

**STRATEGIC DECISION-MAKING MODELS
FOR DESIGNING THE REVERSE LOGISTICS
NETWORK OF A CELL PHONE
MANUFACTURER**

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I dedicate this thesis to my parents, teachers, and friends for their prayers, guidance, and unwavering support throughout this journey.

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THESIS ABSTRACT

NAME: Aamir Hussain
TITLE OF STUDY: Strategic Decision-Making Models for Designing the Reverse Logistics Network of a Cell Phone Manufacturer
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This thesis proposes a systematic approach for managing multi-type warranty returns in closed-loop supply chains (CLSC). The approach involves selecting a reverse logistics (RL) management system using the Analytical Hierarchy Process (AHP) and assessing investment cost uncertainty using Decision Tree Analysis (DTA). A multi-objective Mixed-Integer Linear Programming (MILP) model is then developed to design an RL network that optimizes cost, reduces cycle time, and enhances customer satisfaction, considering multi-type warranty demand and facilities. A case study of a Chinese mobile phone manufacturer demonstrates the approach's effectiveness. This study fills a literature gap by considering multi-type warranty demand in RL network design, examining the cost-customer satisfaction trade-off, and incorporating environmental impact reduction. Sensitivity analysis assesses the RL network's robustness, suggesting variations in facility opening recommendations based on demand probabilities. This thesis provides valuable insights for decision-makers in CLSC.

Keyword: Supply chain management (SCM), reverse logistics (RL), multi-criteria decision making (MCDM), analytical hierarchy process (AHP), decision tree analysis (DTA), mixed-integer linear programming (MILP), optimization, sustainability, facility location (FL), customer satisfaction (CS), scalability

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عنوان الدراسة: نماذج صنع القرار الاستراتيجي لتصميم شبكة الخدمات اللوجستية العكسية لمصنع الهاتف الخليوي

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تقترح هذه الأطروحة نهجاً منهجياً لإدارة عوائد الضمان متعددة الأنواع في سلاسل التوريد ذات الحلقة المغلقة . (CLSC) يتضمن النهج اختيار نظام إدارة لوجستية عكسية (RL) باستخدام عملية التسلسل الهرمي التحليلي (AHP) وتقييم عدم اليقين في تكلفة الاستثمار باستخدام تحليل شجرة القرار . (DTA) ثم يتم تطوير نموذج البرمجة الخطية الصحيحة المختلطة متعددة الأهداف (MILP) لتصميم شبكة RL تعمل على تحسين التكلفة وتقليل وقت الدورة وتعزيز رضا العملاء ، مع مراعاة طلب الضمان متعدد الأنواع والمرافق . وتوضح دراسة حالة إفرادية لمصنع صيني للهواتف المحمولة فعالية هذا النهج. تملأ هذه الدراسة فجوة في الأدبيات من خلال النظر في طلب الضمان متعدد الأنواع في تصميم شبكة RL ، وفحص المفاضلة بين التكلفة ورضا العملاء ، ودمج الحد من التأثير البيئي . يقيم تحليل الحساسية متانة شبكة RL ، مما يشير إلى اختلافات في توصيات افتتاح المنشأة بناءً على احتمالات الطلب . تقدم هذه الأطروحة رؤى قيمة لصانعي القرار في CLSC .

CHAPTER 1

INTRODUCTION

1.1 Supply chain management

In today's globalized and competitive business environment, effective supply chain management (SCM) is crucial for companies to remain competitive. Conventional supply chains prioritize forward logistics, but closed-loop supply chains (CLSC) integrate both forward and reverse logistics, enabling value recovery from used products and promoting sustainability and efficiency [1]. CLSC reduces waste, conserves resources, and achieves sustainability by strategically designing the RL network, closing the loop, and creating a more environmentally conscious supply chain [2], [3].

Implementing CLSC yields economic benefits, including increased efficiency and enhanced customer value, while reducing environmental impacts, specifically carbon emissions, thereby contributing to sustainable development [4]. Reverse logistics (RL) is crucial for driving change towards sustainability and operational efficiency, yielding significant environmental and resource-sharing benefits [5].

In addition to the importance of CLSC and RL, there are three key considerations

that companies must prioritize: environmental considerations, customer satisfaction, and cost optimization.

1.1.1 Environmental consideration

Effective management of diverse returns (end-of-life, end-of-use, and warranty returns) is critical to prevent landfill disposal and promote sustainable resource utilization. Designing a RL network enables efficient handling of returns, refurbishment processes, and conservation of natural resources. Remanufacturing and repair extend product life-cycles, reducing demand for primary resource extraction and minimizing environmental impacts [2], [6]. Moreover, the RL network optimizes transportation routes, resulting in additional carbon footprint reductions and contributing to a more environmentally friendly supply chain [1].

1.1.2 Customer satisfaction

Transparent and efficient RL network policies minimize customer inconvenience, enhance the customer satisfaction and loyalty [7]. The RL network encompasses not only product returns but also prompt resolution of related issues, particularly warranty-related concerns. Effective RL is vital for efficient warranty management, maintaining positive customer relationships, and ensuring long-term customer satisfaction [8]. Minimizing cycle time for refurbishment processes and return handling is also crucial, as it directly impacts customer satisfaction [7]. Companies that integrate environmental considerations into their vision and mission encourage customers to select sustainable products, aligning purchasing decisions with environmental sustainability [9].

1.1.3 Cost optimization

The RL network presents a strategic opportunity for cost reduction through the utilization of returned products, which can be refurbished with minimal energy and resource consumption [1]. By refurbishing these products for resale, companies can avoid disposal costs, divert items from landfills, reduce waste, and promote a more circular economy [10].

Considering the important factors, return management necessitates a robust RL network design, involving strategic facility allocation to meet forecasted demand [11], [12]. The strategic allocation of facilities with dedicated purposes is essential for the RL network design [13]. Product returns generally fall into three categories: warranty-related, end-of-use, and end-of-life, which may involve remanufacturing, recycling, resale, or disposal, thereby completing resource utilization and minimizing waste [14].

However, companies face challenges when managing RL systems, including transportation, handling, and processing costs [15], managerial and financial challenges [1], and a lack of strategic decisions and technical knowledge [16]. To overcome these challenges, companies must prioritize RL network design, facility allocation, and strategic decision-making to achieve sustainability and operational efficiency.

This case study investigates the challenges a cell phone company faces in managing warranty returns. Specifically, it focuses on selecting an optimal RL management structure and designing RL networks that balance cost, environmental, and customer satisfaction factors. In this study, a multi-objective, RL network design is formulated as a mixed-integer linear programming (MILP) model. This approach provides

valuable insights into the optimal location of facility types, the allocation of demand types, environmental considerations, cycle time, and inter-facility transportation. The findings of this study contribute to the development of effective warranty return management strategies that balance economic, environmental, and customer satisfaction objectives.

To address the first part of this study, configuring a RL network involves multiple objectives, criteria, and attributes, making it a challenging problem. Decision-making techniques can help select the optimal network by weighing these factors and identifying the best fit for an organization's needs. Researchers have employed various methods, including multi-objective optimization [17], fuzzy decision-making, and multi-criteria decision-making techniques like AHP [18] and TOPSIS, to balance economic, environmental, and social objectives and address uncertainty. Our literature review identifies a significant research gap in exploring the potential benefits of combining AHP and DTA for selecting the optimal RL management structure.

RL network design has been modeled using various techniques, including linear, nonlinear, mixed-integer linear programming (MILP), and mixed-integer nonlinear programming models, as seen in the literature [19]. The model's inclusion of binary decision variables for facility selection (i.e., selected or not) necessitates the use of MILP in this study. MILP is a powerful optimization technique renowned for its ability to model discrete decision variables, thereby enabling the identification of optimal facility location configurations [20].

Two primary solution approaches are utilized in addressing mathematical models in reverse logistics: heuristics and exact methods. Heuristics offer the advantage of

finding near-optimal solutions efficiently, making them particularly suited for large and complex network design problems, where computational efficiency is crucial [21]. Heuristic techniques such as genetic algorithms (GA) [22] and simulated annealing (SA) [11] are commonly utilized for solving reverse logistics problems. In contrast, exact solvers like GLPK [23], CPLEX [24], and Gurobi guarantees optimal solutions.

This approach achieves a balance between costs (including facility installation, refurbishing, transportation, and environmental costs) and minimizing cycle time, thereby ensuring customer satisfaction [7], [8], [9]. The RL model strategically integrates scalable facilities characterized by adaptable capacity and capability, providing a distinct advantage in navigating variability and accommodating multi-type demand.

1.2 Problem statement

A mobile phone manufacturing company receives customer returns for various reasons, including warranty returns, consumer complaints, and buyer’s remorse. This study focuses on warranty returns, which must be handled within a deadline and are categorized into function or appearance failure, and further graded into different types. Three types of product failures are considered: Type A (minor failures, e.g., minor software issues), Type B (major failures that are repairable, e.g., major software and hardware issues), and Type C (major failures that are non-repairable or not feasible to repair). Each type has dedicated facilities for handling, reflecting varying levels of complexity and repair requirements

To efficiently manage these returns, the company needs to establish facilities in

different cities to receive warranty products. The goal is to develop a decision-making framework that selects the optimal RL management structure (centralized or decentralized) and return channel (carrier or in-store), and designs an efficient multi-objective RL network that can handle graded demand and multiple return channels (same-channel and cross-channel). The selected RL structure will be configured to manage warranty claims, and the company must design an optimal RL network that minimizes cost, environmental impact, and cycle time while maximizing customer satisfaction. The aim is to develop a multi-objective RL network that balances these competing factors and ensures efficient handling of warranty returns.

1.3 Motivation

This research is motivated by the need to optimize warranty return management for electronics companies, enhancing customer satisfaction and loyalty while reducing costs and environmental impact. The study aims to develop a practical solution for selecting an optimal RL management system and designing an efficient RL network, thereby contributing to the advancement of sustainable and effective reverse logistics practices in the industry.

1.4 Objectives

1. To strategically configure the optimal RL network structure (centralized or decentralized) and return channel (carrier or in-store) for handling warranty returns.

2. To design an optimal RL network for an electronics company, the objectives are to minimize total costs—comprising fixed, transportation, and environmental costs—and also minimize the process cycle time, which depends on transportation, refurbishing, and target times.
3. To evaluate the impact of different demand scenarios on the RL network design and performance.

1.5 Contribution

In the first part of Chapter 2, this research makes a contribution to the field of RL by identifying the best RL network configuration for a multi-channel (courier and in-store) and multi-RL system (centralized and decentralized). The study employs AHP and DTA to evaluate and select the most suitable network structure, based on decision criteria identified and demonstrated based on a case study. In the second part of the thesis, Chapter 3, a novel RL network model is designed to incorporate multi-type warranty returns and facility capacity/capability considerations. An optimization model is developed to strategically allocate facilities to locations based on their capacities and capabilities. Additionally, the model initiates inter-facility transportation when facilities exceed capacity or capability thresholds.

1.6 Thesis organization

This thesis is structured into four chapters. Chapter 2 provides a comprehensive literature review and explores RL strategies. Chapter 3 reviews the literature related to RL network design, presents a mathematical model, and discusses the experimentation, results, and sensitivity analysis for RL networks. Chapter 4 summarizes the conclusions, discusses the findings, and outlines future research directions.

CHAPTER 2

REVERSE LOGISTICS

NETWORK STRUCTURE

SELECTION USING DECISION

MAKING TECHNIQUES

2.1 Literature review

Traditionally, the flow of electronic products (EP) to the secondary market is referred to as forward logistics (FL). When an EP becomes non-functional, it enters the RL network. [25] explained the processes in the RL network which include, collection of the returned products, disassembly, recycling, and disposing of them based on their product value. [26] added, that FL included the flow of EP from raw material collection to manufacturing, distribution, use, and reuse.

Usually, RL focuses on the final condition of used products, it starts from the collection of used materials, followed by dismantling and decision-making on whether to re-manufacture, recycle, or dispose of the materials. [27] expanded on this approach by considering both the primary and secondary markets, where recycled and re-manufactured products can be sold at a lower price. After collecting the material from the scrap yard, [28] added more categories manufacturable parts, recyclable materials, non-recyclable but reusable materials, and useless materials.

The methods of customer return and receiving in an RL network are the key to meeting the network objectives. [29] Designed a policy for customer returns which are either collected by a courier or returned to the physical stores and how the retailer manages these returns.

In their classification of product returns, [30] classified them into subcategories including small use, just-opened packaging, performance, and remorse. They discovered that time value decay and new return criteria are the main forces behind RL network configuration. [31] evaluates the effectiveness of a dual-channel retailer's BOPS (buy online, pickup in-store) strategy choice by taking into account a variety of costs, including delivery, shopping trip, operational, transaction, marketing, and employee costs.

Generally, the configuration of an RL network is a challenging management task, as it requires the consideration of single or multiple objectives, multiple criteria, and attributes. Decision-making techniques can be used to select the optimal network by assessing the importance of these factors and by identifying the network that best meets the organization's needs. [17] used multi-objective optimization, fuzzy

decision-making, and MILP to find solutions that balance economic, environmental, and social objectives, and deal with uncertainty in the constraints. Multi-criteria decision-making techniques like AHP and TOPSIS have been widely used in supply chain network problems with multiple criteria and alternatives. [18] proposed a theoretical model for the automotive industry by using price, quality, delivery, and service as criteria and AHP and quality function deployment (QFD) as decision-making techniques to select the third party for a cost-effective supply chain. Using the same criteria as [18], [17] solved a multi-criteria supplier selection problem using AHP, to reduce the overall cost. Moreover, the use of Fuzzy AHP in RL can help to improve the accuracy and robustness of decision-making, by allowing for the incorporation of subjective or uncertain information and by providing a structured and systematic approach to evaluating complex issues. [32], using a hybrid approach combining interpretive structure modeling and fuzzy TOPSIS to select third-party RL.

2.2 RL strategies

This section introduces the assumptions, notations, and formulations that are essential for computing the average costs for the various RL network configurations addressed by this study.

2.2.1 Assumptions

The stakeholders of the supply chain department believe that these assumptions are reasonable and will allow them to select the optimal strategic RL network design for

their company.

1. In a decentralized RL network, the retail store can also decide on warranty claims, unlike a centralized RL network where only the company makes the decisions.
2. In a decentralized RL network, customers can only communicate with retail stores, while in a centralized RL network, customers can communicate with both retail stores and the company.
3. All products returned under warranty have actual problems that fall under the company warranty policy.
4. No refund will be issued for customer defect type C. The returned product will be disposed of and will be replaced by a new product.
5. For the centralized and decentralized RL network, the in-store shipment cost is the same.
6. The in-store shipment cost is less than the courier shipment cost.
7. In a decentralized RL network, warranty claims associated with type A defects will be managed directly by the retail store, while claims related to other defect types will be addressed by the company.

2.2.2 Notations

This notations list describes the variables and parameters used in our study on RL systems. They include descriptions of the types of systems (centralized or decentral-

ized), the different channels for returning and receiving products (courier or in-store), and the activities that take place at the company or retail store. It also includes the different processing and transportation cost elements of the model. Other variables include the different return types and their probabilities.

Table 2.1: Table of notations

Symbol	Description
--------	-------------

Superscripts

s	Activities at stores.
f	Activities at the company.

Subscripts

c	Centralized RL system.
d	Decentralized RL system.
o	Return and receive through a courier.
p	Return and receive in-store.
op	Return courier and receive in-store.
po	Return in-store and receive through a courier.

Parameters

C_A^f	Unit cost to repair warranty claim of defect type A at the company.
C_A^s	Unit cost to repair warranty claim of defect type A at the store.
C_B^f	Unit cost to replace warranty claim of defect type B at the company.
C_C^f	Cost to replace warranty claim of defect type C.

C_{p23}	Total shipment cost between the store and the company using in-store.
C_{o13}	Total shipment cost between customer and company through a courier.
A_p^s	Per unit administration cost at the store using in-store.
A_p^f	Per Unit administration cost at the company using in-store.
A_o^f	Per unit administration cost at the company using a courier (For centralized RL network only).
q_A	The proportion warranty return with defect type A.
q_B	The proportion warranty return with defect type B.
q_C	The proportion warranty return with defect type C.

2.2.3 Strategies

In this study, centralized and decentralized RL networks will be considered. The decentralized RL network brings services closer to customers, whereas the centralized RL network has more decision-making power and lower costs. In the decentralized RL network system, the retail store is part of the system, and repairing the product can be done there, but for major repairs, the retail store will ship the product to the company. In the second system, the retail store serves only as a collection center, and the repairs are done at the factory. Next, we discuss the different possible RL supply chain configurations for the problem at hand.

Same channel decentralized (Scenario 1)

In Figure 1, customers, retail stores, and the company are connected through arrows, the solid arrow indicates the customer's return warranty claim, whereas the dotted arrow indicates the customer receives a warranty claim. According to this configuration, the customers visit the store to return and receive warranty products. After receiving the warranty claim, the store will decide on the product deposition. In the case of a type A defect, the store will handle the claim, otherwise, it will be shipped by the store to the company.

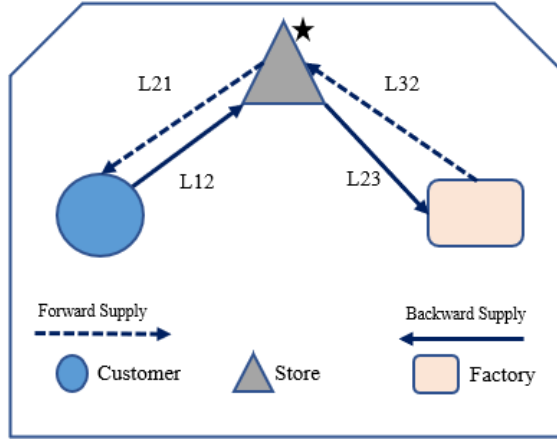


Figure 2.1: Figure of a decentralized RL network with in-store return and receive.

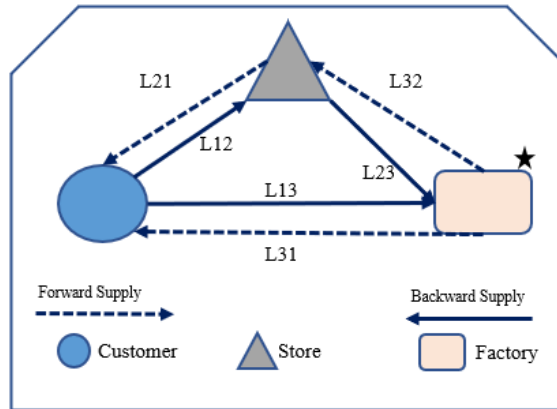


Figure 2.2: Figure of a centralized RL network with the same and cross-channel return and receive.

For handling defect A, the store representative will collect the claim and perform an administrative task, followed by the handling activity. For other defects, shipment is an additional activity. The expected per/unit cost is given in the Equation (2.1). The first, second, and third terms represent the expected administrative and transportation costs for type A, B, and C defects respectively.

$$\text{Expected cost (S}_1\text{)} = [(A_p^s + C_A^S)q_A + (A_p^f + C_{p23} \times 2 + C_B^f)q_B + (A_p^f + C_{p23} \times 2 + C_C^f)q_C] \quad (2.1)$$

The expected cost of warranty claims in a decentralized RL network during return and receive is calculated by summing the expected repairing or replacing, shipping, and administrative costs for each defect type.

Same channel centralized (Scenario 2)

In this scenario, the customer returns the product to the company and receives it through the same channel. The customer, using courier as an option to return and receive a warranty product, will choose the company as a destination. After receiving the warranty return through courier, the company makes the disposition decision, and according to the defect type, processing will be completed, and the customer will receive the warranty through a courier. Equation (2.2) provides the expected cost for

this scenario.

$$\begin{aligned} \text{Expected cost (S}_2\text{)} = & \left[(A_o^f + C_{o13} \times 2 + C_A^f)q_A + (A_o^f + C_{o13} \times 2 + C_B^f)q_B + (A_o^f + \right. \\ & \left. C_{o13} \times 2 + C_c^f)q_C \right] \end{aligned} \quad (2.2)$$

Same channel centralized (Scenario 3)

This scenario is similar to scenario 2 except that the customer can choose the in-store channel, where he visits a store for warranty return, In this scenario, the store is a collection center i.e. store will ship the warranty return and the company will make a disposition decision. The company will carry out the refurbishing processes and return the product to the store, where the customer receives the product.

$$\begin{aligned} \text{Expected cost (S}_3\text{)} = & \left[(A_p^f + C_{p23} \times 2 + C_A^f)q_A + (A_p^f + C_{p23} \times 2 + C_B^f)q_B + (A_p^f + \right. \\ & \left. C_{p23} \times 2 + C_C^f)q_C \right] \end{aligned} \quad (2.3)$$

The Equation (2.3) provides the expected cost of warranty claims for scenario 3.

Cross channel centralized (scenario 4)

In this scenario, the customer can return through a courier and receive in-store and vice versa. The company receives the claim through courier, and after administrative activities, the warranty product is handed over to the warranty department. Based

on the defect type, a refurbishing process occurs, the warranty product is returned to the retail store and the customer receives it in-store. Similarly, customers can use the opposite channel for the return and receiving of the warranty product.

$$\begin{aligned} \text{Expected cost } (S_4) = \frac{1}{2} & \left[(A_o^f + C_{o13} \times 2 + C_A^f)q_A + (A_o^f + C_{o13} \times 2 + C_B^f)q_B + (A_o^f + \right. \\ & C_{o13} \times 2 + C_C^f)q_C \left. \right] + (A_p^f + C_{p23} \times 2 + C_A^f)q_A + (A_p^f + C_{p23} \times 2 \\ & + C_B^f)q_B + (A_p^f + C_{p23} \times 2 + C_C^f)q_C \left. \right] \end{aligned} \quad (2.4)$$

The expected cost of handling warranty claims in a centralized RL network with cross-channel returns is calculated by taking the average of the expressions in Equations (2.2) and (2.3).

2.3 Case study

When configuring an RL network, it is important to consider the cost implications of the different types of returns. In our decentralized RL network, the administrative costs for replacing a defective product are higher compared to the centralized network. This is mainly due to the location of the retail store and the added cost of shipping the replacement part from the company's store. Type C warranty cost is higher than types A and B cost; this is due to the new product price and the added processing cost for disposing of the type C product. This leads to a higher administrative cost compared to the other defects. Courier shipment cost is higher than in-store. In in-store shipments, a vehicle that is returning to the company is typically used, while

special delivery is required for courier returns and receiving of the warranty product.

Based on the data, the total number of warranty returns amounts to 2280 units. The probability of occurrence of defect type A is 14.8%, while the probability of occurrence of defect type B is 82.5%. The probability of occurrence of defect type C is 2.7%. We assume that there is a 50% chance that the warranty rate will either increase or decrease by 20%. The cost of implementing and maintaining the RL system will either increase or decrease by 25%. These probabilities must be taken into consideration when deciding on the appropriate RL system for the company. Using Equations (1-4), Table 2.2 lists the estimated costs for scenarios (1-4).

Table 2.2: Table of total cost for RL network configuration

Strategies	Expected per-unit-cost (\$)
Same channel decentralized (Scenario 1)	18.872
Same channel centralized (Scenario 2)	18.898
Same channel centralized (Scenario 3)	25.298
Cross channel centralized (Scenario 4)	22.098

The AHP method was used to compare the different RL network configurations considering the following criteria;

1. Cost: The cost of implementing and maintaining the strategy.
2. Customer satisfaction: The level of satisfaction that customers will experience.
3. Environmental impact: The effect of the strategy considering environmental impact.
4. Efficacy: The effectiveness of the strategy in achieving its objectives.

This helps the company make informed decisions that aim to find the best balance between the aforementioned criteria. In the stakeholder meeting, weights were systematically assigned to the aforementioned criteria. Table 2.3 lists the normalized average weight for each criterion following the pairwise matrix evaluation process.

Table 2.3: Table of selected criteria weights

Cost	Efficacy	Customer satisfaction	Environmental impact
0.46	0.07	0.16	0.31

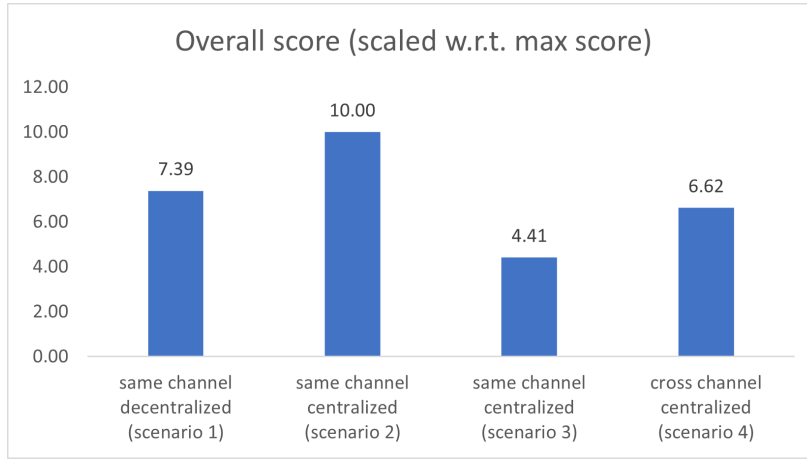


Figure 2.3: Figure of overall score

Figure 2.3 shows the overall score based on AHP results, the same channel centralized (Scenario 2) has the highest overall score, followed by the same channel decentralized (Scenario 1), the cross channel centralized (Scenario 4), and the same channel centralized (Scenario 3). This suggests that the same channel centralized (Scenario 2) is the most preferred option, followed by the same channel decentralized (Scenario 1) and the cross channel centralized (Scenario 4). The same channel centralized (Scenario 3) has the lowest overall score based on the evaluation using AHP. This is due to the high transportation cost and higher environmental impact compared to the other options. However, it does have a higher level of customer satisfaction. When

considering the decision for the RL network, it is important to consider all factors and their relative importance to the company's objectives. After selecting the best scenario using AHP, uncertainty in both cost and demand was addressed using DTA as explained in Fig 2.4 over three periods. Assuming a 0.25 probability of an increase or decrease in cost and demand for each period, the analysis considered the impact of uncertainty on future cash flows. Finally, the Net Present Value (NPV) calculation was employed to determine the present value of expected future cash flows, resulting in a value of \$143,534. This NPV calculation provides a key indicator of financial performance and investment potential.

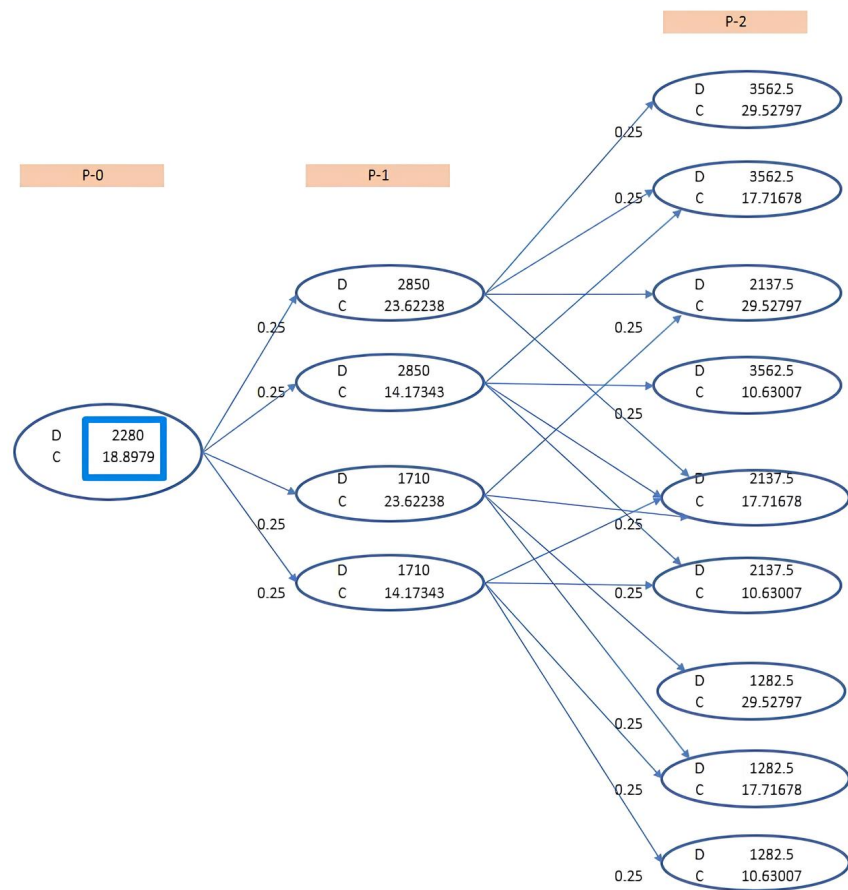


Figure 2.4: Figure of decision tree

CHAPTER 3

A NOVEL NETWORK APPROACH FOR WARRANTY REPAIR COVERAGE

3.1 Literature review

Forward logistics (FL) includes the flow of products from raw material collection to manufacturing, distribution, use, and reuse [26]. In contrast, reverse logistics (RL) focuses on the final condition of products, which starts with the collection of used products, followed by dismantling and decision-making on whether to re-manufacture, recycle, or dispose off them.

The variability in the rate and types of returns influences the company's decision to re-manufacture the product internally or externally. According to [33], remanufacturing is often considered a non-core process for highly variable products. Companies

may choose to outsource the re-manufacturing process to a third-party entity with the capabilities and capacity to handle all returned products. This decision is informed by the complexities and resource requirements emphasized by [34], [35] in their recommendations for selecting third-party reverse logistics providers. This study focuses on in-house refurbishing under company supervision, due to copyright concerns and the need to protect critical business information.

RL network design is complex, requiring consideration of various cost perspectives to ensure effectiveness. Understanding these costs is crucial for optimal RL network design. These costs include 1) fixed costs associated with facility construction, installation, or renting; 2) transportation costs related to product movement across echelons; 3) processing costs for refurbishing returned products; 4) carrying costs associated with holding and storing returned products; 5) grading costs connected to defect identification and segregation; and 6) disposal costs for non-repairable product disposal. Understanding these six key cost components (1-6) is crucial for effective RL network design, and Table 3.1 provides a summary of relevant studies in reverse logistics.

In reverse logistics network design, researchers have proposed various facility roles. For instance, initial collection centers for gathering returned products [36], remanufacturing units for handling returns [37], and combined collection, remanufacturing, and disposal centers [38] have been suggested. Other designs include initial and centralized collection points [39], and inspection, remanufacturing, and recycling centers for RL network optimization [28]. Strategic placement of collection, disassembly, and remanufacturing centers is crucial for robust optimization [41]. These variations are largely due to variability in product type, value, and return rate.

References	Fixed	Transportation	Processing	Carrying	Grading	Disposal	Others
[36]	Y	Y	N	Y	N	N	N
[37]	Y	Y	N	N	N	N	N
[38]	Y	N	N	N	N	N	N
[11]	Y	N	N	N	N	N	N
[39]	Y	Y	N	Y	N	N	N
[28]	Y	Y	Y	N	N	Y	N
[40]	Y	Y	Y	N	N	N	Procurement
[41]	N	Y	Y	Y	N	N	N
[42]	Y	Y	Y	N	N	N	N
[43]	Y	Y	Y	N	N	N	N
[44]	Y	Y	N	N	N	N	Expansion
[32]	Y	Y	Y	N	Y	N	N
[45]	Y	Y	Y	N	N	N	N
[46]	Y	Y	Y	N	N	N	Pooling ef- fect
[47]	Y	Y	Y	Y	N	N	N
[48]	Y	Y	Y	N	N	N	N
[27]	Y	Y	Y	N	Y	Y	N
[49]	Y	Y	Y	N	N	N	N
[50]	Y	Y	N	N	N	N	N
[51]	Y	Y	Y	N	N	N	Procurement
[52]	Y	Y	Y	Y	Y	N	Emissions
[40]	N	Y	N	N	N	N	N
[53]	Y	Y	Y	Y	N	Y	Emissions

Table 3.1: Table of cost considerations in supply chain model design literature

Traditionally, research in reverse logistics and supply chain network design has centered on single-objective optimization, prioritizing cost reduction or profit maximization. However, the growing emphasis on sustainability and social responsibility demands a multi-objective approach, which simultaneously considers cost minimization, environmental impact, customer satisfaction, and social welfare.

Recent studies [54], [49] highlight the importance of recycling, efficient disassembly processes, and responsible disposal of returned products to minimize environmental impacts and support sustainable practices. Furthermore, governments are now establishing and enforcing regulations to ensure a sustainable environment, adding legal imperatives to the growing environmental concerns and emphasizing the need for eco-friendly practices [55]. Effective demand fulfillment is also critical, ensuring efficient handling of returns and requests [32], [38], [43], [45], [56], [46]. Optimizing delivery times is a key objective in RL models, directly enhancing customer satisfaction [45]. Furthermore, allowing flexibility in return deadlines through the concept of tardiness can also improve the customer experience [57]. This study optimizes the reverse logistics network design by minimizing cycle time as the primary objective, while also ensuring demand fulfillment as a key constraint.

Heuristics and exact methodologies have been used to solve RL network design models. Simulated annealing (SA) has been applied to address problems in RL networks [11], while artificial immune systems (AIS) and genetic algorithms (GA) have been utilized to tackle challenges in RL networks [28].

For deterministic RL network design, CPLEX is the preferred solution method, as seen in studies [41], [40]. In deterministic closed-loop networks, researchers have

utilized different approaches, such as GA [42] and CPLEX [43], [44]. According to [58], exact methods like CPLEX are preferred for designing RL networks, as the long-term cost savings justify the additional computational time required.

This study contributes to the advancing field of RL by investigating the optimization of network design costs, including facility location, processing, grading, carbon cap, and transportation expenses, while minimizing the cycle time to maximize customer satisfaction. This research highlights the significance of taking a comprehensive approach to RL network design, which aligns business operations with sustainability and societal well-being. Specifically, this study addresses the literature gaps identified in Table 3.2, providing a thorough analysis of the existing knowledge and furthering the field of RL network design.

A Chinese mobile phone manufacturer operating in Pakistan is experiencing challenges with its warranty return system. The company offers a one-year warranty starting from the purchase date, during which customers can return defective products for repair or replacement. The current inefficient system generates excessive transportation-related CO_2 emissions and longer response times which ultimately leads to customer dissatisfaction. To address these challenges, the company needs a strategically optimized RL network design. This design should optimize facility locations and resource allocations, balancing multi-type demand, costs, and cycle time minimization, to achieve efficient warranty management.

Illustratively, warranty returns for cell phones are categorized into three groups.

1. Type A: minor failures (e.g. minor software issues)

References	Multi RLS	Multi- echelon	Multi- Channel	Warranty Returns	Customer Satisfaction	Case Study	Bill of Material	Sensitivity Analysis
[36]	N	Y	N	N	Y	N	N	Y
[37]	N	Y	N	N	N	Y	N	Y
[38]	N	Y	N	N	Y	Y	N	N
[11]	N	Y	N	N	N	N	N	N
[39]	N	Y	N	N	Y	Y	N	Y
[28]	N	Y	N	N	N	Y	N	N
[40]	N	Y	N	N	N	Y	Y	Y
[41]	N	Y	N	N	N	Y	Y	Y
[42]	N	Y	N	N	Y	Y	N	N
[43]	N	Y	N	N	Y	Y	N	Y
[44]	N	Y	N	N	Y	N	N	Y
[32]	N	Y	N	N	Y	Y	N	Y
[45]	N	Y	N	N	Y	Y	N	Y
[46]	N	Y	N	N	Y	N	N	N
[47]	N	Y	N	N	N	Y	N	N
[48]	N	Y	N	N	N	N	N	Y
[27]	N	Y	N	N	N	Y	Y	N
[49]	N	Y	Y	N	N	N	N	N
[50]	N	Y	N	N	N	Y	N	Y
[51]	N	Y	N	N	N	Y	N	Y
[52]	N	Y	N	N	N	Y	N	Y
[40]	N	Y	N	N	N	Y	N	N
[53]	N	Y	N	N	Y	Y	N	N
[54]	N	Y	N	N	Y	Y	N	Y
This study	N	Y	N	Y	Y	Y	N	Y

Table 3.2: Table of literature gap in supply chain network design

Warranty returned type	Minor service center	Major service center	Company
Type A	Y	Y	N
Type B	N	Y	N
Type C	N	N	Y

Table 3.3: Table of returned type capability matrix

2. Type B: major failures that are repairable (e.g. major software & hardware issues)
3. Type C: major failures that are non-repairable or not feasible to repair

Phones are graded into types A, B, and C based on their return condition. Unlike types B and C, type A is easily repairable, requiring less technical skill.

From the company’s perspective, warranty services comprise a range of activities, including transportation, shipping, refurbishment operations, and environmental expenses. Additionally, the company has established a service level agreement (SLA) for processing warranty claims, defined as the duration between the return and receipt dates, which serves as a key performance indicator for customer satisfaction.

This study proposes a multi-echelon facility network, comprising major and minor facilities with distinct capacities and capabilities to process various types of returns. Table 3.3 outlines the services offered by each facility type, based on their capabilities and capacities. When these capacities are exceeded, transportation to higher-echelon facilities is initiated. Both minor and major facilities operate independently, efficiently managing returns and ensuring seamless warranty service delivery

The facility location strategy takes into account varying fixed and transportation costs across different locations, while assuming the same process costs and refurbishment quality. This approach enables optimization of cost optimization and cycle time

Facilities distance matrix					
Facilities	j_1	j_2	j_3	$\dots$	J
j_1	d_{11}	d_{12}	d_{13}	$\dots$	d_{1L}
j_2	d_{21}	d_{22}	d_{23}	$\dots$	d_{2L}
j_3	d_{31}	d_{32}	d_{33}	$\dots$	d_{3L}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
J	d_{L1}	d_{L2}	d_{L3}	$\dots$	d_{LL}

Table 3.4: Table of an RL network transportation distance matrix

while maintaining SLA and ensuring efficient warranty management.

Table 3.4 $d_{\ell\ell}$ between facilities of type j at various locations, as well as between facilities and the company. This distance matrix is a crucial input for calculating transportation costs, optimizing routes, and informing location-based decisions in the RL network, supporting data-driven decision-making and network optimization.

3.1.1 Model assumptions

1. Products returned comply with the company's warranty policy.
2. Returned products are categorized (A, B, C) with varying refurbishing processes; facility types include minor service centers (for A), major repair centers (for A, B), and the company (for C).
3. A transportation system is in place among the facilities to refurbish returns, considering their respective capacities and capabilities.
4. Multiple customer zones with known demand are identified.
5. Customers are served by the nearest facility based on geographic location.

3.1.2 Notations

Sets

J : Set of facility types (e.g., $J = \{\text{minor service center, major repair center, company}\}$)

L : Set of all possible facility locations.

G : Set of return item grades ($G = \{A, B, C\}$), where A : Minor failures (e.g., minor software issues), B : Major failures that are repairable (e.g., major software & hardware issues) , and C : Major failures that are non-repairable or not feasible to repair

K : Set of customer locations

Indices

j, j' : Indices used to denote facility type ($j, j' \in J$), where j' : Facility where the item is initially returned. and j : Facility where the item is ultimately repaired or handled.

ℓ, ℓ' : Indices used to denote facility location ($\ell, \ell' \in L$).

g : Index used to denote return item grade ($g \in G$).

k : Index used to denote customer location ($k \in K$).

Superscripts

f : superscript for facility installation fixed cost.

r : superscript for refurbishing processes (associated with refurbishing costs and cycle time).

t : superscript for transshipment (associated with transshipment costs and cycle time).

e : superscript for expected or targeted cycle time.

Input Parameters

$C_{j\ell}^f$: Fixed cost of the locating facility type j in location ℓ .

C_g^r : Represents unit refurbishing cost of product returned type g , This cost is independent of facility type j and location ℓ .

$C_{\ell'\ell}^t$: The transportation cost of shipping warranty product from one facility type j' located at ℓ' to another facility type J located at ℓ . This cost is independent of warranty type g and facility type j .

C^d : Unit grading cost of warranty return products. This cost remains constant across facility types.

λ_{gk} : Expected product returns by the customers of type g in zone k .

Q_k : Total returns by the facility to the customer in zone k .

f_g : The fraction of the grade returns g . This is location-independent.

D : A square matrix, with $d_{\ell'\ell}$ elements, which captures distances between the facility types j at different locations ℓ .

$d_{\ell'\ell}$: The element representing the distance between facility type j' located at ℓ' and j located at ℓ .

$R_{j\ell}$: The capacity in hours of the facility j located in ℓ for return type g .

α : The cost priority factor for the RL network design (determines the importance of costs in the optimization process)

β : The cycle time priority factor for the RL network design (determines the importance of cycle time in the optimization process)

γ : The per-unit consumption of CO_2 during transportation.

t_g : The time required for refurbishing warranty returns.

Decision Variables

$X_{j\ell}$: The binary decision variable is equal to 1 if the facility of type j is opened in location ℓ ; 0 otherwise, where j varies based on the different capacity and capability.

$y_{gj'jk\ell'\ell}$: A decision variable that indicates the amount of the product returns type g from the customer zone k is handled by the facility type j at location ℓ through the facility type j' located in ℓ' .

3.1.3 Mathematical model

Minimize:

$$\begin{aligned}
Z = \alpha & \left[\sum_{j \in J} \sum_{\ell \in L} X_{j\ell} \times C_{j\ell}^f + \sum_{g \in G} \sum_{j' \in J} \sum_{j \in J} \sum_{k \in K} \sum_{\ell' \in L} \sum_{\ell \in L} y_{gj'jk\ell'\ell} \times C_g^r \right. \\
& + \sum_{g \in G} \sum_{j' \in J} \sum_{j \in J} \sum_{k \in K} \sum_{\ell' \in L} \sum_{\ell \in L} y_{gj'jk\ell'\ell} \times C_{\ell'\ell}^t \\
& \left. + \sum_{g \in G} \sum_{j' \in J} \sum_{j \in J} \sum_{k \in K} \sum_{\ell' \in L} \sum_{\ell \in L} y_{gj'jk\ell'\ell} \times C_{\ell'\ell}^t \cdot \gamma \right] \\
& + \beta \left[\sum_{g \in G} \sum_{j' \in J} \sum_{j \in J} \sum_{k \in K} \sum_{\ell' \in L} \sum_{\ell \in L} \max(t_g^r + t_{\ell'\ell}^t - t_{g\ell'\ell}^e, 0) \times y_{gj'jk\ell'\ell} \right] \quad (3.1)
\end{aligned}$$

Equation 3.1 comprises two main components: cost-related terms and cycle time-related terms. The first term represents the fixed cost of establishing a facility, which varies depending on the type of repair facility (minor service center or major service

center) and location. The next three terms account for the costs of refurbishing, transportation, and environmental impacts related to handling returned items. The final term calculates the difference between the expected cycle time and the combined refurbishing and transportation time, ensuring a non-negative value. The two sets of terms are weighted by α (cost factors) and β (cycle time factors).

A returned product is sent to a minor service center, which may or may not have the capacity and capability to refurbish it. If the facility (j' at ℓ') can be refurbished, only refurbishment costs and time are incurred. However, if it lacks the necessary capacity or capability, the model initiates resource sharing with another facility (j at ℓ), incurring additional transportation costs, environmental costs, and transportation time.

In this study, capacity refers to the physical resources available, specifically the number of workstations, each operating for 8 hours daily. Capability, on the other hand, refers to the technical expertise and skill set required to repair different types of returned products.

Single facility allocation constraint

$$\sum_{j \in J} X_{j\ell} \leq 1, \quad \forall \ell \in L \quad (3.2)$$

Equation 3.2 guarantees that each location ℓ is assigned no more than one facility type j , regardless of the facility type, to prevent multiple allocations to the same location.

Demand satisfaction constraint

$$\sum_{j' \in J} \sum_{j \in J} \sum_{\ell' \in L} \sum_{\ell \in L} y_{gj'jk\ell'\ell} = \lambda_{gk} \quad \forall g \in G, \forall k \in K, \quad (3.3)$$

Equation 3.3 ensures that customer demand is fully met, by allocating the total quantity of warranty returns to their nearest facilities, thereby satisfying the demand requirements.

Total conservation of the returned products

$$\sum_{g \in G} f_g \times \lambda_{gk} = Q_k \quad \forall k \in K, \quad (3.4)$$

Constraint 3.4 ensures that all products received at repair facility centers are refurbished and returned to their respective customers, maintaining a closed-loop process where every product is accounted for and returned to its original owner.

Capacity constraints

$$\sum_{g \in G} \sum_{j' \in J} \sum_{k \in K} \sum_{\ell' \in L} y_{gj'jk\ell'\ell} \times t_g \leq R_{j\ell} \times X_{j\ell} \quad \forall j \in J, \ell \in L \quad (3.5)$$

The operating hours of an opened facility type j in location ℓ are limited by its capacity, which is defined in terms of hours. This time-based representation assumes consistent processing times for all items, ignoring any variability. However, Constraint (3.5) can be modified to account for human factors by introducing t_g , a variable dependent on facility type j , to capture the impact of human factors on processing times.

Capability constraints

If product grade is 'C' and facility type is 'company', handling is allowed (non-negative):

$$y_{gj'jkl'l} \geq 0, \quad \forall g \in C, j = \text{'company'}, \quad \forall j' \in J, k \in K, l' \in L, l \in L$$

If product grade is 'A' and facility type is 'minor', handling is allowed (non-negative):

$$y_{gj'jkl'l} \geq 0, \quad \forall g = \text{'A'}, j = \text{'minor'}, \quad \forall j' \in J, k \in K, l' \in L, l \in L$$

If product grade is 'A' and 'B' and facility type is 'major', handling is allowed (non-negative):

$$y_{gj'jkl'l} \geq 0, \quad \forall g = \text{'A'}, \text{'B'}, j = \text{'major'}, \quad \forall j' \in J, k \in K, l' \in L, l \in L$$

In all other cases, handling is not allowed, and facility sharing will be initiated by the model:

$$y_{gj'jkl'l} = 0, \quad \forall g \in G, j \in J, \quad \forall j' \in J, k \in K, l' \in L, l \in L \quad (3.6)$$

Environmental constraint

$$\sum_{g \in G} \sum_{j' \in J} \sum_{j \in J} \sum_{k \in K} \sum_{l' \in L} \sum_{l \in L} y_{gj'jkl'l} \times C_{l'l}^t \cdot \gamma \leq C_{\text{cap}} \quad (3.7)$$

According to [59], carbon policies are integrated into the objective function, allocating a carbon cap to warranty return management. This cap sets the maximum carbon emissions allowed over the planning horizon. The study uses γ to represent the carbon emission percentage attributed to transportation costs, which must stay below the allocated cap to avoid penalty costs.

Company location constraint

The company, distinguished by its facility type, is already operational, thereby incurring zero fixed costs for opening. Furthermore, this facility type is exclusively

capable of addressing problem type C.

$$X_{j,\ell} = 1 \quad \forall j = \text{'company'}, \ell = \ell_1, \quad (3.8)$$

Binary and non-negative constraint

$$X_{j\ell} \in \{0, 1\} \quad \forall j \in J, \forall \ell \in L \quad (3.9)$$

Equation 3.9 defines a binary variable that indicates whether a facility type j at location ℓ is operational (1) or closed (0).

The non-negative integer constraint for $Y_{gj'jk\ell'\ell}$ is given by:

$$Y_{gj'jk\ell'\ell} \in \mathbb{Z}_+ \quad (3.10)$$

3.2 Model experimentation

This study applies the proposed RL network design model to a real-world scenario with a Chinese mobile phone manufacturer. The company, chosen for its extensive data, plans to implement the model in its Pakistani branch, providing a practical test of the model's effectiveness.

The current warranty return process, which relies on courier services, is costly, inefficient, and environmentally harmful. It leads to high costs, frequent customer complaints, and increased CO_2 emissions due to the use of individual couriers for each return, posing significant environmental concerns.

The company management is committed to resolving warranty return issues, recognizing their impact on customer satisfaction and environmental sustainability. They aim to efficiently manage returns, addressing customer needs across different regions.

The study divides customers into five zones (k1-k5) and allocates facilities based on capacity and capability to handle warranty returns. Returns are categorized into three types: minor software failures (A), repairable major failures (B), and non-repairable major failures (C). Out of 7.7 million mobile phone sales, the average warranty return rate is 0.05%. Type A returns account for 14.1%, Type B returns for 76.1%, and Type C returns for 9.8% of total warranty returns.

Facilities are structured based on their handling capabilities and capacities to ensure efficient management of warranty returns. Each workstation operates for 8 hours per day and is active for 26 days per month. Consequently, facilities are categorized as follows: minor facility centers, equipped with one workstation and a capacity of 208 hours per month, are designated for handling type A refurbishments; major facility centers, equipped with five workstations and a capacity of 1041 hours per month, can manage type A and B refurbishments; and the company, having four workstations and a capacity of 832 hours per month, exclusively handles type C warranty returns. The average refurbishment time for warranty returns remains consistent and independent of location. Refurbishment times vary by warranty return type: type A takes 1 hour, type B takes 1.5 hours, and type C takes 2 hours. Transportation time varies based on facility location distances. The company has an SLA that commits to a specific time frame for handling returned products. The net time, which is the difference between actual handling time (refurbishing and transportation) and targeted time, is always

	ℓ_1	ℓ_2	ℓ_3	ℓ_4	ℓ_5
ℓ_1	0.00	0.92	6.81	1.99	2.02
ℓ_2	0.92	0.00	7.53	3.18	1.75
ℓ_3	6.81	7.53	0.00	9.64	8.80
ℓ_4	1.99	3.18	9.64	0.00	1.12
ℓ_5	2.02	1.80	8.80	1.12	0.00

Table 3.5: Table of an RL network transportation cost matrix (\$)

non-negative. The Table 3.6 displays the transportation time in hours between various locations. The table provides a comprehensive overview of the time required to transport goods from one location to another, facilitating the planning and optimization of logistics operations.

The company currently handles warranty returns at location ℓ_1 . It can open one additional facility, either a minor or a major facility center, at each location ℓ . Facility centers (minor and major) receive and categorize warranty returns. Transportation decisions are then made based on the return type. Transportation costs vary depending on the distance between facilities, with per-unit costs listed in Table 3.5 for different facility locations.

The fixed costs for opening facility centers at five locations (ℓ_1 to ℓ_5) vary depending on the location, capacity, and capability of each facility. For major facility centers, the estimated facility opening costs are \$31,000 at ℓ_1 , \$27,000 at ℓ_2 , \$34,500 at ℓ_3 , \$28,000 at ℓ_4 , and \$31,500 at ℓ_5 . Meanwhile, minor facility centers have estimated opening costs of \$19,000 at ℓ_1 , \$22,000 at ℓ_2 , \$23,000 at ℓ_3 , \$21,000 at ℓ_4 , and \$21,000 at ℓ_5 . These variations in fixed costs are attributed to the location, capacity, and capability (skill required to handle the warranty return type) of each facility. The unit grading cost is \$5 across all locations and facility types. Refurbishing costs vary

	ℓ_1	ℓ_2	ℓ_3	ℓ_4	ℓ_5
ℓ_1	0.00	2.0	15.7	5.4	4.3
ℓ_2	2.0	0.00	17.3	6.3	4.5
ℓ_3	15.7	17.3	0.00	18.4	19.1
ℓ_4	5.4	6.3	18.4	0.00	2.4
ℓ_5	4.3	4.5	19.1	2.4	0.00

Table 3.6: Table of an RL network transportation time matrix (hr)

by warranty return type: \$15 for type A, \$30 for type B, and \$550 for type C, but remain consistent across locations and facility types.

The mathematical model (Section 3.1.3) was solved by using GLPK (version 5.0). To find an optimal solution, GLPK first employs the simplex algorithm to solve the LP relaxation of the problem. Then, due to the presence of integer variables, it utilizes a branch-and-bound method. This solution process was computationally efficient, exhibiting a near-negligible solution time on a 12th generation, core i7 with 12 [1.7 GHZ] cores and 16 GB RAM. The results are detailed in the following section.

3.3 Results

This study presents a multi-objective mixed-integer linear programming (MILP) model designed to optimize warranty return operations within a reverse logistics (RL) network. The model strategically minimizes costs associated with facility opening, refurbishment, transportation, and environmental expenses, while also reducing cycle time. The case company's experts have designated weights α and β for the purpose of this analysis. These weights enable the model to balance between minimizing costs α and maximizing customer satisfaction β by optimizing cycle time. Our analysis shows that the proposed model can efficiently handle the total demand of 3995 warranty

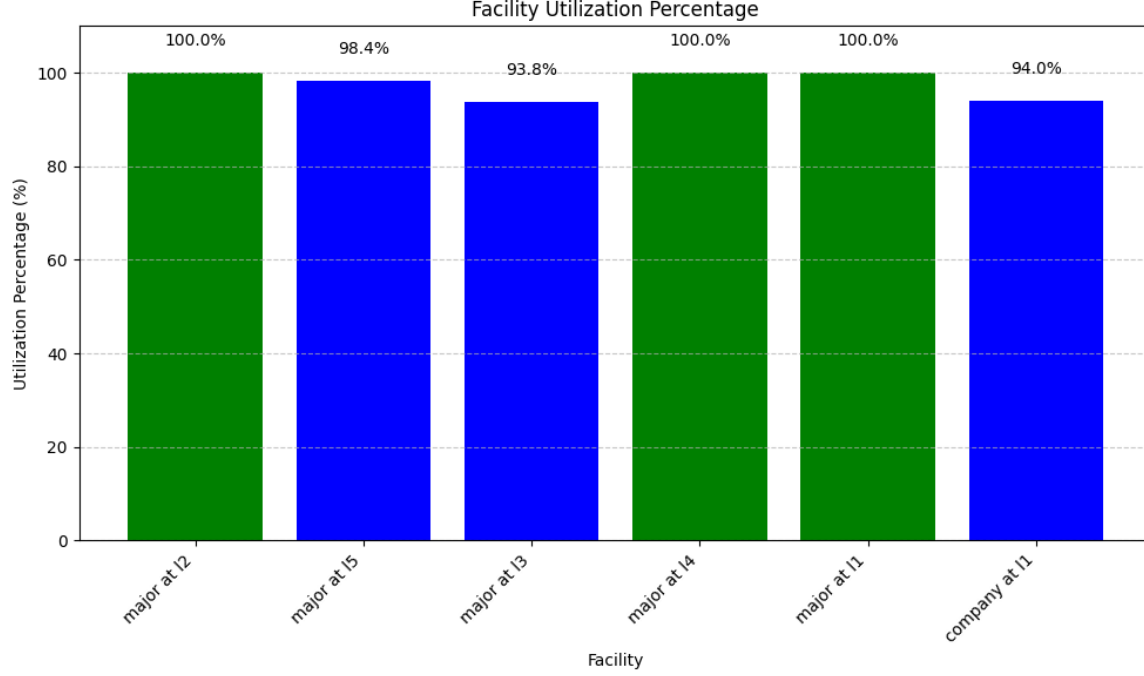


Figure 3.1: Figure of facility utilization

returns at a cost of \$0.255 million, demonstrating its cost-effectiveness. Moreover, the optimal solution achieves a total cycle time of 109,084 hours, highlighting the model's ability to optimize the RL network design while minimizing costs and total cycle time. Notably, the model identifies five major facilities for handling type A and B returns, complementing the existing company dedicated to type C returns. These findings contribute to the development of a more efficient and sustainable RL network, highlighting the potential of MILP modeling in optimizing warranty return operations.

The Figure 3.1 reveals that major facilities at ℓ_1 , ℓ_2 , and ℓ_4 are fully utilized, while facilities at ℓ_3 and ℓ_5 are underutilized. Additionally, the company located at ℓ_1 is underutilized. These findings indicate that demand can be rerouted from fully utilized facilities at ℓ_1 , ℓ_2 , and ℓ_4 to underutilized facilities at ℓ_3 and ℓ_5 .

To ensure demand satisfaction and enhance customer service satisfaction, the model incorporated flexibility for inter-facility product transportation. When demand exceeded individual facility capacity and/or capability, as depicted in Figure 3.2, a total of 1394 warranty returns were transported between facilities, incurring a transportation cost of \$2434. A significant proportion of warranty returns comprise type B products, accounting for 20% of the total type B received. This is attributed to their higher demand and the limited capacity of major service centers to handle them. In contrast, type A products constitute 68% of the total type A received, and can be handled by both major and minor service centers, resulting in minimal transportation requirements due to capacity constraints. Meanwhile, type C products make up 100% of the total type C received and always require transportation due to the lack of direct communication between customers and the company.

This study’s findings offer valuable insights for optimizing warranty return operations. By implementing a multi-objective MILP model, the company can design an efficient RL network that minimizes costs and cycle time while maximizing customer satisfaction. The model identifies suitable facilities, prioritizing major service centers for type A and B returns and utilizing minor service centers for type A returns when demand is high. The company can achieve a balance between cost and customer satisfaction by adjusting weights α and β . The MILP model’s ability to accommodate demand variations makes it a valuable tool for navigating uncertain demand scenarios. By adopting a data-driven approach, the company can make informed decisions and drive business success.

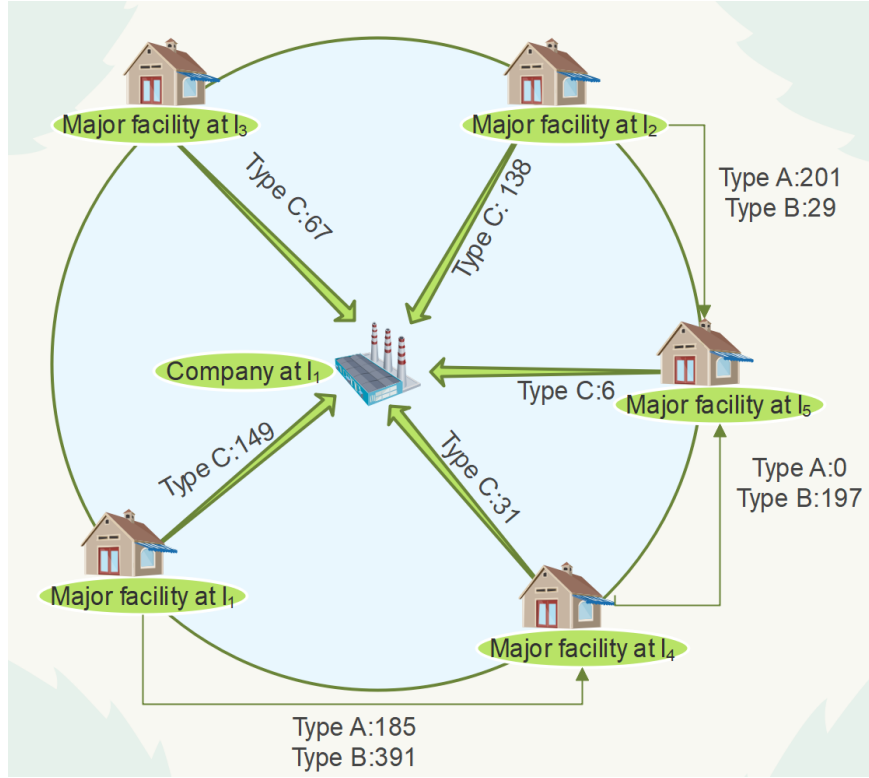


Figure 3.2: Figure of quantity transportation

3.4 Sensitivity analysis

The company's strategic decision to open a Reverse Logistics (RL) network for warranty return management requires a robust design phase. To address demand variability, this study conducts sensitivity analysis to test the network's performance under different demand scenarios, ensuring the optimal design parameters and adaptability to handle variations in demand data, and providing a reliable solution. Given that demand is always satisfied and capacity always met, Table 3.7 illustrates a series of scenarios, numbered from 1 to 36 with a step size of 0.1. The sum of probabilities for occurrences categorized as $P(A)+P(B)+P(C)=1$, no probability is less than 0.1. The objective function represents the RL network's total cost in million \$, while cycle time

is measured in hours for each scenario.

Table 3.7: Table of scenario analysis: Costs (\$ million (M)) and cycle time (hours)

Sc.No	P(A)	P(B)	P(C)	O.F (M)	CT (hour)	Sc.No	P(A)	P(B)	P(C)	O.F (M)	CT (hour)
1	0.1	0.1	0.8	\$1.00	427,301	19	0.3	0.4	0.3	\$0.46	196,491
2	0.1	0.2	0.7	\$0.91	387,918	20	0.3	0.5	0.2	\$0.37	156,749
3	0.1	0.3	0.6	\$0.79	338,375	21	0.3	0.6	0.1	\$0.25	105,107
4	0.1	0.4	0.5	\$0.70	300,052	22	0.4	0.1	0.5	\$0.68	291,698
5	0.1	0.5	0.4	\$0.59	250,966	23	0.4	0.2	0.4	\$0.57	243,888
6	0.1	0.6	0.3	\$0.47	203,088	24	0.4	0.3	0.3	\$0.46	195,171
7	0.1	0.7	0.2	\$0.38	163,145	25	0.4	0.4	0.2	\$0.36	155,428
8	0.1	0.8	0.1	\$0.26	110,967	26	0.4	0.5	0.1	\$0.24	103,282
9	0.2	0.1	0.7	\$0.89	382,638	27	0.5	0.1	0.4	\$0.56	240,232
10	0.2	0.2	0.6	\$0.78	334,892	28	0.5	0.2	0.3	\$0.45	193,846
11	0.2	0.3	0.5	\$0.69	295,569	29	0.5	0.3	0.2	\$0.35	150,261
12	0.2	0.4	0.4	\$0.58	249,653	30	0.5	0.4	0.1	\$0.24	101,920
13	0.2	0.5	0.3	\$0.47	201,710	31	0.6	0.1	0.3	\$0.45	190,944
14	0.2	0.6	0.2	\$0.37	158,073	32	0.6	0.2	0.2	\$0.35	148,900
15	0.2	0.7	0.1	\$0.26	109,641	33	0.6	0.3	0.1	\$0.23	100,583
16	0.3	0.1	0.6	\$0.78	333,214	34	0.7	0.1	0.2	\$0.34	144,610
17	0.3	0.2	0.5	\$0.69	293,892	35	0.7	0.2	0.1	\$0.23	96,806
18	0.3	0.3	0.4	\$0.57	246,183	36	0.8	0.1	0.1	\$0.22	94,943

In Figure 3.3, the X-axis represents the scenarios, as explained earlier in Table 3.7, and the Y-axis represents the percentage of the facility types opened, distinguished with different colors.

1. Sensitivity analysis reveals that opening more than 50% of company facilities is optimal when the probability of type C warranty returns ($P(C)$) exceeds 0.4, emphasizing the importance of robust company-level operations in managing high demand.

2. When $P(A)$ is low (scenarios 1 and 3), the minor service center remains closed.

However, the analysis emphasizes the need for at least one facility type to be

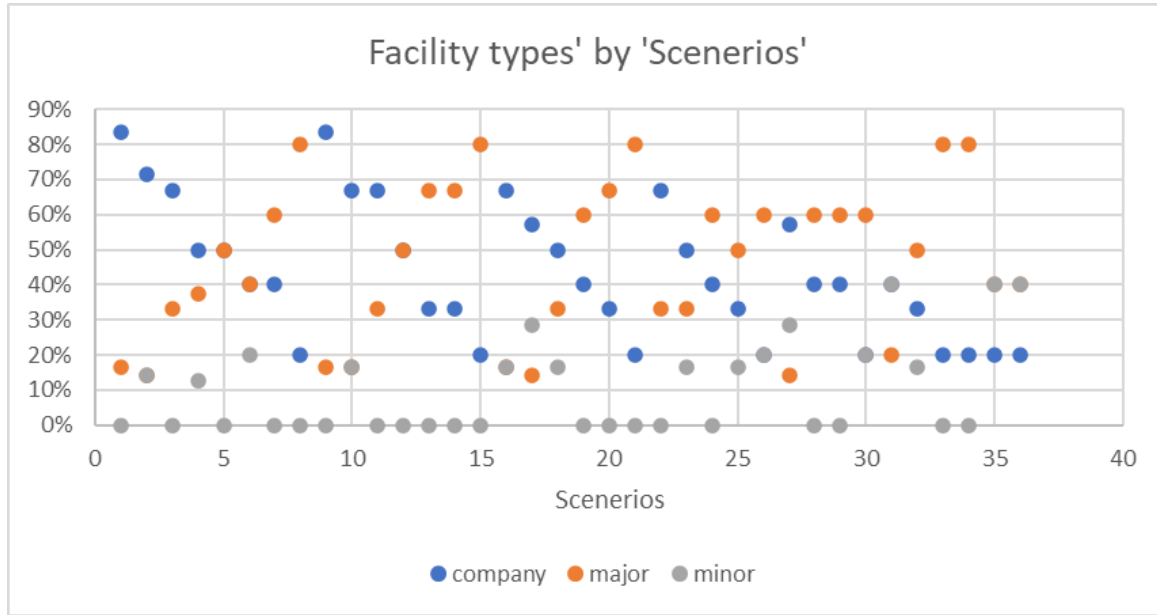


Figure 3.3: Figure of scenario analysis: facility allocation

operational, with a preference for opening major and company facilities to efficiently manage warranty returns.

3. The sensitivity analysis highlights the strategic importance of prioritizing major facilities over minor service centers, despite slightly higher facility-related costs. By prioritizing major facilities, costs (transportation, environmental) and cycle time are minimized, due to their higher capacity and capability.
4. Based on demand data, sensitivity analysis reveals distinct feasibility ranges for facility openings. To effectively manage Type C returns, the model mandates opening a minimum of 20% of company facilities, with a maximum of 83% to accommodate demand fluctuations with higher probabilities of Type C returns. Major facilities demonstrate adaptability, with a feasibility range of 14% to 80%, reflecting their capacity to handle both Type A and B returns. Minor service

centers, primarily focused on Type A returns, exhibit a narrower range of 0% to 40%.

Figure 3.4 shows a decreasing trend in costs and cycle time for the first seven scenarios, with a significant reduction in both metrics. This is primarily due to the decrease in type C products and the closure of company facilities with high fixed costs, which also have higher refurbishing costs and times. However, as type C products increase and more company facilities are installed, cycle time increases, leading to a temporary surge. Ultimately, the trend decreases again in the final scenarios as the percentage of type A increases, resulting in lower fixed cost facility installation and reduced cycle time.

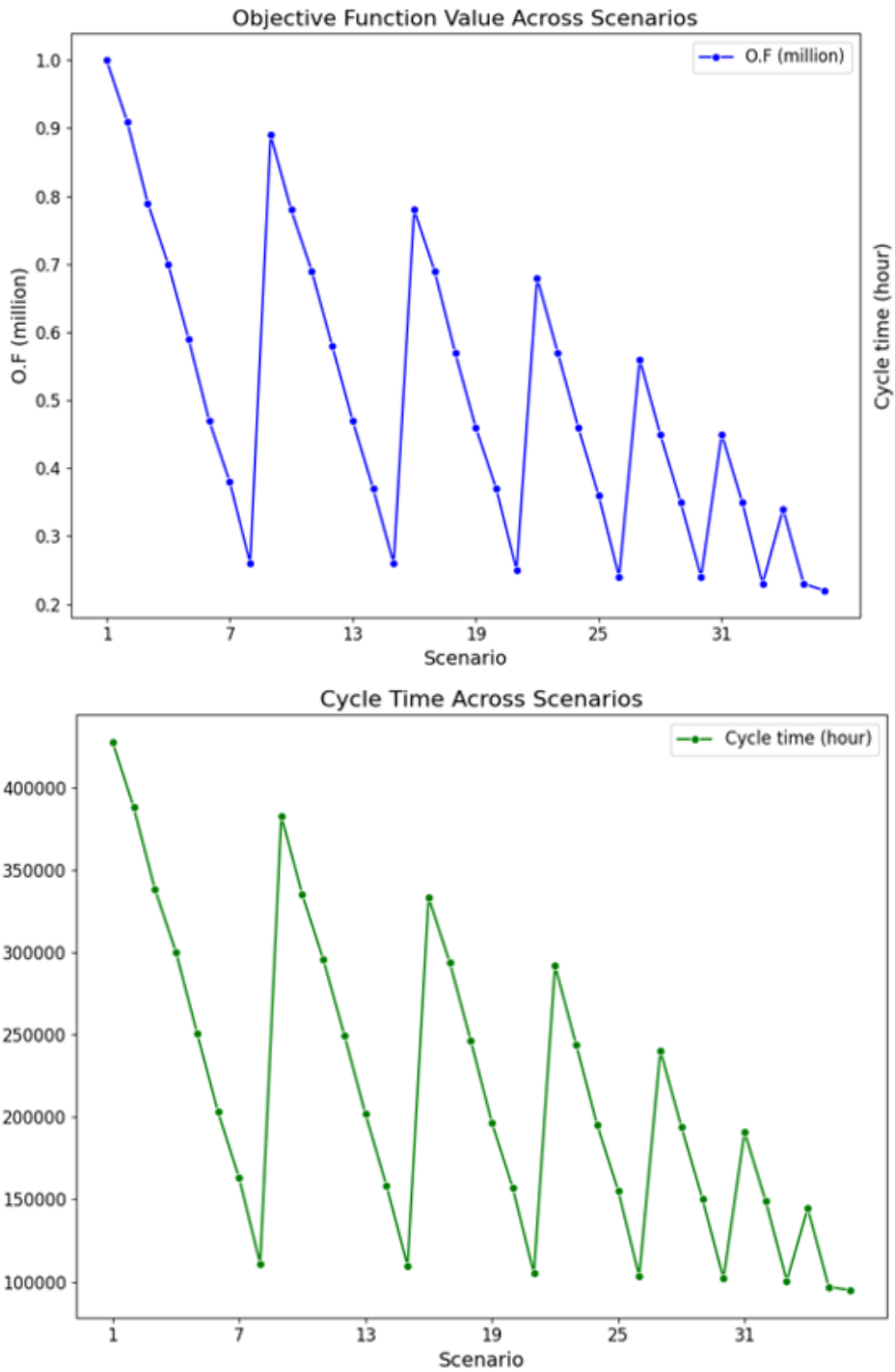


Figure 3.4: Figure of scenario analysis: impact on objective function

CHAPTER 4

CONCLUSION

This study has addressed the strategic-level design considerations involved in establishing an RLMS for an electronics company and selecting the best one. The methodology includes the AHP for comparing different return mechanisms. Additionally, DTA has been used to calculate the expected values of uncertain parameters in the AHP analysis.

Based on AHP results, the same channel centralized (Scenario 2) has the highest overall score, followed by the same channel decentralized (Scenario 1), the cross channel centralized (Scenario 4), and the same channel centralized (Scenario 3). This suggests that the same channel, centralized (Scenario 2), is the most preferred option, followed by the same channel decentralized (Scenario 1) and the cross channel centralized (Scenario 4). The same channel centralized (Scenario 3) has the lowest overall score based on the evaluation using AHP. This is due to the high transportation cost and higher impact on the environment compared to the other options. However, it does have a higher level of customer satisfaction. When considering the decision for the reverse logistics (RL) system, it is important to consider all factors and their

relative importance to the company's objectives.

Some managerial insights that may be useful for considering an RL network configuration include: An RL network can provide cost savings through reduced waste and improved resource efficiency, it can improve customer satisfaction by offering convenient and efficient return and repair options, and it can reduce environmental impact by reducing waste and improving resource efficiency. However, an RL network may require significant investments in infrastructure, such as transportation and repair facilities, and may also require changes to company processes and policies. It is important to carefully evaluate the feasibility of implementing an RL before committing to it. Finally, AHP can be used to compare different options for an RL based on a set of predefined criteria, such as cost, customer satisfaction, efficacy, and environmental impact. This can help the company choose the option that is most suitable for its needs and objectives. In making a strategic choice regarding the RL management system, it is imperative to comprehensively evaluate all relevant factors while considering their respective importance to the company's overarching objectives.

In order to provide the solution for the second part, this study presents a multi-objective mixed-integer linear programming (MILP) model designed to optimize warranty return operations within an RL network. The model strategically minimizes costs associated with facility opening, refurbishment, transportation, and environmental expenses, while also reducing cycle time. The case company's experts have designated weights α and β for the purpose of this analysis. These weights enable the model to strike a balance between minimizing costs α and maximizing customer satisfaction β by optimizing cycle time. Our analysis shows that the proposed model

can efficiently handle the total demand of 3995 warranty returns at a cost of \$0.255 million, demonstrating its cost-effectiveness. Moreover, the optimal solution achieves a total cycle time of 109,084 hours, highlighting the model's ability to optimize the RL network design while minimizing costs and total cycle time. Notably, the model identifies five major facilities for handling type A and B returns, complementing the existing company dedicated to type C returns. These findings contribute to the development of a more efficient and sustainable RL network, highlighting the potential of MILP modeling in optimizing warranty return operations.

The model accommodates variations in demand, a critical aspect of reverse logistics design. It facilitates inter-facility transportation to mitigate scenarios where demand surpasses the capacity and/or capability of a single facility.

Sensitivity analysis, conducted across diverse demand scenarios, establishes a foundation for determining the maximum number of facilities required to efficiently satisfy demand. The analysis recommends minor service centers when there's a substantial likelihood of type A returns. Major facilities emerge as a priority due to their capacity and capability to process type A and B returns, emphasizing their significance in streamlining operations. Where type C returns are highly probable, company facilities prove essential, highlighting their specialized function within the network.

4.1 Future research directions

1. Investigate how uncertainty in demand, supply, or other factors affects RL network performance and develop strategies to mitigate these effects.

2. Extend MILP models to accommodate multiple channels and investigate the impact on RL network efficiency and effectiveness.

REFERENCES

- [1] K. Govindan, H. Soleimani, and D. Kannan, “Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future,” *European Journal of operational research*, vol. 240, no. 3, pp. 603–626, 2015.
- [2] M. T. Islam and N. Huda, “Reverse logistics and closed-loop supply chain of waste electrical and electronic equipment (weee)/e-waste: A comprehensive literature review,” *Resources, Conservation and Recycling*, vol. 137, pp. 48–75, 2018.
- [3] V. D. R. Guide Jr and L. N. Van Wassenhove, “Or forum—the evolution of closed-loop supply chain research,” *Operations research*, vol. 57, no. 1, pp. 10–18, 2009.
- [4] N. Kazemi, N. M. Modak, and K. Govindan, “A review of reverse logistics and closed loop supply chain management studies published in ijpr: a bibliometric and content analysis,” *International Journal of Production Research*, vol. 57, no. 15-16, pp. 4937–4960, 2019.
- [5] H. Yu and W. D. Solvang, “A fuzzy-stochastic multi-objective model for sustainable planning of a closed-loop supply chain considering mixed uncertainty and network flexibility,” *Journal of Cleaner Production*, vol. 266, p. 121702, 2020.

- [6] F. Pulansari, D. S. Donoriyanto, and N. Masruroh, “Customer’s perception and expectation for reverse logistics implementation,” in *2016 Global Conference on Business, Management and Entrepreneurship*. Atlantis Press, 2016, pp. 208–211.
- [7] R. L. Trends, “Going backwards: Reverse logistics trends and practices,” 1998.
- [8] J. Stock, T. Speh, and H. Shear, “Managing product returns for competitive advantage,” *MIT Sloan management review*, vol. 48, no. 1, p. 57, 2006.
- [9] V. Jayaraman and Y. Luo, “Creating competitive advantages through new value creation: a reverse logistics perspective,” *Academy of management perspectives*, vol. 21, no. 2, pp. 56–73, 2007.
- [10] R. S. Tibben-Lembke, “Life after death: reverse logistics and the product life cycle,” *International Journal of Physical Distribution & Logistics Management*, vol. 32, no. 3, pp. 223–244, 2002.
- [11] M. S. Pishvaei, K. Kianfar, and B. Karimi, “Reverse logistics network design using simulated annealing,” *The International Journal of Advanced Manufacturing Technology*, vol. 47, pp. 269–281, 2010.
- [12] “Network design for reverse logistics,” *Omega*, vol. 36, no. 4, pp. 535–548, 2008.
- [13] A. Jakubovskis, “Strategic facility location, capacity acquisition, and technology choice decisions under demand uncertainty: Robust vs. non-robust optimization approaches,” *European Journal of Operational Research*, vol. 260, no. 3, pp. 1095–1104, 2017.

- [14] S. H. Amin, G. Zhang, and M. N. Eldali, “A review of closed-loop supply chain models,” *Journal of Data, Information and Management*, vol. 2, pp. 279–307, 2020.
- [15] J. R. Huscroft, B. T. Hazen, D. J. Hall, J. B. Skipper, and J. B. Hanna, “Reverse logistics: past research, current management issues, and future directions,” *The International Journal of Logistics Management*, vol. 24, no. 3, pp. 304–327, 2013.
- [16] S. Chung and C. Zhang, “An evaluation of legislative measures on electrical and electronic waste in the people’s republic of china,” *Waste management (New York, N.Y.)*, vol. 31, pp. 2638–46, 08 2011.
- [17] S. H. Amin and G. Zhang, “A multi-objective facility location model for closed-loop supply chain network under uncertain demand and return,” *Applied Mathematical Modelling*, vol. 37, no. 6, pp. 4165–4176, 2013.
- [18] D. Kannan, A. Diabat, and K. M. Shankar, “Analyzing the drivers of end-of-life tire management using interpretive structural modeling (ism),” *The International Journal of Advanced Manufacturing Technology*, vol. 72, no. 9-12, pp. 1603–1614, 2014.
- [19] S. Agrawal, R. K. Singh, and Q. Murtaza, “A literature review and perspectives in reverse logistics,” *Resources, Conservation, and Recycling*, vol. 97, pp. 76–92, 2015.
- [20] K. Govindan, H. Mina, A. Esmaili, and S. M. Gholami-Zanjani, “An integrated hybrid approach for circular supplier selection and closed loop supply chain net-

- work design under uncertainty,” *Journal of Cleaner Production*, vol. 242, p. 118317, 2020.
- [21] M. Zhalechian, R. Tavakkoli-Moghaddam, B. Zahiri, and M. Mohammadi, “Sustainable design of a closed-loop location-routing-inventory supply chain network under mixed uncertainty,” *Transportation research part E: logistics and transportation review*, vol. 89, pp. 182–214, 2016.
- [22] H. J. Ko and G. W. Evans, “A genetic algorithm-based heuristic for the dynamic integrated forward/reverse logistics network for 3pls,” *Computers & Operations Research*, vol. 34, no. 2, pp. 346–366, 2007.
- [23] E. S. Roudbari, S. F. Ghomi, and M. S. Sajadieh, “Reverse logistics network design for product reuse, remanufacturing, recycling and refurbishing under uncertainty,” *Journal of Manufacturing Systems*, vol. 60, pp. 473–486, 2021.
- [24] S. Ghayebloo, M. J. Tarokh, U. Venkatadri, and C. Diallo, “Developing a bi-objective model of the closed-loop supply chain network with green supplier selection and disassembly of products: The impact of parts reliability and product greenness on the recovery network,” *Journal of Manufacturing Systems*, vol. 36, pp. 76–86, 2015.
- [25] J. A. Stuart, M. K. Low, D. J. Williams, L. J. Turbini, and J. C. Ammons, “Challenges in determining electronics equipment take-back levels,” *IEEE Transactions on Components, Packaging, and Manufacturing Technology: Part C*, vol. 21, no. 3, pp. 225–232, 1998.

- [26] X. Zeng, J. Li, A. Stevels, and L. Liu, "Perspective of electronic waste management in china based on a legislation comparison between china and the eu," *Journal of Cleaner Production*, vol. 51, pp. 80–87, 2013.
- [27] S. T. John, R. Sridharan, and P. Ram Kumar, "Reverse logistics network design: a case of mobile phones and digital cameras," *The International Journal of Advanced Manufacturing Technology*, vol. 94, pp. 615–631, 2018.
- [28] M. Mahmoudzadeh, S. Mansour, and B. Karimi, "To develop a third-party reverse logistics network for end-of-life vehicles in iran," *Resources, Conservation, and Recycling*, vol. 78, pp. 1–14, 2013.
- [29] M. Radhi and G. Zhang, "Optimal cross-channel return policy in dual-channel retailing systems," *International Journal of Production Economics*, vol. 210, pp. 184–198, 2019.
- [30] V. D. R. Guide Jr, G. C. Souza, L. N. Van Wassenhove, and J. D. Blackburn, "Time value of commercial product returns," *Management Science*, vol. 52, no. 8, pp. 1200–1214, 2006.
- [31] P. Zhang, B. Xia, and V. Shi, "The dual-channel retailer's channel synergy strategy decision," *Journal of Theoretical and Applied Electronic Commerce Research*, vol. 16, no. 7, pp. 3184–3201, 2021.
- [32] M. S. Pishvaei, S. A. Torabi, and J. Razmi, "Credibility-based fuzzy mathematical programming model for green logistics design under uncertainty," *Computers & Industrial Engineering*, vol. 62, no. 2, pp. 624–632, 2012.

- [33] H. Yu and W. D. Solvang, “A general reverse logistics network design model for product reuse and recycling with environmental considerations,” *The International Journal of Advanced Manufacturing Technology*, vol. 87, pp. 2693–2711, 2016.
- [34] A. Jayant, P. Gupta, S. Garg, and M. Khan, “Topsis-ahp based approach for selection of reverse logistics service provider: a case study of mobile phone industry,” *Procedia engineering*, vol. 97, pp. 2147–2156, 2014.
- [35] M. Ferguson *et al.*, “Strategic and tactical aspects of closed-loop supply chains,” *Foundations and Trends® in Technology, Information and Operations Management*, vol. 3, no. 2, pp. 101–200, 2010.
- [36] H. Min, H. J. Ko, and C. S. Ko, “A genetic algorithm approach to developing the multi-echelon reverse logistics network for product returns,” *Omega*, vol. 34, no. 1, pp. 56–69, 2006.
- [37] D.-H. Lee and M. Dong, “A heuristic approach to logistics network design for end-of-lease computer products recovery,” *Transportation Research Part E: Logistics and Transportation Review*, vol. 44, no. 3, pp. 455–474, 2008.
- [38] Z. Lu and N. Bostel, “A facility location model for logistics systems including reverse flows: The case of remanufacturing activities,” *Computers & operations research*, vol. 34, no. 2, pp. 299–323, 2007.

- [39] A. Diabat, D. Kannan, M. Kaliyan, and D. Svetinovic, “An optimization model for product returns using genetic algorithms and artificial immune system,” *Resources, conservation and recycling*, vol. 74, pp. 156–169, 2013.
- [40] L. Q. Dat, D. T. T. Linh, S.-Y. Chou, and F. Y. Vincent, “Optimizing reverse logistic costs for recycling end-of-life electrical and electronic products,” *Expert systems with applications*, vol. 39, no. 7, pp. 6380–6387, 2012.
- [41] S. A. Alumur, S. Nickel, F. Saldanha-da Gama, and V. Verter, “Multi-period reverse logistics network design,” *European Journal of Operational Research*, vol. 220, no. 1, pp. 67–78, 2012.
- [42] H.-F. Wang and H.-W. Hsu, “A closed-loop logistic model with a spanning-tree based genetic algorithm,” *Computers & operations research*, vol. 37, no. 2, pp. 376–389, 2010.
- [43] N. Ö. Demirel and H. Gökçen, “A mixed integer programming model for re-manufacturing in reverse logistics environment,” *The International Journal of Advanced Manufacturing Technology*, vol. 39, pp. 1197–1206, 2008.
- [44] H. Min and H.-J. Ko, “The dynamic design of a reverse logistics network from the perspective of third-party logistics service providers,” *International Journal of Production Economics*, vol. 113, no. 1, pp. 176–192, 2008.
- [45] A. Mirakhorli, “Fuzzy multi-objective optimization for closed loop logistics network design in bread-producing industries,” *The International Journal of Advanced Manufacturing Technology*, vol. 70, pp. 349–362, 2014.

- [46] E. D. Santibanez-Gonzalez and A. Diabat, “Solving a reverse supply chain design problem by improved benders decomposition schemes,” *Computers & Industrial Engineering*, vol. 66, no. 4, pp. 889–898, 2013.
- [47] E. Roghanian and P. Pazhoreshfar, “An optimization model for reverse logistics network under stochastic environment by using genetic algorithm,” *Journal of Manufacturing Systems*, vol. 33, no. 3, pp. 348–356, 2014.
- [48] S. M. Hatefi, F. Jolai, S. A. Torabi, and R. Tavakkoli-Moghaddam, “A credibility-constrained programming for reliable forward–reverse logistics network design under uncertainty and facility disruptions,” *International Journal of Computer Integrated Manufacturing*, vol. 28, no. 6, pp. 664–678, 2015.
- [49] Y. Yun, A. Chuluunsukh, and M. Gen, “Sustainable closed-loop supply chain design problem: A hybrid genetic algorithm approach,” *Mathematics*, vol. 8, no. 1, p. 84, 2020.
- [50] N. Esmaili, E. Teimoury, and F. Pourmohammadi, “A scenario-based optimization model for planning and redesigning the sale and after-sales services closed-loop supply chain,” *RAIRO-Operations Research*, vol. 55, pp. S2859–S2877, 2021.
- [51] M. Eslamipirharati, F. Jolai, and A. Aghsami, “A bi-objective two-stage stochastic optimization model for sustainable reverse supply chain network design under carbon tax policy and government subsidy considering product quality,” *Journal of Industrial and Production Engineering*, pp. 1–21, 2023.

- [52] K. Gharibi and S. Abdollahzadeh, “A mixed-integer linear programming approach for circular economy-led closed-loop supply chains in green reverse logistics network design under uncertainty,” *Journal of Enterprise Information Management*, 2021.
- [53] K. N. Reddy, A. Kumar, A. Choudhary, and T. E. Cheng, “Multi-period green reverse logistics network design: An improved benders-decomposition-based heuristic approach,” *European Journal of Operational Research*, vol. 303, no. 2, pp. 735–752, 2022.
- [54] S. Ahmadi and S. H. Amin, “An integrated chance-constrained stochastic model for a mobile phone closed-loop supply chain network with supplier selection,” *Journal of cleaner production*, vol. 226, pp. 988–1003, 2019.
- [55] K. Govindan and H. Soleimani, “A review of reverse logistics and closed-loop supply chains: a journal of cleaner production focus,” *Journal of cleaner production*, vol. 142, pp. 371–384, 2017.
- [56] H. Yu, X. Sun, W. D. Solvang, and X. Zhao, “Reverse logistics network design for effective management of medical waste in epidemic outbreaks: Insights from the coronavirus disease 2019 (covid-19) outbreak in wuhan (china),” *International journal of environmental research and public health*, vol. 17, no. 5, p. 1770, 2020.
- [57] F. Du and G. W. Evans, “A bi-objective reverse logistics network analysis for post-sale service,” *Computers & Operations Research*, vol. 35, no. 8, pp. 2617–2634, 2008.

- [58] S. Al-Shihabi and M. AIDURGAM, “Multi-objective optimization for the multi-mode finance-based project scheduling problem,” *Frontiers of Engineering Management*, vol. 7, pp. 223–237, 2020.
- [59] F. Mohammed, S. Z. Selim, A. Hassan, and M. N. Syed, “Multi-period planning of closed-loop supply chain with carbon policies under uncertainty,” *Transportation Research Part D: Transport and Environment*, vol. 51, pp. 146–172, 2017.

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