



RISK MANAGEMENT IN REVERSE LOGISTICS OF ELEVATOR SPARE PARTS AND COMPONENTS

SUBMITTED BY

Badhon Paul (12402567)

Shakshi Singh (12418050)

Karpaga Soma Sundaram T (12415771)

SUPERVISED BY

Dr. Nand Gopal

Assistant Professor

DEPARTMENT OF OPERATIONS & IT

MITTAL SCHOOL OF BUSINESS

LOVELY PROFESSIONAL UNIVERSITY

PHAGWARA-144411, PUNJAB (INDIA)

ABSTRACT

Reverse logistics of elevator spare parts is a critical factor in ensuring service continuity, safety, and customer satisfaction in the elevator industry. It is a complex process that includes the collection, inspection, repair, refurbishment, testing, and reintegration of components. The process, however, is vulnerable to a variety of operational and financial risks, including delays, supplier dependency, data inaccuracies, inspection errors, and high emergency procurement costs. Such risks, in turn, have a direct impact on elevator downtime and service performance.

This research first identifies and then ranks the most significant risks of a reverse logistics process for elevator spare parts using a staged risk assessment method. The research design was both exploratory and descriptive. One of the main data sources was a structured questionnaire from three industry professionals representing the engineering/quality, procurement, and warehouse functions. Secondary data from academic and industry sources were also used to support the analysis. The risks were examined through a Failure Mode and Effects Analysis (FMEA) and a probability impact risk matrix. Schindler India is

regarded as the case context.

Most of the risk categories identified in the research are of a high or critical nature. Among these risks are the most significant ones identified as obsolete spare parts, delays in supplier approvals, errors in inspections, limitations in testing capacities, and additional costs related to emergency procurement. The research points out that these process gaps, coordination problems, and inaccuracies in information account for a larger share of risk exposure than technical failures. Real mitigations in the form of better supplier coordination, inspection accuracy, capacity planning, and digital tracking are recommended to increase the reliability of reverse logistics.

Keywords:

Reverse logistics, Elevator spare parts, Risk assessment, Failure Mode and Effects Analysis (FMEA), Supplier dependency, Service downtime, Reverse supply chain

CHAPTER 1

Introduction

Elevators and escalators are the main components of metropolitan mobility. Due to rapid urbanization, vertical transportation has become a must for residential complexes, commercial buildings, hospitals, and transportation hubs. The safety, reliability, and customer satisfaction aspects of elevator operations are what keep the elevators going, hence spare parts availability and maintenance services are very important in this sector. In the case of most consumer products, whose downtime does not have a significant immediate impact, elevator malfunctions can, however, stop the whole operation of a building, cause a mobility disruption for hundreds of users daily, and even result in serious safety hazards. Thus, it is of strategic importance to ensure the timely and efficient handling of spare parts and components (Zhang et al., 2021).

Over time, the elevator industry has seen a surge in the importance of reverse logistics. This concept refers to the movement of used products, spare parts, or components back through the supply chain for inspection, reuse, refurbishment, or recycling. Importantly, reverse logistics is a source of twofold value: initially, it contributes to service continuity through the recovery and refurbishment of indispensable parts, and subsequently, it lessens the ecological footprint by the reuse of components and materials. Nonetheless, the implementation of reverse logistics in the elevator sector is riddled with obstacles despite the feasible advantages. These obstacles represent risks that have the potential to affect the quality of the service, exert pressure on the costs, and sustainability.

Among these risks, four stand out as particularly critical (Singh et al., 2021):

- Delays: Time sensitivity is paramount in elevator repair and maintenance. Delays in spare part recovery or delivery often translate into extended downtime, customer dissatisfaction, and reputational damage for service providers.

- **High Costs:** Reverse logistics involves transportation, inspection, testing, warehousing, and reprocessing, all of which add to operational costs. The cost intensity increases when international shipments, urgent replacements, or specialized handling are required.
- **Supplier Dependency:** Elevator systems are technologically complex and often rely on a small pool of specialized suppliers. Dependency on single or limited suppliers exposes companies to risks such as supply chain disruptions, contractual rigidities, or sudden price escalations.
- **Uncertainty of Demand:** Predicting the demand for spare parts is highly challenging.

Failures are often random and influenced by factors such as usage intensity, environmental conditions, and maintenance quality. Moreover, as elevator models evolve, the need for obsolete spare parts adds further unpredictability.

The complex interaction of these risks positions reverse logistics in elevators as a high, stakes operation that cannot be done without meticulous planning and risk management. To give an example, a malfunction in the elevator of a hospital tower may require that spare parts be readily available so that the movement of patients is not hindered. If the right component is delayed, it is not only the quality of the service that is endangered but safety as well. In the same way, depending too much on one supplier for control boards or drive systems may cause that the company is not able to get the necessary components if, for instance, a natural disaster or geopolitical crisis occurs.

1.1 Need for Risk Management in Elevator Spare Parts Reverse Logistics

Most traditional supply chain risk management frameworks tend to focus on forward logistics that deal with the movement of products from manufacturers to customers. Nevertheless, reverse logistics entail entirely different complexities: returns are less predictable, volumes are smaller, and the economic value of recovered items can vary substantially. In the elevator industry, the stakes are higher because:

- Many components are safety-critical (e.g., brake systems, door sensors).
- Downtime penalties are severe, as they directly affect service contracts and customer trust.
- Inventory holding costs for spare parts are high, given their technical specialization and long lifecycles.

Robust risk management is essential for organizations to avoid financial losses, operational inefficiencies, and reputational setbacks. Effective risk management makes it possible to decide what risks require immediate attention, use resources efficiently, and create resilient supply chains that are capable of adapting to disruptions.

1.2 Research Objectives

This study is motivated by the urgent need to address risks in reverse logistics for elevator spare parts and components. The objectives are:

- To identify and categorize the risks associated with reverse logistics in the elevator industry, with a focus on delays, high costs, supplier dependency, and uncertain demand.
- To apply structured analytical tools, specifically Failure Mode and Effects Analysis (FMEA) and risk matrix modelling, to prioritize these risks and evaluate their impact on operations.

- To develop and validate risk mitigation strategies through real-world case studies of global and regional elevator service providers.
- To contribute to theory and practice by proposing a framework for risk management tailored to elevator spare parts reverse logistics.

1.3 Research Contribution

This paper makes several contributions:

- It extends reverse logistics literature by applying it to the under-researched elevator industry.
- It develops a risk management framework integrating FMEA and risk matrix tools, offering a structured way to prioritize risks.
- It provides case-based evidence demonstrating how global and regional elevator firms address these challenges in practice.

It offers managerial guidelines for elevator manufacturers, service providers, and policymakers on improving resilience and sustainability in spare parts reverse logistics.

1.4 Structure of the Project Report

The project report is organized into different sections: Section 2 gives an overview of the literature) on reverse logistics and risk management. Section 3 describes the research methods, detailing how FMEA and risk matrix tools were employed. Section 4 and Section 5 showcase the in, depth case studies of a global elevator manufacturer and a regional service provider, respectively. Section 6 provides a discussion of the findings, cross, case analysis, and managerial implications. Section 7 wraps up with the major insights, limitations, and suggestions for further research.

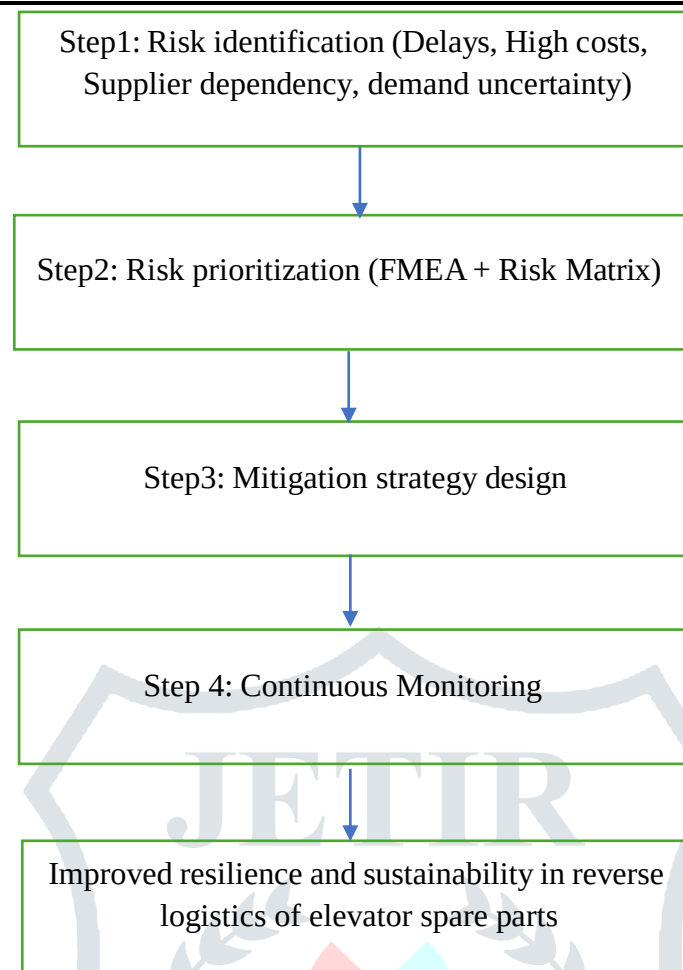


Figure 1: Framework for risk management in reverse logistics of elevator spare parts

CHAPTER 2

Literature Review

2.1 Reverse Logistics in Manufacturing and Service Industries

In their research, Dabo and Hosseinian-Far (2023) delved into the issue of reverse logistics as one of the elements of a circular economy and merged different existing frameworks to illustrate the role of the return flows in material recovery, reuse, remanufacturing, and recycling. Based on the integrative literature review, the authors of the paper identify three main enablers—product design for disassembly, digital traceability (IoT and data platforms), and inter-organizational collaboration—and depict the obstacles like policy fragmentation, economic trade-offs, and information silos. By this research, the authors move the conceptual connection of reverse logistics with circularity results further by stating that technological and design interventions significantly reduce the transaction costs and operational uncertainty in return streams. The conceptual framework presented here is a means of evaluating reverse-logistics strategies in contexts where regulatory compliance and environmental sustainability are of significant importance.

Erikshammar et al., (2025) decided to use a case-study and interview-based method to learn how companies categorize returns, choose the best remanufacturing or disposal method for the products, and

establish indicators for returns handling. The findings reveal that operational clarity (segmentation rules, inspection procedures, and KPIs) significantly lowers the processing time as well as the number of errors made in the disposition of products. Besides, the thesis introduces a practitioner-oriented decision framework for spare-part handling that harmonizes theoretical RL models with implementation constraints at the firm level; therefore, it becomes a valuable resource for studies that examine the translation of RL theory into practice at the firm level.

Nnamdi's (2018) is a local case study within a spare parts division of an elevator Original Equipment Manufacturer. The authors in the case study examine internal data on inventory, returns, and demand patterns to figure out the causes of excess and dead stock. Certain variables are forecasting error (difference between forecasted and actual demand), lead times, part life-cycle phase (new, mature, declining), and presence or absence of a returns / reverse logistics (RL) policy. The methods comprise root-cause analysis, descriptive statistics of inventory turnover and returns batches, and qualitative assessment of policy and process gaps. The research reveals that the biggest part of the excess inventory is due to the mis-forecasting of demand for slow-moving components and the lack of a disciplined returns policy which allows dead stock to accumulate without anyone noticing. Consequently, the writers suggest a "toolbox" of measures which include life-cycle pricing, better forecasting, disposal or transshipment, etc. tailored to elevator spare-parts as examples of strategic, proactive, and reactive interventions. Implication: RL policy and lifecycle control are under-utilized levers in well-run OEMs that can be used to reduce carrying costs and dead stock risks.

Senthil et al. (2018) explores risk prioritization in reverse logistics networks by gathering input from industry experts across various sectors. The data/context is expert scoring of risk categories such as transportation risk, quality risk, process risk, demand uncertainty, regulatory risk, etc. The variables are severity and likelihood of each risk, impact on cost, time, and customer satisfaction, as well as the feasibility of mitigation. The method used to capture expert uncertainty in the decision to combine fuzzy logic / fuzzy extensions of decision matrices with Analytic Hierarchy Process (AHP) is followed by rankings via FTOPSIS or PROMETHEE. One of the main discoveries is that transportation risk and demand uncertainty are generally the most significant factors in the majority of RL networks, particularly when return flows are irregular or unpredictable. Another point is that fuzzy methods are useful in capturing expert judgment in areas where data is scarce and subjective. For elevator spare-parts, similar risk categories (transport delays, unpredictable repair returns) may also require prioritization through the same hybrid methods

Baltussen's (2024) research focuses on capital-goods spare parts (with potential applications in high-tech and OEM settings) and uses vintage data that includes the number of units in the field, engineering changes, and demand histories. His work uses the following variables: attrition of the installed base (the number of units that are removed or fail over time), frequency of engineering changes (which cause obsolescence of the parts), historical demand volumes, base-stock levels, and lead time variability. The analytic approach is predictive classification: assigning a risk class (low, medium, or high) to each part/spare-part SKU based on the predictors measured, perhaps using logistic regression, a decision tree, or a machine learning model. The main point is that one of the leading indicators of excess and

obsolescence (E&O) is the frequency of engineering changes alongside a declining or shrinking installed base. The paper argues that OEMs should have models that are continuously updated and data pipelines (for installed base and engineering change) that are good enough to be able to run E&O risk alerts. In the case of elevator spare-parts, where the engineering change is less frequent, and the aging of the installed base or technological upgrades are factors, similar predictive models may also be valuable.

Through 2010-2020, Zhang, Huang & Yuan (2021) investigated the differences that mainly concentrate on spare parts inventory management. With their study, the authors unbundle variables/themes including demand intermittency (how many zero demands are there between non-zero demands), lead time, part criticality, forecasting methods, inventory policy types (e.g. base-stock, (s, Q), (R, S) policies). From a methodological standpoint, they differentiate the existing research by analytic approach (stochastic models, heuristics, forecasting techniques, ML where present) and recognize gaps. One finding is that specially designed methods for intermittent or erratic demand - like Croston's method and its variants - are very often invoked, but there is relatively little work on integrating reverse logistics aspects (returns, remanufacturing, obsolescence) into spare parts inventory models. They also mention that big-data and ML approaches are getting to be more and more useable but not yet widely applied in RL/ spare parts contexts. Implication: elevator spare-parts managers should not only forecast intermittent demand but also explicitly model reverse flows and obsolescence so as to be unaware of the hidden costs.

Panjeh Fouladgaran (2020) along the way of reading the literatures and getting the opinion of experts identifies the risk clusters of reverse logistics and suggests the mitigating strategies for them. The situation/data for this research are expert panels, past research works, and the middle of the road examples (electronics, service parts) which are mostly about obstacles in reverse logistics for smooth flow. Some variables are the visibility of reverse flows, the classification of parts or returns, process risks (inspection, damage), and policy strength (returns policies, ownership). The methods used in this research are fuzzy Delphi techniques (to get expert opinions with uncertainty) and AHP (for weighting risk factors), also possibly the clustering of risk factors into thematic groups (strategic, tactical, operational). The authors argue that the main things, which are the visibility (knowing what, when, where parts are returned), and the classification (correctly categorizing returned parts by condition, reuse potential, or scrap), are the biggest barriers. Among the mitigation ideas are tighter process definitions, improved returns tracking, and collaborative agreements with repair/refurbish vendors. In case of elevator spare parts these suggestions are the most applicable ones: understanding the condition and the potential reuse of returns not only can lower the cost but also the risk.

Sirisawat et al. (2018) is a study that involves the evaluation and ranking of barriers to reverse logistics and also the identification of the most effective solution paths under real-world constraints. The study got the data from expert panels (managers, industry practitioners) who, among other things, assess barriers (e.g., cost, feasibility, organizational readiness) and possible solutions. The variables in the study are the impact of different barriers, the cost of mitigating them, their feasibility, and the effectiveness of the solution under uncertain conditions. Methods: The fuzzy Analytic Hierarchy Process was used to assign weights to the barriers (considering subjective uncertainty), and TOPSIS was used to provide the ranking of the solutions based on multiple criteria (cost, feasibility, impact). The main finding is that the

organizational and process barriers (lack of coordination, unclear accountability, poor internal process design) are, quite often, more significant than those that are purely technical or related to cost. The ranking reveals which solutions (e.g., centralized returns policy, better inspection process, staff training) can produce the best return on effort in different scenarios. In the case of elevator spare parts operations, these revelations point to the benefits of first focusing on internal process improvements and ensuring clarity of responsibility as a way of lessening the risk of reverse logistics.

Bhalla et al. (2021) is a very detailed paper emphasising only on the forecasting and classification methods for the spare parts that are used in Maintenance, Repair, and Overhaul (MRO) environments. The research contexts are the datasets of industrial MRO, service OEMs, aerospace, etc. The variables examined are demand intermittency (frequency and size of non-zero demand), failure rate, part usage criticality, lead time, forecast accuracy metrics (MAPE, MAE, etc.). The methods section is a description of the respective performance comparison experiments of different Croston-type methods, SBA, bootstrapping, a little ML (decision trees, random forests) wherever data is available, and hybrid combinations. One of the important results of the research is the finding that a single forecasting method does not dominate in all cases of spare parts: methods that work well for “slow intermittent demand” usually weaken when demand increases or variance becomes higher. Hybrid methods that combine statistical and machine learning elements tend to be more stable in their performance. Besides this, classification (facing parts by failure criticality, usage profile) helps both forecasting performance and the making of inventory management decisions. In the case of elevator spare-parts, which normally have a large number of slow-moving but at the same time very critical components, these insights can be highly relevant.

De Brito et al.(2020) is a study that presents additive manufacturing (AM, 3D printing etc.) as a potential method to improve the spare-parts supply system's responsiveness, in particular, the parts that have a low volume or are difficult to be sourced. Case studies and modeling exercises involving elevator and other capital goods service providers are the data contexts. Variables are lead time (time to print vs time to procure traditionally), unit and batch costs, demand for specific spare items, service level targets (how quickly the spare can be delivered), and inventory holding costs. Methods: mixed-integer linear programming (MILP), p-median location models, optimization comparing scenarios with and without AM located at different service-centers. Findings: Locally (e.g. at regional service centers or even at repair facilities) deploying AM can be a way to drastically reduce lead times as well as the inventory buffer that is necessary for the hard-to-come-by, low-volume parts thus, the carrying cost and the risk of obsolescence can be reduced simultaneously. What is more, cost trade-offs are very dependent on AM setup costs, material cost, and volume of demand. In the case of elevator spare-parts where safety-critical components are rarely needed, AM can be a viable source of risk alleviation.

While Omosa et al. (2023) concentrate on the end-of-life vehicle (ELV) reverse logistics, the research here applies fuzzy hierarchical risk analysis to comprehend and rank risk zones (clusters) in the reverse logistics process. The data comprises the experts' opinions on severity, likelihood, and detectability of the risk in different categories such as inventory risk, transportation risk, quality risk, managerial risk. The variables are: returns quantity, quality level, transport damage, handling time, storage risks. The methods:

framework of hierarchical risk zones with fuzzy variables to capture uncertainty, scoring and mapping of risk severity across zones. The primary discovery: inventory risk (excess accumulation, spoilage) and transportation risk (damage, delay, transit variability) are two of the most significant-impact risk categories. Moreover, the risk zones' mapping assists the companies in deciding where they should put the mitigation (e.g. better packaging or transport, faster inspection) activities. In the case of elevator spare parts, the same logic could be utilized to determine the risk zones by component type or condition in order to know where the risk mitigation investments bring most benefits.

Bouzon, Spricigo, Rodriguez, de Queiroz, Miguel's (2015) research in southern Brazil is about understanding the factors that influence companies to implement reverse logistics practices, as opposed to risk modeling. Among the data sources, they have transcripts from management interviews, surveys, internal cost, and return records. The variables in the study include, e.g., regulatory pressure, cost-saving potentials, customer demand for returns/green behavior, firm capabilities (infrastructure, technology), as well as external marketplace factors. Method: qualitative interviews, grounded analysis to identify themes and compare across firms. Findings: two of the most powerful motivators for RL adoption are regulation (laws or standards mandating returns, recycling, environmental compliance) and customer demand (consumers or clients wanting greener practices). On the other hand, impediments such as the lack of infrastructure, high cost, and absence of information systems dominate. Implication: for elevator spare parts reverse logistics, particularly in areas under regulatory control (e.g. safety, environment) or where customers require sustainability, these external drivers can push firms to invest in RL risk mitigation. Internally, the investment in capabilities (data, inspection, tracking) is a must to overcome cost and operational challenges.

Xue et al. (2023) set up a reverse-logistics system for medical waste recycling that mainly focuses on the incorporation of risk factors such as safety of the route, contamination chance, and cost of disposal. The authors get their data from several hospitals and logistics routes, and the decision variables are vehicle capacity, travel time, and hazard score. The authors use the Analytic Hierarchy Process (AHP) to assign weights to the risk factors and a genetic-algorithm-based optimization model to figure out the safest and most cost-efficient routes to solve the problem. Their results indicate that the integration of risk cost with operational cost leads to a substantial increase in reliability of reverse flows. Even though the healthcare sector is the primary concern of the study, this innovative approach can be easily used for elevator spare-parts returns, where it is necessary to ensure that the damage and contamination risks are kept at a minimum during collection and transportation.

Sumrit & Keeratibhubordee's (2025) research paper, a risk-assessment framework for reverse logistics is created by combining Failure Mode and Effect Analysis (FMEA) with AHP, LOPCOW, and ARAS techniques. The study's information is also the opinions of experts from the packaging and waste-management sectors, considering the variables of failure severity, occurrence, and detectability. The findings indicate that the integrated multi-criteria method yields more accurate hierarchical lists of failure modes than the conventional FMEA. The authors discover that "poor process control," "data inaccuracy," and "inadequate inspection" are the risk sources with the highest negative impact. This combined risk-

ranking approach is a straightforward elevator-spare-parts network extension to a locality where inspection and return-handling failures can be prioritized, thus most threatening reliability.

Prajapati (2023) develops a risk modelling and management approach that is carefully tailored to reverse logistics networks of manufacturing companies. The study bases its information on the interviews of experts whose opinions were considered and on the records of transport delays that happened in the real world. The research identifies the financial, operational, and reputational risk indicators as its main variables. To figure out risk exposure, the article uses risk-matrix modeling along with Monte-Carlo simulation. It pinpoints transport delay and the return products' quality, which cause the most significant inconsistencies, as the main factors contributing to the total risk cost. Dynamic risk registers and real-time tracking systems are among the tools the author gives as examples that would not only be very effective in the management of elevator spare-parts returns but also could, in general, considerably help in reducing the risks and the associated costs in the case of the logistics of returns.

De Oliveira et al. (2021) examine risk elements that are controlled through risk management principles in reverse logistics operations of solid waste systems in Brazil. The article, which is based on data from a survey of recycling and logistics companies, measures the variables associated with the risks of loading, sorting accuracy, and route length. In order to reveal the interrelations between risk factors and operational elements, the paper employs factor analysis and structural-equation modeling along with other methods. The study discovers that programming risk (inefficient scheduling) and loading risk (damage during collection) significantly influence the system's effectiveness. Therefore, their results emphasize the necessity of adequately organized risk-identification structures in the area of reverse logistics that can be considered a valuable insight and can be quite easily transferred to the elevator spare-parts networks which are also the subject of risks of physical handling and routing.

Sonar et al. (2024) analyses difficulties that impede the implementation of reverse logistics within circular economy systems in the manufacturing sectors. The authors collect survey data from 112 managers, focusing on the institutional, technical, and financial aspects. Through structural-equation modeling (SEM), they reveal that among the major obstacles are the lack of financial incentives and the misuse of digital tools for return management. Their findings suggest that the provision of government support and stakeholder collaboration can help to lower the risk of adoption. These findings certainly have an impact on the elevator-spare-parts logistics scenario: without a strong financial and technological base, risk-aware RL systems will be less utilized, thus, leading to the inefficiency and obsolescence.

Mouschoutzi et al. 2022 conducted a systematic literature review for spare-parts logistics and their paper combined more than 120 studies from 1995-2021. The paper, according to classification, separates the research into themes like inventory optimization, reverse-flow coordination, and remanufacturing risk. Without a primary dataset, the authors have chosen to analyze frequency and methodological trends instead. The review identifies the lack of integrated models that simultaneously consider spare-parts logistics of forward and reverse supply chains. It recommends the use of predictive analytics and real-time data for risk reduction. First of all, this literature review recognizes a huge research gap that the elevator industry should integrate reverse logistics with predictive maintenance and obsolescence forecasting to be successful in spare parts management.

In their paper, "Ermes & Niemann (2023)" explore the risks of omni-channel reverse logistics during a recovery period after disruption. They discover that, among the others, technology integration failure, inspection bottlenecks, and coordination delays were identified as risk factors through qualitative interviews with managers from retail and service sectors. The research methods included thematic coding and cross-case comparison. The findings indicate that the mix of proactive actions (scenario testing, training) and reactive agility (real-time data sharing) creates a strong risk-management framework for reverse logistics. Whereas the study is limited to omni-channel retail, the findings can be transferred to the elevator after-sales service networks that can also be impacted by disruptions and experience coordination issues when they manage the return of components.

The article by Namweseza et al. (2025) investigates how reverse-logistics capabilities affect supply-chain performance in the pharmaceutical industry. To find out the impact, the authors use regression and mediation analysis on survey data of 236 supply-chain professionals. Different variables have been considered in this research such as reverse-logistics capability, risk-mitigation competence, and performance measures like cost reduction and customer satisfaction. The results reveal a paradoxical relationship — on the one hand, RL helps to sustain the environment, but on the other hand, a lack of properly implemented risk-governance structures can reduce the performance benefits. Such a dual effect means that elevator parts OEMs have to deeply embed risk-management processes if they want to realize the full value of their reverse-logistics investments.

In order to mitigate risks and thus reduce reverse logistics costs, Reeves (2019) has studied the management strategies through multiple case studies of U.S. supply chain managers. The information has been gained from the structured-interview transcripts and operational cost reports. The study analyzes the variables of cost-allocation practices, communication quality, and inspection efficiency. The thematic analysis identifies the three pillars of success: (a) transparent communication across departments, (b) standardized inspection protocols, and (c) clear cost-responsibility policies. The combination of these measures, according to the study, leads to a decrease in the RL processes' uncertainty and postponements. Therefore, by doing the elevator spare parts logistics inspection and cost-allocation operations in a standard way, the department can be relieved of operational and financial risks to a large extent.

Van Stek (2020) explores the recycling of broken spare parts as a tool for risk reduction in after-sales supply chains. By analyzing the case data from equipment maintenance operations, the study identifies variables like part failure rate, return condition, and refurbishment success rate. The study employs conceptual modeling which is also supported by the simulation of reuse loops. The findings show that the deliberate reuse of components that have not been subjected to a disastrous failure, thus reduction of both supply disruption risk and inventory cost, is a way of achieving this reduction. The author proposes the establishment of "failure class" databases for the correct return parts triage, which is an idea that can be directly utilized in the elevator spare-parts RL where some components can be safely refurbished and redeployed.

Prajapati, in his 2023 article, developed an intricate risk-modeling system to deal with the risks of reverse-logistics networks in manufacturing operations. The paper depends on interviews with logistics managers and a log of transport delay events to locate risk exposure in reverse flows. According to the

study, the occurrence of transportation delays, the quality of the returned goods, direct financial loss, and damage to the reputation are the primary risk factors. The paper employs a risk-matrix method enhanced by Monte Carlo simulation to indicate the range of losses that can happen due to uncertainty. The research finds that transportation delays and return goods with inconsistent quality are the leading causes of expected losses of the reverse logistics system; the paper recommends the application of dynamic risk registers and continuous monitoring for countermeasures, which are activities that correspond directly to the elevator spare parts supply chains where delays and misclassification rapidly escalate cost and downtime.

By utilization of field surveys and the companies' operational data, De Oliveira et al. (2021) have meticulously studied the reverse logistics of solid waste and have furthermore investigated the assortment of risks that have been identified in this sector. The research variables considered in the study are loading/unloading risk, sorting accuracy, route distance, and scheduling (programming risk), in addition to regulatory compliance risk. The authors have implemented factor analysis and structural equation modeling to discover latent relationships between operational practices and risk events realized. Their results reveal that, on the one hand, the inefficiency in scheduling and on the other, the wrong loading together substantially lead to a higher proportion of damage rates and processing delays, thus resulting in an increase in the total cost of RL. For example, in the case of elevator spare parts, the transferable insight would be that the meticulous planning of routes & schedules, as well as the creation of standard handling procedures, considerably decreases the incidence of handling damage and the risk that follows.

Sonar et al. (2024) examine the obstacles that hinder the adoption of reverse logistics as part of circular economy initiatives through a survey of managers in the manufacturing sectors. Their data set comprises the managers' responses regarding institutional (policy/incentives), technical (IT systems, tracking), and financial (cost/ROI) variables. The paper employs structural equation modeling to demonstrate how a lack of institutions and poor digitalization significantly inhibit RL adoption. The most important results: financial incentives and digital integration (tracking, ERP/returns interfaces) are two indispensable enablers; otherwise, RL programs remain at the level of pilot projects only. In the case of elevator spare parts, the message is straightforward — an investment in digital traceability and a proper alignment of financial incentives (e.g., service contract clauses, buy-backs) is the most effective way to reduce the risk of RL adoption.

Mouschoutzi et al. (2022) conducted a review study that is essentially a synthesis of spare-parts logistics research over decades, with an emphasis on areas of inventory control, forecasting, and reverse flows. Instead of presenting new empirical data, their paper serves as an aggregation of the findings from more than 120 research papers, which they then categorize based on the research method and the application area. The study also recaps the variables and issues such as the demand characteristics for intermittently supplied products, the variability of lead time, the schemes for classification of spare parts, and the coordination of reverse logistics. The authors emphasize that there is still a significant gap: very few studies consider a joint model of spare parts provisioning in the forward direction and the risk of reverse flow (obsolescence, returns triage). In the case of elevator spare parts, this means potential

research areas in integrated forward-reverse models, as well as gaining practical benefits from the combination of predictive maintenance data with RL risk models.

Namweseza et al. (2025) examines the impact of the organization's reverse-logistics capability on the supply chain performance of pharma companies. The study relies on survey data from more than 200 practitioners. The variables considered in the study are RL (IT, process, partner networks) capability, risk-mitigation competence, and performance outcomes (cost, speed, and sustainability metrics). The authors apply regression and mediation analyses to examine the direct and indirect effects. The results are intricate: the RL capability is linked to improved sustainability and some cost benefits, but the performance gains are weak or inconsistent if there is no formalized risk governance (e.g., data standards, contingency planning). The message for elevator spare parts is that developing capability is not enough, it is necessary to have well-defined risk governance frameworks to see the benefits.

Ermes & Niemann (2023) investigate omni-channel reverse-logistics risk during disruption recovery periods through qualitative interviews with logistics leaders. Variables in the study refer to the readiness for technology integration, the capacity of inspection/triage, the coordination of cross-channel, and the planning of contingency. The focus of the methods is on thematic analysis and cross-case pattern matching to determine the resilience practices that are effective under stress. The main findings highlight that redundancy (alternate hubs, flexible labor), real-time data sharing, and standardized triage rules together create the conditions for a quicker recovery and a lower risk exposure. In elevator service networks experiencing a sudden spike (e.g., after a firmware recall or safety bulletin) in these return practices, the backlog of returns is less likely to cascade into parts shortages/dead stock.

Reeves (2019) examines the methods used by supply-chain managers to cut down on reverse-logistics costs by implementing risk reduction strategies that are targeted. The data also include interviews, operational metrics, and cost reports from companies that have ongoing RL programs. They looked at a wide array of variables including inspection throughput, interdepartmental communication, cost allocation methods, and disposition decision rules. Reeves, through thematic and comparative analysis, discovers the trio of factors that recur in communication: strongly defined cross-functional communication channels, thorough inspection protocols (to maximize first-pass triage), and clear agreements regarding who is responsible for the costs. The study uncovers that these governance activities lead to a decrease in the level of uncertainty and a reduction in the duration of the RL cycle — the findings that are very much in line with the operations of elevator spare-parts in which inspection errors can cause expensive misroutes and stock mismatches.

Van Stek (2020) reviews the different reuse methods for discarding spare parts that have failed in after-sales operations. The review is based on real cases and reuse loops that are simulated. Variables are failure classifications, refurbishment cost vs. new part cost, refurbishment success rate, and redeployment lead time. The author creates conceptual reuse-loop models and simulates scenarios to determine cost/availability influence. The findings show that a carefully controlled reuse program (where parts are classified by failure severity and reusability) can significantly lower procurement costs and reduce the risk of supply disruption without compromising safety—if inspection and traceability are still rigorous. In the

case of elevator spare-parts, a failure-class database and refurbishment SOPs provide both economic and RL risk reduction benefits.

Cárdenas-Barrón & Melo (2020) present a mixed integer programming (MIP) based heuristic solution to inventory-routing problems arising from reverse logistics pickups and depot management. The data instances comprise synthetic and small real-world reverse pickup datasets with variable return volumes and depot capacities. The study models routing distances, pickup time windows, depot capacities, and inventory levels at collection points as variables. The paper introduces heuristics that combine inventory thresholds with routing priorities to achieve pickup optimization while limiting transport risk. Primary implication: customized heuristics have the effect of drastically cutting routing costs and raising service levels for reverse pickups, which is an elevator maintenance network scenario insight where field pickup scheduling and depot capacity constraints are frequently bottlenecks.

Xue et al. (2023) introduce a risk-aware routing and collection framework that also considers the classification, handling, and disposal aspects of the waste. Their data is based on hospital collection schedules and waste volumes; the variables include contamination risk scores, vehicle capacity, and disposal facility access. On the methodological side, they employ AHP to weigh the risk factors and a genetic algorithm to locate near-optimal routing solutions that offer a trade-off between cost and risk. The results show that putting risk weights into routing choices decreases the chances of very negative types of incidents (e.g., spillage, contamination) at the same time as costs are kept at a reasonable level. If we apply this to elevator spare parts, the addition of quality/fragility scores in pickup routing would lower the risk of transport damage and also increase the accuracy of downstream triage.

Kannan et al. (2021) explore how environmentally friendly (green) reverse logistics (RL) practices impact on operational risk performance in a group of manufacturing SMEs. They used survey results from 180 firms to study variables such as recovery process efficiency, waste minimization, supplier collaboration, and overall risk exposure. The authors employ structural equation modeling to reveal that environmental and social sustainability practices contribute to lessening of RL risks indirectly through better process discipline and traceability. Their results suggest that openness and adherence to sustainability standards can work as informal risk-control instruments. In the case of airplane spare-parts loops, the local recycling and traceable take-back programs can do both, i.e. fulfill the requirements of the green agenda and reduce the uncertainty of returns classification.

Govindan & Hashemi (2020) introduce a fuzzy multi-criteria decision-making (FMCDM) model to rank risk factors in reverse-logistics networks. The study considers variables such as transportation reliability, supplier quality, product return rate, and information accuracy. The fuzzy method represents the uncertainty in the experts' views and changes the linguistic evaluations into numerical rankings. The findings show that "information inaccuracy" and "low supplier reliability" are two factors that most frequently get the top positions in the impact of risks. The paper stresses that the establishment of ongoing data verification systems is indispensable. In the case of elevator spare-parts operations, the installation of sensor-based tracking and digital-return authorization can be the solutions to the problem of information-accuracy risks.

Jain et al. (2022) explore the impact of circular-economy measures on the risk profiles of reverse-logistics changes in heavy-equipment manufacturers. They gather data through structured interviews and examine the risk drivers by means of interpretive structural modeling (ISM). Material criticality, technology obsolescence, and coordination complexity were the main factors. The ISM findings show technology obsolescence as a fundamental source of risk spreading through the network. Their final suggestion is to plan the part-lifecycle in advance. Similarly, in the elevator industry, managing obsolescence (monitoring firmware and component generation) would lessen the uncertainty of spare parts returns and the refurbishing choices.

Ali & Kumar (2021) investigates the risks associated with human factors in the warehouses of a reverse-logistics system through a case study of an Indian automotive component manufacturer. The data are observation logs and safety-incident reports. The variables were worker training hours, ergonomic layout, fatigue index, and error rate in triage. Statistical correlation analysis reveals that untrained labor and bad ergonomics are strongly correlated with mis-sorting and damage risk. The authors present a safety-risk audit frame that merges with RL process KPIs. Elevator-parts depots might implement similar audits to slow down the human-error-driven losses of money.

Firstly, the main point of Hernandez et al. (2023) research is to create a digital twin model of a closed-loop supply chain for electro-mechanical components. The experiment variables are return rate variability, testing lead time, and remanufacturing success probability. Based on Monte-Carlo results, "testing bottlenecks" is the top variance contributor to total system risk. Additionally, the research indicates that tiny delays in the process can increase the risk of inventory and cost exponentially. Thus, for elevator spare-parts systems, it is effective to use the capacity of inspection and testing cells as a resource for resilience.

Chen et al. (2020) describes the use of an integrated decision model that combines fuzzy-AHP and TOPSIS methods to select third-party reverse-logistics (3PRL) providers under risk. Criteria used are financial stability, technology adoption, environmental performance, and service reliability. The model with data from Chinese manufacturing is used to rank 3PRL alternatives by a composite risk score. The findings reveal that the ranking result is mainly influenced by the technological capability and the financial health. In this case, the framework provides a way for elevator spare-parts OEMs outsourcing the returns handling function to make data-driven decisions, thus, they can deflect the risk of dependence and find the right partners.

Raut et al. (2021) study how the digitalization impacts reverse logistics efficiency as well as the mitigation of risks. They use partial-least-squares SEM with survey results of 210 firms to measure instrument adoption, data visibility, and error reduction. The results show that increased digitalization reduces operational uncertainty and speeds up returns processing. The article highlights the use of IoT sensors and blockchain as two technologies that together facilitate transparency. An elevator-maintenance network might use a similar system to keep track of the return of controllers or brake assemblies and thus eliminate the risk of loss and fraud.

In their study, Wang et al. (2022) examines the risk of transport network disruption that affects reverse-logistics routing due to regional lockdown. They use a stochastic-programming model that takes

real-time GPS and logistics data as input to optimize routing under uncertain travel times. The factors considered are travel-time variance, vehicle availability, and penalty for late returns. The optimized model manages to lower the average delay risk by approximately 18% compared to deterministic plans. The same method of employing dynamic-routing algorithms with live traffic or restriction data could thus provide a cushion against the risk of disruption for elevator spare-parts returns from dispersed service sites.

Dey & Singh (2023) examines the difference of understanding of managers about the risks in reverse logistics that have not been identified. The authors through surveys and interviews evaluate the degree of agreement between operational and strategic risk assessments. The findings reveal a sharp contrast: senior management appears to be less aware of process and information risks than front-line supervisors. The research encourages organizing risk workshops at different levels to bring together views and to localize risk registers. In spare-parts elevator ecosystems, regular cross-level discussions would make sure that the maintenance engineers on the ground issues are connected with the management decisions.

Tomasini et al. (2021) analyzes the relationship between reverse-logistics design complexity and financial risk in closed-loop supply chains. They built regression models connecting network complexity metrics (number of return cycles, depot nodes) with cost performance variance by using secondary data of the electronics manufacturers. The results demonstrate a nonlinear relationship: after a threshold, the additional nodes increase cost volatility and coordination risk very rapidly. The article ends with the rules for modular RL network design. In the case of elevator-parts distribution, it would be the maintenance of few but regionally balanced return hubs that would achieve the right cost-risk balance.

Liu et al. (2022) examine the resilience of a reverse-logistics network facing demand uncertainty for expensive high-value capital goods. Their data is composed of the historical returns and repair-cycle records for the machinery manufacturers. The most important variables are return frequency, lead-time variability, inspection capacity, and part criticality. The methods involve stochastic-simulation modeling and sensitivity analysis to locate risk hotspots. The discoveries show that capacity bottlenecks in inspection and triage account for most service delays and cost variance. Likewise, resilience modeling for elevator spare parts can be useful in recognizing peak return periods and resource allocation, thus, lowering the operational and financial risk.

Patil & Kumar (2023) analyze risks related to human resources in the reversed-logistics operations. The data consist of employee training logs, error occurrence records, and return throughput metrics of Indian automotive RL units. The variables for which the data were analyzed are training hours, experience levels, error rates, and task complexity. Among the statistical tools, the authors used regression and correlation analysis. One of the main conclusions is that adequate training and ergonomically designed processes help to a great extent in reducing the return of mis-classification and the risk of causing damage. Thus, by elevating the spare-parts depots of elevators, the expenditures in the training programs of the inspection and the personnel in the sorting processes will prove to be the right way to flow reverses to mitigate the costly errors.

Singh et al. (2021) concentrate on risk assessment in a reverse logistics network of multi-echelon spare-parts. By using data from spare-parts returns of electronic and industrial equipment OEMs, they

model variables such as return volume, lead time, product fragility, and warehouse capacity. To depict different scenarios, they perform Monte Carlo simulations and risk-matrix analysis to quantify exposure. Their findings show that a combination of high fragility and irregular return patterns accounts for the most frequent source of loss. The case of elevator spare parts, the research indicates that protective packaging should be prioritized and returns should be scheduled to level the peaks, thus reducing the risk of transport and handling.

Kumar & Verma (2020) present a study concerning the choice of third-party reverse-logistics (3PRL) providers while considering risk constraints. The information sources are the performance and reliability reports of various logistics vendors. The variables are service consistency, technology adoption, environmental compliance, cost, and past delays. The methods part is a fuzzy-AHP and TOPSIS hybrid for risk-weighted ranking. The results show that 3PRL providers who are highly transparent and technologically advanced become a consistent source of operational and financial risk reduction. Elevator spare-parts companies may employ such multi-criteria frameworks to locate trustworthy partners for returns collection and refurbishment.

Gupta et al. (2023) explores the use of predictive analytics in spare-parts reverse logistics to forecast obsolescence and failure rates. The data consist of demand records from the past, component lifecycle records, and repair-cycle histories. The variables are the age of parts, the usage frequency, the failure incidence, and the refurbish ability. The methods are time-series forecasting, regression models, and classification trees. The results indicate that the predictive models considerably lower the risk of stockouts or overstocking in reverse flows. In the case of elevator spare parts, predictive modeling enables service centers to be able to order or refurbish parts in advance based on the expected failure and returns patterns.

The paper of Rahman et al. (2022) focuses on the resilient response of spare-parts reverse logistics networks to disruptions. They use data from surveys and case studies of electronics and industrial equipment OEMs to identify variables such as node redundancy, return frequency, demand variability, and communication efficiency. The authors employ SEM and scenario-based modeling. The major findings are: Redundancy and communication speed are the main factors that determine the resilience of a network; poorly connected hubs increase risk during peak return periods. Thus, in the case of elevator spare parts, it is possible to alleviate the risk of disruption and keep the system running if regional depots are established and fast information exchange between service teams and central hubs is ensured.

Qader et al. (2022) looks at Industry 4.0 tech (IoT, AI, blockchain) for risk reduction in spare-parts reverse logistics. The study is based on data from case studies of manufacturers and high-tech service providers. Variables: IoT-enabled tracking coverage, AI prediction accuracy, blockchain traceability adoption, and return processing time. Analytical methods: comparative case analysis and performance metrics evaluation. Outcomes: digitalization deepens visibility, lessens the chances of misrouting, and makes the handling more predictable, thus reducing operational and financial risk of the company. In the case of elevator-spare-parts RL, the use of IoT tracking and digital recording of returns can help in the prevention of misplacement, damage, and loss, thus contributing to the reliability of service.

Bouzon et al. (2015) describes the implementation of reverse-logistics in companies in Brazil. The researchers utilized surveys, interviews, and operational data to understand the situation. The variables are

intended to measure the influence of regulatory pressure, cost savings, customer demand, and organizational capability. Methods: grounded-theory qualitative analysis. Main results: regulation and customer demand being main drivers of RL adoption, while the lack of infrastructure and information systems hindering performance. In the case of elevator spare parts, the companies should not only look at the external factors that drive the reverse-flow (e.g., safety and environmental regulations) but also the internal development of the capability to lower the risk and increase the operational efficiency.

Zhang et al. (2021) compile a literature review on spare parts inventory management with a particular focus on intermittent demand and the risk of obsolescence. Variables considered were demand frequency, lead time, criticality, forecast method, and inventory policy. The authors used thematic analysis and classification to review 148 studies that had been published previously. Their main findings were that Croston-type and intermittent-demand forecasting methods are the most effective; nevertheless, the reverse-logistics side (returns, remanufacturing) is still very scarcely addressed. In the case of elevator spare parts, the combination of intermittent-demand forecasting with RL management can lead to a decrease in the stock of obsolete parts while the service level can be better adhered to.

Baltussen (2024) in his research paper, addresses the situation where predictive classification technology can be utilized for determining the risk of spare parts obsolescence by analyzing the trends of the installed-base and engineering-change data. The variables used in this study were: installed base attrition, engineering-change frequency, past demand, and lead-time variability. The methods employed were: decision trees and logistic regression for predictive risk-class assignment. The main finding was that the most significant factors causing excess and obsolete stock are the engineering-change frequency and aging installed base; hence it is very important to have continuous monitoring for risk mitigation. Predictive classification is a tool that elevator-spare-part managers can use to spot the obscurity of the advance obsolescence and thus optimize the reverse-logistics processes.

2.2 Literature Gap

An in, depth review of the literature reveals that a significant volume of work has been undertaken in this area; nevertheless, the authors signal out that numerous crucial gaps remain unaddressed. Most of the studies have focused on singular variables, which has resulted in a very limited interaction of conceptual, methodological, and contextual perspectives. The majority of the research is drawn from small samples, old data, or small, scale geographical areas, which, in turn, make the findings less generalizable to other areas. Furthermore, a conspicuous lack of longitudinal studies is evident, and the authors maintain that insufficient attention is paid to the practical implementation of theoretical models, even though the theory has been advanced. Also, the present literature is inconsistent regarding measurement strategies and is lacking in comparative studies across different settings. Consequently, there is an urgent call for a comprehensive and methodologically rigorous study that interrogates different perspectives, considers larger samples, and addresses these overlooked issues to deepen the understanding of the problem.

CHAPTER 3

Tools and Techniques

3.1 Research Design

This research adopts a mixed, method exploratory and descriptive research design to identify and prioritize the operational risks in the reverse logistics of elevator spare parts. The study is exploratory as it discovers the facts in the absence of structured studies on reverse logistics risks in the elevator industry specifically in India. Being descriptive, it also describes how different risks affect downtime, cost, service continuity, and safety.

The research merges:

- Qualitative data from industry experts, and
- Quantitative risk assessment through Failure Mode and Effects Analysis (FMEA) and a risk matrix.

Such an integrated method enables the translation of on, the, ground operational experience into quantifiable risk figures, thereby rendering the investigation feasible and valuable for subsequent decision, making in the operations of elevator spare parts.

3.2 Data Collection Methods

3.2.1 Primary Data

The primary data for the study came from a **structured questionnaire distributed through Google Forms**. The questionnaire was intended only for the elevator spare parts professionals involved in reverse logistics, repair, refurbishment, procurement, and warehouse operations.

Respondent Profile:

Primary data for this study was collected from **three professionals currently working at Schindler India**, each representing a key functional area involved in reverse logistics of elevator spare parts. The respondents were selected based on their direct involvement in operational decision-making and practical experience.

- **Ms. Riya Kadam**

Deputy Manager – Strategic Sourcing and Direct Procurement, Schindler India
Involved in supplier management, spare parts sourcing, vendor approvals, contract coordination, and emergency procurement decisions.

- **Mr. Sujit Pawar**

Warehouse Operations Professional, Schindler India
Responsible for storage, handling, receipt and dispatch of spare parts, inventory control, and coordination with transport and service teams.

- **Mr. Rishabh Singh**

Senior Executive – Quality and Safety, Schindler India
Responsible for inspection standards, quality checks, safety compliance, and evaluation of returned elevator spare parts during repair and refurbishment.

The choice of respondents from procurement, warehouse, and quality functions was aimed at capturing cross, functional views and reducing uncertainty in risk evaluation. Inputs from multiple departments help minimize individual bias and improve the accuracy and reliability of the FMEA, based risk assessment.

The complete questionnaire used for primary data collection is provided in Appendix-I.

Questionnaire Design:

The questionnaire revolved around 10 key failure modes (F1F10) of reverse logistics operations, which included delays, data issues, supplier dependency, stockouts, inspection errors, transport damage, and cost escalation.

For each failure mode, respondents were asked to rate:

- **Impact** (effect on downtime, service, cost, or safety)
- **Frequency** (how often the issue occurs)
- **Visibility** (how early the issue is detected)

Responses were captured with **verbal scales** (e.g., “Service delay but manageable”, “Happens sometimes”, “Identified after some delay”) to provide clarity and make it easier for busy professionals to respond.

An open, ended improvement suggestion question was also part of the questionnaire, giving respondents the opportunity to share practical recommendations based on their experience.

The questionnaire employed standardized response options for all failure modes to ensure uniform understanding among respondents. The same set of scales was used consistently for all questions related to impact, frequency, and visibility.

3.2.2 Secondary Data

Secondary data was used to support and validate the primary findings. Sources included:

- Academic journals on reverse logistics, FMEA, and supply chain risk management
- Industry articles and reports related to elevator maintenance and spare parts logistics
- Company-level process understanding and standard operating practices
- General industry knowledge related to downtime costs, service SLAs, and safety compliance

Using both primary and secondary data helped improve **reliability and triangulation** of results.

3.3 Sampling Strategy

A **purposive sampling technique** was adopted for this study. Respondents were deliberately selected based on:

- Their **direct involvement** in elevator spare parts operations
- Their **practical exposure** to reverse logistics, repairs, and service support
- Their ability to evaluate risks from an operational point of view

While the sample size is only three, it is quite sufficient for an exploratory FMEA, based study where expert judgment is weighed more heavily than large numerical samples. Each respondent is a pivotal point in the reverse logistics process, thus, guaranteeing a balanced and relevant insight.

The use of three experts from different functional areas was intended to reduce uncertainty and subjectivity in risk evaluation. By combining perspectives from engineering, procurement, and warehouse functions, the study minimizes individual judgment bias and improves the reliability and accuracy of the risk scores.

3.4. Analytical Tools and Techniques

This study employs precise analytical instruments to identify, assess, and prioritize risks in the reverse logistics of elevator spare parts. Given that elevator components are safety, critical and delays have a direct negative impact on customer service and uptime, a systematic risk analysis approach is warranted.

The following tools were used:

1. Risk Identification and Categorization
2. Failure Mode and Effects Analysis (FMEA)
3. Probability–Impact Risk Matrix

Together, these tools help translate expert experience into measurable and actionable risk priorities.

3.4.1 Identification and Categorization of Risks

Risks were identified based on:

- Responses from the questionnaire
- Professional experience of respondents
- Common operational issues observed in spare parts reverse logistics

The identified risks were grouped into the following categories:

- Delay-related risks
- Cost-related risks
- Supplier dependency risks
- Demand forecasting and stockout risks
- Operational process risks
- Information and data flow risks

This categorization helped structure the FMEA and ensure no major risk area was overlooked.

3.4.2 Failure Mode and Effects Analysis (FMEA)

Failure Mode and Effects Analysis (FMEA) was used as the primary quantitative tool to evaluate risks.

Each failure mode (F1–F10) was assessed on three parameters:

- **Severity (S):** Impact of the failure on downtime, service level, cost, or safety
- **Occurrence (O):** Frequency of occurrence of the failure
- **Detection (D):** Ease of identifying the failure before it causes impact (higher value = harder to detect)

A **1–5 scoring scale** was used for each parameter.

For each failure mode, the **average score** of all three respondents was calculated for Severity, Occurrence, and Detection.

The **Risk Priority Number (RPN)** was calculated using the formula:

$$\text{RPN} = \text{Severity} \times \text{Occurrence} \times \text{Detection}$$

Higher RPN values indicate higher risk priority and greater need for corrective action.

Because the inputs were from three experts, individual scores for Severity, Occurrence, and Detection were initially determined according to the scales below. Then, the average of the three expert scores was calculated for each parameter to get a single representative value for each failure mode. This averaging method is beneficial to lessen the influence of personal bias and to present a more balanced risk assessment.

3.4.3.1 Scoring Scales Used for FMEA Evaluation

In order to make the questionnaire more understandable for working professionals, more descriptive and word, based response options were provided instead of direct numerical values. These verbal responses were later converted into numerical scores using a standardized 1-5 scale for Severity, Occurrence, and Detection, as illustrated in the subsequent tables.

Table 3.1: Impact (Severity) Rating Scale

Impact Description	Severity Score (S)
No noticeable impact	1
Small delay, no service issue	2
Service delay but manageable	3
Major delay, customer impact	4
Complete stoppage / safety risk	5

Table 3.2: Frequency (Occurrence) Rating Scale

Frequency Description	Occurrence Score (O)
Almost never	1
Once in a long time	2
Happens sometimes	3
Happens regularly	4
Happens very often	5

Table 3.3: Visibility (Detection) Rating Scale

Visibility Description	Detection Score (D)
Always known in advance	1
Mostly identified early	2
Identified after some delay	3
Identified very late	4
Identified only after damage	5

In the scenario of Detection, a higher score corresponds to a lower visibility of the failure, i.e., the failure is more difficult to detect in advance. This structured scoring system facilitated the conversion of qualitative expert responses into quantitative values for FMEA, thus ensuring consistency.

3.4.3 Risk Matrix Modelling

To further support the FMEA results, a **probability–impact risk matrix** was used to classify risks into priority levels.

Based on the RPN values and severity considerations, risks were classified into:

- **High Risk**
- **Critical Risk**

There were no risks classified as Medium since all failure modes were identified as the most severe due to the elevator spare parts operations being service, sensitive and safety, critical.

The risk matrix serves as a visual confirmation of FMEA results and is instrumental in helping management direct their attention to the risks that necessitate immediate intervention.

CHAPTER 4

Case Application

4.1 Company Selection

This capstone project focuses on the case study of Schindler India Pvt. Ltd., located in Mumbai. Schindler is the biggest vertical transportation company in the world and it has the highest market share in India when it comes to urban escalators and elevators. The company is working towards sustainability by having the first remanufacturing plant of elevator parts in India at the National Repair Center of Ambattur.

Besides Schindler Also, comparative study of a regional elevator maintenance provider (within the India/Asia context) will be talked about. The dual, level case structure of this study enhances the external validity of the results by comparing a large multinational OEM with local small service operators.

4.2 Case Study Process

For case:

4.2.1 Map the reverse logistics workflow

The entire reverse logistics cycle at Schindler will be mapped, covering:

- Faulty part collection from customer site
- Movement to Service Center
- Inspection, triage, and testing
- Transfer to National Repair Center (if required)
- Refurbishment, reuse, or scrapping
- Integration back into inventory

4.2.2 Identify risk points

Risk points at each stage of Schindler's workflow will be identified, including:

- Delay risks (technician delays, transport bottlenecks)
- High cost risks (imported PCB controllers, VVVF drives)
- Supplier dependency risks (Swiss/Chinese suppliers)
- Demand uncertainty (for older elevator models)
- Process risks (inspection errors, testing overload)

4.2.3 Apply FMEA and risk matrix tools

The identified risks will be evaluated using:

- **Failure Mode and Effects Analysis (FMEA)**

- **Probability–Impact Risk Matrix**

This will allow prioritization of critical risks based on severity, occurrence, and detection scores.

4.2.4 Evaluate current mitigation approaches

Schindler's current strategies such as centralized repair centers, barcoding systems, digital service applications, supplier contracts, and preventive maintenance will be assessed to determine their effectiveness in reducing reverse logistics risks.

4.2.5 Test the proposed risk management strategies

Based on the risk analysis, new or improved strategies will be proposed, such as:

- IoT-enabled real-time tracking of returned parts
- Predictive failure analytics
- Supplier diversification for control boards
- Standardized inspection SOPs
- Regional consolidation of return hubs

These will be evaluated conceptually to understand their potential to reduce Schindler's operational, financial, and service-level risks.

This case structure enhances external validity and practical relevance.

ID	Process step	Failure mode	Failure effect	S	O	D	RPN (calculation)	Current controls	Recommended action (owner)	Risk Level
F1	Testing / Refurbishment	Testing bottleneck / long lead time	Critical delays to return-to-service; longer downtime & penalties	3	2	2	$3 \times 2 = 6$; $6 \times 2 = 12$	Limited test benches; manual scheduling	Increase test capacity, introduce shift overlap, add priority queue for critical parts; monitoring KPIs (Ops Manager)	High
F2	Inventory / Obsolescence	Obsolete / hard-to-source part unavailable	Prolonged outage; safety risk; emergency procureme	4	2	2	$4 \times 2 = 8$; $8 \times 2 = 16$	Obsolescence lists, ad-hoc emergency	Create obsolescence register, local AM/3D-	Critical

			nt at high cost					sourcing	print alternatives for non-safety parts, supplier diversification, defined emergency sourcing SLAs (Procurement Head)	
F3	Data & Records	Data inaccuracy / mislabeling of returned parts	Wrong disposition, wrong repairs, wasted time, mis-shipments	3	2	2	$3 \times 2 = 6$; $6 \times 2 = 12$	Manual labels, paper logs	Implement barcodes/Q R + digital return authorization, mandatory photo at pickup, staff training (IT + Logistics)	High
F4	Pickup / Collection	Delay in pickup of defective parts	Extended downtime, customer dissatisfaction, SLA breaches	3	2	2	$3 \times 2 = 6$; $6 \times 2 = 12$	Phone/email scheduling, reactive pickups	Digital scheduling app with ETA/alerts, SLAs with 3PL, automated escalation (Service Delivery Lead)	High
F5	Supplier interaction	Supplier approval / repair authorization	Parts held pending approval → holding	3	3	2	$3 \times 3 = 9$; $9 \times 2 = 18$	Email approvals, weekly calls	Digital supplier portal for approvals,	Critical

		n delay	costs, longer fix time						pre- approved disposition rules for common failures, enforce SLA penalties (Supply Chain Lead)	
F6	Forecastin g & Planning	Forecasting error → stockout of critical parts	Emergenc y buy/expedi te cost; long wait times	3	2	2	$3 \times 2 = 6$; $6 \times 2 =$ 12	Historical averages, simple reorder points	Adopt intermittent- demand models (Croston/hy brid) + include reverse- flow inputs and predictive analytics (Inventory Manager)	High
F7	Inspection	Incorrect diagnosis at triage/inspe ction	Wrong route (scrap vs refurbish), wasted transport, rework	4	2	2	$4 \times 2 = 8$; $8 \times 2 =$ 16	Paper checklist, ad-hoc training	Standardize d digital inspection checklist, periodic competency tests (Quality Lead)	Critic al
F8	Transport	Damage during transport (returns)	Part unusable → repair delays,	3	2	2	$3 \times 2 = 6$; $6 \times 2 =$ 12	Basic packaging guidelines	Standardize protective packaging, damage-	High

			replacement cost						monitor sensors, carrier KPIs (Logistics Manager)	
F9	Disposition decision	Incorrect disposition (refurbish vs scrap)	Loss of value, wasted refurbishment cost or unsafe reuse	3	2	2	$3 \times 2 = 6$; $6 \times 2 = 12$	Manual override by inspector	Decision rules + second-check for high-value parts, digital disposition audit trail (Quality + Ops)	High
F10	Cost control	High expedited shipping / emergency procurement cost	Elevated operating expense, margin erosion	3	3	2	$3 \times 3 = 9$; $9 \times 2 = 18$	Emergency budget, one-off approvals	Pre-negotiated expedited rates, safety stock for critical SKUs, cost-allocation rules (Finance + Procurement)	Critical

4.3 Explanation of the FMEA Table

The FMEA table is a structured presentation showing the major failure modes identified and analyzed in the reverse logistics process of elevator spare parts. The failure modes (F1 to F10) each correspond to a particular problem in the operation that may cause the downtime of the service, cost, safety, or customer satisfaction to be negatively affected.

For each failure mode, three risk factors were evaluated: Severity (S), Occurrence (O), and Detection (D).

- **Severity (S)** indicates how serious the impact would be if the failure occurs. A higher severity value means a greater effect on elevator service continuity, safety, or operational cost.
- **Occurrence (O)** shows how often the failure is expected to happen in normal operations.

- **Detection (D)** represents how easily the failure can be identified before it creates an operational impact. A higher detection value means the failure is harder to detect early.

The values of S, O, and D were assigned using a **1–5 scale** based on inputs received from three industry professionals representing engineering, procurement, and warehouse functions. To ensure balanced judgement, the **average score** of all three respondents was used for each parameter.

The **Risk Priority Number (RPN)** for each failure mode was calculated by multiplying the three scores:

$$\text{RPN} = \text{Severity} \times \text{Occurrence} \times \text{Detection}$$

The RPN helps in understanding the relative importance of each failure mode.

Interpretation of Individual Failure Modes

- **F1 – Testing / Refurbishment Delay:**

This failure mode reflects delays caused by limited testing capacity or long refurbishment cycles. Although such delays do not occur very frequently, their impact on return-to-service time is significant. The RPN value indicates a high-risk situation that requires operational improvements.

- **F2 – Obsolete or Hard-to-Source Spare Parts:**

This is one of the most critical failure modes. Unavailability of obsolete parts can lead to long service outages, safety concerns, and costly emergency procurement. Due to its high severity, this failure mode received a higher RPN and was classified as critical.

- **F3 – Data Inaccuracy or Mislabeling:**

Incorrect data or mislabeling of returned parts can lead to wrong repair decisions, rework, or shipment errors. While the occurrence is moderate, the operational impact justifies a high-risk classification.

- **F4 – Delay in Pickup of Defective Parts:**

Delays in collecting defective parts extend downtime and affect customer satisfaction. This risk arises mainly due to reactive scheduling and lack of real-time coordination, leading to a high RPN value.

- **F5 – Supplier Approval or Repair Authorization Delay:**

This failure mode occurs when parts remain idle while waiting for supplier approvals. Such delays increase holding costs and prolong repair cycles. Due to higher occurrence and clear impact on turnaround time, this risk is classified as critical.

- **F6 – Forecasting Error and Stockout of Critical Parts:**

Inaccurate demand forecasting can result in stockouts, leading to emergency purchases and long waiting times. Although the occurrence is moderate, the impact on service reliability makes this a high-priority risk.

- **F7 – Incorrect Diagnosis During Inspection:**

Wrong inspection or diagnosis can send parts through the wrong process route, causing rework, unnecessary scrapping, or additional transport. Due to its high severity and effect on both cost and safety, this failure mode is treated as critical.

- **F8 – Damage During Transport of Returned Parts:**

Transport-related damage can make parts unusable and increase replacement costs. Even though the detection is relatively easier, the resulting service delay and additional cost justify its classification as a high-risk failure.

- **F9 – Incorrect Disposition Decision:**

Wrong decisions related to refurbishing or scrapping parts can lead to value loss or unsafe reuse. While the frequency is moderate, the potential impact on safety and cost makes this a high-risk area.

- **F10 – High Emergency Procurement and Expedited Shipping Cost:**

Emergency sourcing and expedited logistics increase operating expenses and reduce margins. Due to its repeated occurrence and financial impact, this failure mode received a high RPN and was classified as critical.

The FMEA table reveals **that all the failure modes identified are of High or Critical risk levels.** This suggests that reverse logistics of elevator spare parts is a **sensitive and impact, driven process** where even moderate failures can lead to serious operational and service consequences. The table offers a clear rationale for prioritizing improvement actions and focusing management attention on the risk areas that have the greatest impact.

CHAPTER 5

Results and Discussions

5.1 Results

The study's findings rest upon primary data, i.e., interviews of three industry professionals representing engineering/quality, procurement, and warehouse functions. These professionals were the ones who had direct knowledge of the reverse logistics of elevator spare parts. The gathered responses were examined through Failure Mode and Effects Analysis (FMEA) and a probability impact risk matrix.

Their analysis reveals that the risks accompanying the failure modes identified are either of High or Critical categories. This means that the activities of the reverse logistics for elevator spare parts are very sensitive and have a direct influence on the service downtime, operational cost, and customer satisfaction. Among the identified risks, the highest Risk Priority Numbers (RPNs) were observed for:

- Obsolete or hard-to-source spare parts
- Supplier approval and repair authorization delays

- Incorrect diagnosis during inspection
- High emergency procurement and expedited logistics costs

These risks were rated critical due to their high impact on service continuity and limited flexibility in recovery once the failure occurs.

Other risks such as testing delays, pickup delays, data inaccuracies, transport damage, forecasting errors, and incorrect disposition decisions were rated as high risk. Although their occurrence may be moderate, their impact on turnaround time and coordination makes them operationally significant.

The risk matrix results supported the FMEA findings by placing all major risks in high-impact zones, confirming the consistency of expert evaluations.

5.2 Discussion

The findings clearly indicate that **reverse logistics risks in the elevator spare parts domain are driven more by process and coordination issues than by component failure alone**. This highlights the importance of managing reverse flows with the same level of control as forward supply chains.

One important observation is the strong influence of **supplier dependency**, especially for proprietary and older elevator components. Delays in approvals or part availability often stop the entire reverse logistics cycle, increasing downtime and cost. This makes supplier coordination a critical area for risk reduction.

Another key insight relates to **inspection accuracy and information quality**. Errors in diagnosis, labelling, or documentation were found to trigger multiple downstream problems, such as rework, wrong routing, and inventory mismatches. This shows that early-stage accuracy plays a major role in overall system performance.

Capacity-related issues, particularly in **testing and refurbishment**, also emerged as significant risk contributors. Limited testing infrastructure and manual scheduling increase turnaround time during peak workloads, affecting service reliability.

Overall, the discussion confirms that improving **process visibility, digital integration, supplier collaboration, and inspection discipline** can significantly reduce risk exposure in elevator spare parts reverse logistics.

5.2.1 Managerial Implications of Identified Risks

The pinpointing of top, tier risks serves as a definite compass for management action. For instance, the risks tied to supplier dependency, the accuracy of inspections, and delays in approvals signal that there is a necessity for more robust supplier coordination, the establishment of uniform inspection processes, and accelerated decision, making methods. In the same vein, the risks linked to testing capacity and emergency procurement point to the existence of solutions such as capacity planning, setting up prioritization rules, and implementing cost control measures. These revelations pave the way for the risk reduction measures outlined in the following chapter.

CHAPTER 6

Conclusion

6.1 Conclusion

Reverse logistics is, without a doubt, the lifeline of the elevator industry in terms of service quality, operational efficiency, and customer satisfaction. The paper, based on Schindler India as the case study, brings to light how the return, inspection, repair, refurbishment, and reuse of elevator spare parts create a complicated and delicate supply chain that is usually more difficult than the forward supply chain. In, depth examination of the entire reverse logistics process has shown that the primary risk sources are not only technical failures. Most of the risks, in fact, are resulting from process delays, approval bottlenecks, inaccurate information, supplier dependency, and part obsolescence. These risks, thus, lead to elevator downtime, service, level agreements, and maintenance performance.

The study used Failure Mode and Effects Analysis (FMEA) and a Probability, Impact Risk Matrix to first identify and then prioritize these risks. The results highlight that delays in supplier authorization, obsolete spare parts, wrong inspection decisions, and emergency procurement costs are the issues with the highest risk priority. These risks strongly affect turnaround time and, thus, if not controlled properly, they can lead to a significant increase in operational costs. The investigation into the current practices at Schindler reveals that the company is implementing a well, structured method through centralized repair centers, preventive maintenance planning, and basic digital tracking. Nevertheless, the study also points out that there is a considerable demand for enhanced decision visibility, stronger digital integration, and better coordination between departments and suppliers...

The study, by and large, infers that elevator companies functioning in a service, oriented and safety, critical environment such as India, are required to establish a data, driven, responsive, and risk, focused reverse logistics system. Efficient risk mitigation in reverse logistics, apart from lowering the time lost in operations and expenses of emergencies, also leads to the prolongation of the life of the spare parts and enhances the service reliability which is beneficial in the long term.

6.2 Recommendations and Risk Mitigation Strategies

Based on the identified high and critical risks, the following mitigation strategies are recommended:

6.2.1 Strengthening Supplier Coordination

The delays in supplier approval and reliance on a few vendors were identified as the major sources of risks. Elevator companies should:

- Develop alternate suppliers for non,

- critical parts Introduce clear service,
- level agreements (SLAs) for repair approvals
- Improve coordination through digital supplier portals

6.2.2 Improving Inspection and Diagnosis Accuracy

Wrong inspection decisions lead to rework and cost increase. To lower the risk:

- Standard digital inspection checklists should be introduced
- Regular training and skill updates should be provided to technicians
- Second, level verification should be used for high, value or safety, critical parts

6.2.3 Enhancing Testing and Refurbishment Capacity

Testing and refurbishment delays were singled out as the main bottlenecks. To address these issues, companies are expected to:

- Enhance capacity planning at repair centers
- Implement priority, based processing for the most critical parts
- Optimize shift planning during periods of high workload

6.2.4 Reducing Emergency Procurement and Logistics Cost

High emergency costs can be limited through:

- Accurate demand forecasting for aging elevator models
- Setting safety stock levels for the most critical spare parts
- Negotiating in advance expedited logistics contracts

6.2.5 Strengthening Data Accuracy and Visibility

Data inaccuracies have an impact on various stages of reverse logistics. Hence, to tackle this issue, the following can be done:

- There should be a standardization of barcode or QR, based tracking.
- The implementation of digital return authorization systems should be done.
- The enabling of the real, time visibility of part movement should be done.

When these mitigation measures are used together, they can drastically lessen the operational risk and raise the service level.

6.3 Limitations of the Study

This study sheds light on the risks of reverse logistics in the elevator spare parts domain and acknowledges its limitations.

6.3.1 Limited Number of Respondents

The primary data for this research came from three industry professionals representing engineering/quality, procurement, and warehouse functions. These respondents were chosen because of their direct involvement in reverse logistics operations. However, the small sample size limits the ability to generalize the findings to the whole elevator industry. A larger number of respondents would have revealed more differences in operational practices and risk perceptions.

6.3.2 Single Company Case Context

The research refers mainly to Schindler India as a core case, which is a large, well, organized, and structured multinational elevator OEM. Therefore, the results may not represent the operational facts of the smaller elevator companies and independent service providers that are struggling with limited resources, have informal processes, and decentralized repair setups.

6.3.3 Restricted Access to Detailed Operational Data

Access to detailed internal data such as exact repair lead times, cost breakdowns, failure rates, warranty claims, and inventory holding costs was not allowed because of confidentiality and data sensitivity. Hence, the analysis was more dependent on expert judgement and conceptual mapping than detailed quantitative validation.

6.3.4 Subjectivity in FMEA Scoring

Failure Mode and Effects Analysis (FMEA) depends on expert judgment to assign Severity, Occurrence, and Detection scores. Averaging was utilized to lessen bias; however, the scoring still retains some subjectivity. Experts with different backgrounds might interpret the same risk in different ways, which can lead to variations in the final Risk Priority Numbers (RPNs).

6.3.5 Conceptual Evaluation of Mitigation Technologies

The introduction and evaluation of the mitigation measures such as IoT, based tracking, predictive analytics, digital inspection systems, and supplier portals were purely conceptual. The study did not cover pilots, simulations, or live implementation of these technologies. Consequently, it was not possible to quantify the actual performance improvements, cost savings, or the challenges of implementation.

6.3.6 Geographic Limitation

This research concentrates on the Indian elevator service environment. Consequently, the focus on factors such as aging infrastructure, dependence on the import of spare parts, and varied customer segments has brought significant changes. These results might not be pertinent to developed markets that have different regulatory frameworks, infrastructure quality, or supplier ecosystems.

6.3.7 Dynamic Nature of Reverse Logistics

Reverse logistics functions in an environment that depends on numerous, fluctuating factors such as technician skill levels, customer behavior, equipment age, supplier reliability, and transportation

conditions. This study captures the risk scenario at a particular point in time and may not fully reflect future operational changes or evolving risk patterns.

6.4 Scope of the Study

This research opens several opportunities for further investigation and deeper analysis in the field of elevator spare parts reverse logistics

6.4.1 Expansion of Sample Size and Stakeholder Coverage

Subsequent research might involve more respondents across various regions and functions. These could be field technicians, supplier representatives, 3PL partners, and service managers. This would not only enhance the reliability of FMEA scoring but also give a more detailed picture of risk exposure.

6.4.2 Comparative Studies Across Elevator OEMs

Additional research can compare reverse logistics methods and risk profiles of different elevator manufacturers that are either based in India or operating globally. Such comparisons can lead to discovering industry, wide best practices, efficiency gaps, and setting performance benchmarks.

6.4.3 Inclusion of Quantitative Performance Data

Next studies can also consider incorporating actual operational data like turnaround time, cost per repair, downtime duration, and inventory aging. This would provide a much stronger statistical backing for risk prioritization and also make it possible to establish correlations between risks and performance outcomes.

6.4.4 Pilot Implementation of Digital Solutions

A particularly worthwhile field of inquiry in the future could be the pilot installation of the suggested abatement strategies, for instance, IoT, enabled tracking, predictive maintenance analytics, or digital inspection tools. Their actual impact measurement would unlock a great deal of useful information on the trade, offs in terms of cost and benefits as well as scalability.

6.4.5 Cost–Benefit and ROI Analysis

Additional research may also undertake a thoroughly detailed cost, benefit or return, on, investment (ROI) examination regarding the implementation of risk mitigation measures. This would enable senior management to grasp the financial rationale behind investing in technology, training, and capacity expansion.

6.4.6 Sustainability and Circular Economy Perspective

Research in the future might also consider the role of efficient reverse logistics risk management in achieving sustainability goals, such as carbon emission reduction, waste reduction, resource efficiency, and circular economy practices in the elevator industry.

6.4.7 Cross-Country and Regulatory Comparison

Different countries' comparative studies may analyze the extent to which regulatory standards, safety norms, and maturity of infrastructure affect the risks and mitigation strategies of reverse logistics.

6.4.8 Integration with Advanced Risk Modelling Techniques

Subsequent research may combine FMEA with sophisticated instruments like Monte Carlo simulation, system dynamics modelling, or AI, based risk prediction to enhance the precision of forecasting and facilitate proactive risk management.

CHAPTER 7

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7.2 Appendix – I: Questionnaire Used for Primary Data Collection

Reverse Logistics Risk Assessment in Elevator Spare Parts Operations

This questionnaire is part of our academic research study to identify key operational risks in reverse logistics, repair, refurbishment, and spare parts management processes.

The responses will help prioritize risks and recommend improvements for future operations. All responses will be kept confidential and used only for academic purposes.

Estimated time: 7–10 minutes

The respondent's email (riyakadam38@gmail.com) was recorded on submission of this form.

Email *

riyakadam38@gmail.com

Phone Number *

.....

Current Functional Role *

- ☐ Engineering / Quality / Technical Support (Elevator systems or spare parts)
- ☒ Procurement / Strategic Sourcing (Spare parts, vendors, contracts)
- ☐ Warehouse / Stores / Logistics (Spare parts handling and dispatch)

INSTRUCTIONS

Please answer based on your practical experience.

Impact = Effect on downtime, service level, cost, or safety

Frequency = How often the issue occurs

Visibility = How early the issue is known (higher = harder to detect)

F1 – Testing / Refurbishment Delay

F1 – Impact: If testing or refurbishment takes longer than expected, what is the impact on operations?

- ☐ No noticeable impact
- ☐ Small delay, no service issue
- ☒ Service delay but manageable
- ☐ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F1 – Frequency: How often do testing or refurbishment delays occur?

- ☐ Almost never
- ☐ Once in a long time
- ☒ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F1 – Visibility: How early are such delays usually known?

- ☐ Always known in advance
- ☒ Mostly identified early
- ☐ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F2 – Visibility: Is the risk of part non-availability known in advance?

- ☐ Always known in advance
- ☐ Mostly identified early
- ☒ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F2 – Obsolete or Hard-to-Source Spare Parts

F2 – Impact: If required spare parts are unavailable or obsolete, what is the impact?

- ☐ No noticeable impact
- ☐ Small delays, no service issue
- ☐ Service delay but manageable
- ☒ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F3 – Incorrect Data / Mislabeling of Returned Parts

F3 – Impact: What is the impact of incorrect data or mislabeling of returned parts?

- ☐ No noticeable impact
- ☒ Small delay, no service issue
- ☐ Service delay but manageable
- ☐ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F2 – Frequency: How often does this situation occur?

- ☐ Almost never
- ☐ Once in a long time
- ☒ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F3 – Frequency: How often do data errors or mislabeling occur?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F3 – Visibility: How easily are such errors detected before repair or dispatch?

- ☐ Always known in advance
- ☐ Mostly identified early
- ☒ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F4 – Delay in Pickup of Defective Parts

F4 – Impact: How does delayed pickup affect downtime or service levels?

- ☐ No noticeable impact
- ☒ Small delay, no service issue
- ☐ Service delay but manageable
- ☐ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F4 – Frequency: How often are pickups delayed?

- ☐ Almost never
- ☐ Once in a long time
- ☒ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F4 – Visibility: Are pickup delays usually known in advance?

- ☐ Always known in advance
- ☐ Mostly identified early
- ☒ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F5 – Supplier Approval / Repair Authorization Delay

F5 – Impact: What is the impact when supplier approvals are delayed?

- ☐ No noticeable impact
- ☐ Small delay, no service issue
- ☒ Service delay but manageable
- ☐ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F5 – Frequency: How often do approval delays occur?

- ☐ Almost never
- ☐ Once in a long time
- ☒ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F5 – Visibility: Can approval delays be predicted early?

- ☐ Always known in advance
- ☒ Mostly identified early
- ☐ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F6 – Visibility: Are stockout risks identified before actual requirement?

- ☐ Always known in advance
- ☐ Mostly identified early
- ☐ Identified after some delay
- ☒ Identified very late
- ☐ Identified only after damage

F6 – Forecasting Errors Leading to Stockouts

F6 – Impact: What is the impact of stockouts of critical spare parts?

- ☐ No noticeable impact
- ☒ Small delay, no service issue
- ☐ Service delay but manageable
- ☐ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F7 – Incorrect Diagnosis During Inspection

F7 – Impact: How serious is the impact of incorrect inspection or diagnosis?

- ☐ No noticeable impact
- ☐ Small delay, no service issue
- ☒ Service delay but manageable
- ☐ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F7 – Frequency: How often does incorrect diagnosis occur?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F6 – Frequency: How often do such stockouts occur?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F7 – Visibility: How easily is incorrect diagnosis detected?

- ☐ Always known in advance
- ☐ Mostly identified early
- ☒ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F8 – Visibility: Is transport damage detected immediately on receipt?

- ☐ Always known in advance
- ☒ Mostly identified early
- ☐ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F8 – Damage During Transport of Returned Parts

F8 – Impact: What is the impact when returned parts are damaged during transport?

- ☐ No noticeable impact
- ☐ Small delay, no service issue
- ☒ Service delay but manageable
- ☐ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F9 – Incorrect Disposition Decision (Refurbish vs Scrap)

F9 – Impact: What is the impact of incorrect disposition decisions?

- ☐ No noticeable impact
- ☒ Small delay, no service issue
- ☐ Service delay but manageable
- ☐ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F8 – Frequency: How often does transport damage occur?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F9 – Frequency: How often do such incorrect decisions occur?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F9 – Visibility: How easily can wrong disposition decisions be identified?

- ☐ Always known in advance
- ☒ Mostly identified early
- ☐ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F10 – Visibility: Can emergency situations be anticipated early?

- ☐ Always known in advance
- ☐ Mostly identified early
- ☒ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F10 – High Emergency Procurement / Expedited Logistics Cost

F10 – Impact: How much do emergency procurement or expedited logistics costs affect expenses?

- ☐ No noticeable impact
- ☒ Small delay, no service issue
- ☐ Service delay but manageable
- ☐ Major delay, customer impact
- ☐ Complete stoppage / safety risk

Improvement Suggestion

From your role, what one improvement would most reduce downtime or delays in the reverse logistics or repair process?

F10 – Frequency: How often are emergency actions required?

- ☐ Almost never
- ☐ Once in a long time
- ☒ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

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Reverse Logistics Risk Assessment in Elevator Spare Parts Operations

This questionnaire is part of our academic research study to identify key operational risks in reverse logistics, repair, refurbishment, and spare parts management processes.

The responses will help prioritize risks and recommend improvements for future operations. All responses will be kept confidential and used only for academic purposes.

Estimated time: 7–10 minutes

The respondent's email (sujitpawar1396@gmail.com) was recorded on submission of this form.

Email *

sujitpawar1396@gmail.com

Phone Number *

[REDACTED]

Current Functional Role *

- ☐ Engineering / Quality / Technical Support (Elevator systems or spare parts)
- ☐ Procurement / Strategic Sourcing (Spare parts, vendors, contracts)
- ☒ Warehouse / Stores / Logistics (Spare parts handling and dispatch)

INSTRUCTIONS

Please answer based on your practical experience.

Impact = Effect on downtime, service level, cost, or safety

Frequency = How often the issue occurs

Visibility = How early the issue is known (higher = harder to detect)



F1 – Testing / Refurbishment Delay

F1 – Impact: If testing or refurbishment takes longer than expected, what is the impact on operations?

- ☐ No noticeable impact
- ☐ Small delay, no service issue
- ☐ Service delay but manageable
- ☒ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F2 – Obsolete or Hard-to-Source Spare Parts

F2 – Impact: If required spare parts are unavailable or obsolete, what is the impact?

- ☐ No noticeable impact
- ☐ Small delays, no service issue
- ☐ Service delay but manageable
- ☒ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F1 – Frequency: How often do testing or refurbishment delays occur?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F2 – Frequency: How often does this situation occur?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F1 – Visibility: How early are such delays usually known?

- ☐ Always known in advance
- ☒ Mostly identified early
- ☐ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F2 – Visibility: Is the risk of part non-availability known in advance?

- ☐ Always known in advance
- ☒ Mostly identified early
- ☐ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F3 – Incorrect Data / Mislabeling of Returned Parts

F3 – Impact: What is the impact of incorrect data or mislabeling of returned parts?

- ☐ No noticeable impact
- ☐ Small delay, no service issue
- ☐ Service delay but manageable
- ☒ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F3 – Frequency: How often do data errors or mislabeling occur?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F3 – Visibility: How easily are such errors detected before repair or dispatch?

- ☐ Always known in advance
- ☒ Mostly identified early
- ☐ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F4 – Delay in Pickup of Defective Parts

F4 – Impact: How does delayed pickup affect downtime or service levels?

- ☐ No noticeable impact
- ☐ Small delay, no service issue
- ☐ Service delay but manageable
- ☒ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F5 – Supplier Approval / Repair Authorization Delay

F5 – Impact: What is the impact when supplier approvals are delayed?

- ☐ No noticeable impact
- ☐ Small delay, no service issue
- ☐ Service delay but manageable
- ☒ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F4 – Frequency: How often are pickups delayed?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F5 – Frequency: How often do approval delays occur?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F4 – Visibility: Are pickup delays usually known in advance?

- ☒ Always known in advance
- ☐ Mostly identified early
- ☐ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F5 – Visibility: Can approval delays be predicted early?

- ☐ Always known in advance
- ☒ Mostly identified early
- ☐ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F6 – Forecasting Errors Leading to Stockouts

F6 – Impact: What is the impact of stockouts of critical spare parts?

- ☐ No noticeable impact
- ☐ Small delay, no service issue
- ☐ Service delay but manageable
- ☐ Major delay, customer impact
- ☒ Complete stoppage / safety risk

F7 – Incorrect Diagnosis During Inspection

F7 – Impact: How serious is the impact of incorrect inspection or diagnosis?

- ☐ No noticeable impact
- ☐ Small delay, no service issue
- ☐ Service delay but manageable
- ☒ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F6 – Frequency: How often do such stockouts occur?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F7 – Frequency: How often does incorrect diagnosis occur?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F6 – Visibility: Are stockout risks identified before actual requirement?

- ☒ Always known in advance
- ☐ Mostly identified early
- ☐ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F7 – Visibility: How easily is incorrect diagnosis detected?

- ☐ Always known in advance
- ☒ Mostly identified early
- ☐ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F8 – Damage During Transport of Returned Parts

F8 – Impact: What is the impact when returned parts are damaged during transport?

- ☐ No noticeable impact
- ☐ Small delay, no service issue
- ☐ Service delay but manageable
- ☒ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F9 – Incorrect Disposition Decision (Refurbish vs Scrap)

F9 – Impact: What is the impact of incorrect disposition decisions?

- ☐ No noticeable impact
- ☐ Small delay, no service issue
- ☐ Service delay but manageable
- ☐ Major delay, customer impact
- ☒ Complete stoppage / safety risk

F8 – Frequency: How often does transport damage occur?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F9 – Frequency: How often do such incorrect decisions occur?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F8 – Visibility: Is transport damage detected immediately on receipt?

- ☐ Always known in advance
- ☒ Mostly identified early
- ☐ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F9 – Visibility: How easily can wrong disposition decisions be identified?

- ☐ Always known in advance
- ☒ Mostly identified early
- ☐ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

F10 – High Emergency Procurement / Expedited Logistics Cost

F10 – Impact: How much do emergency procurement or expedited logistics costs affect expenses?

- ☐ No noticeable impact
- ☐ Small delay, no service issue
- ☐ Service delay but manageable
- ☒ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F10 – Frequency: How often are emergency actions required?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F10 – Visibility: Can emergency situations be anticipated early?

- ☐ Always known in advance
- ☒ Mostly identified early
- ☐ Identified after some delay
- ☐ Identified very late
- ☐ Identified only after damage

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3/28/25, 2:05 AM

Reverse Logistics Risk Assessment in Elevator Spare Parts Operations

Improvement Suggestion

From your role, what one improvement would most reduce downtime or delays in the reverse logistics or repair process?

Check parts availability, lead time, customer satisfaction level.

Reverse Logistics Risk Assessment in Elevator Spare Parts Operations

This questionnaire is part of our academic research study to identify key operational risks in reverse logistics, repair, refurbishment, and spare parts management processes.

The responses will help prioritize risks and recommend improvements for future operations. All responses will be kept confidential and used only for academic purposes.

Estimated time: 7–10 minutes

The respondent's email (rishabh.singh@schindler.com) was recorded on submission of this form.

Email *

rishabh.singh@schindler.com

Phone Number *

8657967260

Current Functional Role *

1 point

- ☒ Engineering / Quality / Technical Support (Elevator systems or spare parts)
- ☐ Procurement / Strategic Sourcing (Spare parts, vendors, contracts)
- ☐ Warehouse / Stores / Logistics (Spare parts handling and dispatch)

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- ☒ Service delay but manageable
- ☐ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F1 – Frequency: How often do testing or refurbishment delays occur?

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- ☐ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F1 – Visibility: How early are such delays usually known?

- ☐ Always known in advance
- ☒ Mostly identified early
- ☐ Identified after some delay
- ☐ Identified very late
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F2 – Obsolete or Hard-to-Source Spare Parts

F2 – Impact: If required spare parts are unavailable or obsolete, what is the impact?

- ☐ No noticeable impact
- ☐ Small delays, no service issue
- ☒ Service delay but manageable
- ☐ Major delay, customer impact
- ☐ Complete stoppage / safety risk

F2 – Frequency: How often does this situation occur?

- ☐ Almost never
- ☒ Once in a long time
- ☐ Happens sometimes
- ☐ Happens regularly
- ☐ Happens very often

F2 – Visibility: Is the risk of part non-availability known in advance?

- ☐ Always known in advance
- ☒ Mostly identified early
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- ☐ Identified very late
- ☐ Identified only after damage



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F3 – Impact: What is the impact of incorrect data or mislabeling of returned parts?

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F3 – Frequency: How often do data errors or mislabeling occur?

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2/28/25, 2:05 AM

Reverse Logistics Risk Assessment in Elevator Spare Parts Operations

Improvement Suggestion

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