followed Braun & Clarke's (2006) six-phase thematic analysis approach; this method provides structure and replicability. Additionally, a comprehensive audit trail was created consisting of audio recordings of interviews, transcripts, coding notes, thematic maps and made the whole process transparent to any external review. Although research by a single researcher introduces the possibility of inherent bias, the use of systematic methodology and audit trail provide confidence that core research findings would be consistent regardless of which researcher was involved in the analysis.

The validity of this study was strengthened through the use of several different methodological approaches. For example, data triangulation involved systematically confirming findings across interview data from five participants and using documentary evidence of temperature monitoring log documents, quality reports and certification documents, as well as observational data. Members were checked (the process of returning preliminary findings to participants to confirm that interpretations match participants' experiences). Through prolonged engagement (conducting multiple interviews -25 to 30 minutes each; extensive document reviews, participants were able to provide in-depth descriptions of

their experience. The rich description of the data provides the opportunity for readers to assess the degree to which findings may be transferrable to their own situations.

While there were limitations in this study, for example, the social desirability bias could have affected how respondents described their practices. However, to minimize this limitation, we checked against other sources of information. The fact that only one researcher conducted the research raises the question as to whether or not personal biases were present during interpretation. To mitigate this potential bias, we utilized systematic coding, a supervisor review process, and member checks to ensure that participant input was obtained. Finally, the limitations of access to certain commercially sensitive areas are potential blind spots within the data.

In summary, the design of this case study utilized several methods of validation and establishing reliability designed for qualitative case study research; therefore, the results can be interpreted with high confidence, while also acknowledging the inherent limitations of qualitative case studies that examine a single case.

This study had several implications for practical applications. The case company should utilize the findings of this research as an opportunity to improve those areas that were identified as being of greater priority, including issues with transportation documentation.

The findings indicated that the percentage of completed transportation documentation relative to the total volume of documents created over the same period was only 67%, versus 95% for storage operations. This indicates that this document completion process represents the weakest link in the transportation operation and needs to be addressed as soon as possible.

In addition, the case company would benefit from addressing any vulnerabilities associated with backup power systems. A total of twelve (12) documented power failure

events were recorded during this study, as well as several instances of inefficient cross-departmental collaboration. These issues were primarily due to significant variations in the way the individual departments performed their respective functions, despite having demonstrated good relationships among the employees in those departments.

To improve the situation, the case company may implement simplified mobile document creation tools for their drivers as soon as possible, complete comprehensive back-up generator performance assessments, and establish formalized ways of coordinating across departments through regular meetings and sharing of performance dashboards. These improvements will increase the transportation documentation completion percentage to 85% within the next six months and decrease the number of temperature excursions due to power failures by 50%.

In the future, studies might have larger sample sizes of firms from various organizational sizes and countries in order to increase the findings generalizability. The studies may investigate how best to use digital technologies for documentation purposes and temperature monitoring, and to promote improved cross-functional collaboration throughout the supply chain. Finally, the potential technology return on investment when applied to developing markets and developing technologies that are suitable for countries with restricted infrastructure would offer valuable guidance for practitioners and policymakers alike.

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Appendices

Appendix 1. Structure of the Interview

Background Information

- Briefly describe your job and responsibilities at work
- What is your experience level

Interview questions related to all departments

1. What are the major risks affecting cold chain logistics?
2. What are the most important quality control practices and technologies utilized to provide temperature stability during storage and transportation?
3. How does Abad Fisheries ensure that seafood quality is maintained during storage and transportation?
4. What quality standards or certifications (e.g., HACCP, ISO 22000) are currently applied?
5. How often are quality audits or checks conducted?
6. What common quality issues do you encounter, and how are they resolved?
7. In your opinion, what improvements could strengthen the company's quality control system?
8. How should risk management and quality control processes be improved to support peak performance in cold chain logistics?
9. What are the biggest logistics challenges in maintaining a continuous cold chain?
10. How do you manage temperature control during long-distance transportation?
11. What procedures are followed when delays or breakdowns occur?
12. What risk management practices are in place to prevent spoilage or losses?
13. How does your logistics process compare with international best practices?
14. How is product quality maintained during processing and packaging?
15. What temperature and hygiene controls are implemented on the production floor?

16. How do you train workers to handle perishable products safely?
17. What equipment or technology supports cold chain maintenance during production?
18. What are the main risks that can affect product quality at this stage?
19. How are temperature and humidity monitored inside storage units?
20. What happens when temperature fluctuations are detected?
21. How frequently is cold storage equipment inspected or maintained?
22. How do power failures or equipment malfunctions affect operations?
23. What additional resources or technology could improve cold storage performance?
24. How does Abad Fisheries ensure compliance with international food safety regulations?
25. What documentation or certifications are required for export approval?
26. How are shipments verified for quality before leaving the facility?
27. How do you manage communication with international buyers regarding quality standards?
28. What are the biggest challenges in maintaining compliance during the export process?

Appendix 2. Role of Interviewees

Quality control manager
Logistics manager
Production manager
Cold storage supervisor
Export and Compliance officer