Optimizing Returnable Transport Item Repositioning in a Global Supply Chain

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ABSTRACT

The automotive industry is an exemplary leader in the use of returnable cases for the transportation of inbound freight. Their use reduces the need of expensive and expendable packing and contributes to lower greenhouse gas emissions. However, the utilization of returnable cases is hindered when there is high variability in demand and lead times that make the return process challenging. This imposes a network design challenge in which the flow must be analyzed and determined to guarantee delivery continuity. Focusing on this problem, this research deals with an expanded network that enables more possibilities for the transportation of returnable transport items. The results will measure the potential total costs reductions and the impact on greenhouse gas emissions that result from the new network design. With this motivation, we developed a series of single-objective mathematical models to obtain minimum costs and emissions targets. We then used goal programming on a bi-objective mixed-integer linear program to investigate the quantity and flows of returnable cases that minimized both costs and emissions targets obtained previously. The optimal solution is reached with a 3.4% decrease in costs, 1% increase in CO_2 emissions, and a 51% reduction in the use of expendable packing.

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1 INTRODUCTION

1.1 Motivation

Global warming is accelerating and making the planet hotter. In 2020, the global average temperature was about 1.2° Celsius above the pre-industrial (1850-1900) level. This change creates extreme weather conditions, and natural disasters are more likely to happen. The number of climate related disasters have doubled in the last 30 years, and economic losses have increased by more than 400% (World Meteorological Organization, 2021).

One of the main causes for this increase in temperature is the Greenhouse Gas (GHG) emissions. It has the effect of trapping heat in the atmosphere. Due to human activity, GHG in the atmosphere increased by 45% in the past 30 years (United States Environmental Protection Agency, n.d.). To deal with this issue at an international level, the Paris Agreement was adopted in 2015, in which countries that signed it promised to develop plans and actions to keep the global temperature rise in this century below 2° Celsius compared to pre-industrial levels and pursue efforts to limit the rise to 1.5° Celsius (United Nations, n.d.).

Climate change is also a problem for companies' supply chain management. In the past few decades, supply chains became more global and complex; should any disruption occur in a certain area, it may interrupt the entire supply chain flow of a company or industry. For example, in 2011, Thailand suffered from severe flooding. Various manufacturing plants in the disaster area were damaged, causing global supply shortages for several industries.

To carry on with sustainable development and growth, companies need to be responsible for the environment while increasing their profitability in business. Since passenger vehicles are one of the main contributors of GHG emissions, reducing GHG emissions is a high-interest topic among automotive companies, including the sponsor of this project, Nissan (Ritchie, 2020).

Nissan is a Japanese automotive company with headquarters based in Kanagawa Prefecture. It produces more than 4 million vehicles per year. Vehicles are produced in more than 20 countries with 131,461 employees globally. The company is conscious about the environment. One of its notable achievements is that they brought the world's first mass-produced electric vehicle to the market, the Nissan Leaf. In addition, Nissan set a policy called *Nissan Green Program (NGP)* to reduce GHG emissions within its reach. The program lists the following four points as key issues and challenges: 1) Climate Change / Carbon Neutrality; 2) Resource Dependency: No new material resource use; 3) Air Quality: Zero impact; 4) Water Scarcity: Zero stress.

Regarding the first objective, the company set a goal to achieve carbon-neutrality by 2050 (Nissan Motor Co., Ltd., n.d.). The objective of this research is to investigate a solution for Nissan to reduce GHG emissions. From a supply chain management perspective, a reduction of shipping can reduce the environmental impact as well as save packing costs (Katephap & Limnararat, 2017).

Sustainable supply chains can perform their basic functions, such as purchasing, manufacturing, and, while reducing or minimizing their impact on the environment (Hsu, Tan, & Zailani, 2016). is considered a crucial dimension for sustainable supply chains, not only due to the materials used to build them, but also for their function of protecting the product to avoid waste. One-use or expendable is, therefore, not an effective sustainable solution.

1.2 Problem Statement

A particular business function in Nissan, Aftersales, currently acquires a vast quantity of spare parts from different suppliers around the world and ships them inside expendable to the markets that demand them. Aftersales has particular constraints that hinder its ability to use returnable packing, but we are looking to redesign a specific segment of their international logistics network as a way of working around those constraints and enhance the use of returnable packing. In the following paragraphs, we will explain more about the Aftersales business function, its supply chain process, and its constraints on returnable packing.

To support the after-market needs, that is, the products and services that Nissan offers to clients that already possess one or more of their vehicles or products, there is an entire organizational branch within the company called Aftersales. Its structure mirrors that of the Manufacturing division in most ways, but there are fundamental differences between the two. While Manufacturing is more process- and cost-oriented in order to produce competitive vehicles, the Aftersales department focuses on a value proposition for the clients, based on spare parts sales, maintenance, recalls and car warranty.

The Aftersales supply chain's main objective is to deliver spare parts to dealers and customers. Spare parts are supplied in almost every case by either a Nissan Manufacturing plant or by a Nissan-certified supplier (most likely a current production parts supplier or a previous production parts supplier of out-of-market vehicles). The demand for a spare part begins when a new vehicle starts being sold and continues long after the production for that vehicle has ended, depending on the vehicle lifespan. Nevertheless, the spare parts demand is extremely uncertain and erratic compared to the manufacturing demand, which is most often tied to a stable production plan. In addition, whereas a production part is supplied to a few destinations such as manufacturing plants, spare parts need to reach every region in which a vehicle is sold. The combination of these two factors explains the added complexity in the Aftersales supply chain when compared to the manufacturing supply chain. This complexity makes transportation planning and utilization more challenging.

A particular challenge for the Aftersales supply chain is how to ship spare parts in an environmentally sound yet cost-effective way. Specifically, many spare parts are acquired in disposable packing since utilizing returnable packing in reverse logistics is most frequently found in large and stable operations. Only small quantities of spare parts are shipped in returnable cases called Returnable Transport Items (RTIs). In the case of Nissan Motor Co., Ltd., the use of RTIs is restricted to bilateral trading (only between two countries) in order to ensure the proper return flow.

Returnable packing is beneficial in two aspects: cost and environment. Despite requiring significant investments in the initial design and production, returnable cases can be used multiple times and can be repaired to extend their lifetime. In addition, since they require returns to origin, their use provides leverage for the procurement of transportation in terms of volume utilization and lanes contract negotiation. From the environmental perspective, RTIs significantly reduce the impact on the environment. Since they are durable and recyclable, RTIs can be used multiple times, thus minimizing the total number of cases a system requires to operate. The carbon footprint is lower due to the fewer quantities produced when compared to expendable packing, that has a high impact on emissions due to the widespread use of cardboard and wood. However, these benefits cannot always be captured if there is not a proper network design to support the use of RTIs. The drawback of returnable packing is that it needs to be transported back to the warehouse and then back to the manufacturer in a timely manner to support future deliveries; otherwise, there are increased risks of unfulfilled orders and additional packing and freight costs.

This capstone will develop a logistics network model that could support the replacement of disposable packing with returnable packing in a multilateral trading perspective, in order to reduce both costs and environmental impact. The research questions are: 1) How many RTI cases can be introduced? 2) What are the optimal flows for each lane?

2 LITERATURE REVIEW

Motivated to contribute with the company's sustainability efforts, our research aims to find a cost-effective way to introduce returnable packing in an international logistics network for an automotive company in its aftermarket division. Initially, the methodology proposed to answer this question is a network design problem. The literature review will focus on finding the foundations for a proper network design, returnable transport items, packing costs models, and closed-loop supply chains. First, a brief summary on automotive supply chains will be provided, followed by an analysis on returnable transport items and their importance as a supply chain initiative. Closed-loop supply chains are later discussed to provide context on supply chains that support the introduction of returnable transport items. Network design literature is introduced, as it is a possible methodology for the resolution of the company's problem, with the inclusion of packing and CO_2 emissions costs models as they may be necessary for any proposed model.

2.1 Automotive Supply Chain

An automotive manufacturer's supply chain can be considered highly complex. Since the market necessitates continuous product portfolio renovation, the industry is required to continually invest and renovate. Automakers have transferred the majority of the product development to their supplier network, specifically parts manufacturers. The majority of the suppliers tend to be close to the manufacturing sites, although a sizeable portion of the supply remains overseas. Companies can have several hundreds of parts suppliers for any manufacturing site. The logistics networks have intricate configurations, where truck, railway, ocean freight, and air transportation modes are carefully planned.

From a parts manufacturer perspective, there are two production instances, one being the production of original parts for an Original Equipment Manufacturer (OEM) such as car makers, and the second is the production for the spare parts market (Gomez, Noroña, & Marco, 2018), which they can channel through distributors or the OEMs themselves. OEMs classify parts manufacturers according to the stage in which they target their supply. Tier 1 suppliers are parts manufacturers that supply directly to the automaker, whereas Tier 2 and upper stream suppliers provide to their subsequent tier (Gomez, Noroña, & Marco, 2018). Parts manufacturers partly explain the complexity of the automotive supply chain, for any OEM can have several hundreds of them spread worldwide. For instance, there are more than 600 parts manufacturers for the automotive industry, of which 30% are Tier 1, solely in Mexico.

The aftermarket supply chain is also challenging due to the variability of the demand, often characterized by being intermittent and sparse, with sometimes lengthy periods of no demand (Andersson & Jonsson, 2018). The automotive aftermarket is composed of parts sales, warranties, and services businesses. There are five major stakeholder groups involved in this sector: parts manufacturers (OEMs or Tier-1 suppliers), parts distributors, workshops (dealers, centers, small garages, among others), intermediaries (insurances, leasing companies, among others), and end customers (Breitschwerdt, Cornet, Kempf, Michor, & Schmidt, 2017). Automakers tend to centralize the majority of the parts supply for this industry by leveraging their manufacturing procurement and extending it to the aftermarket. This way, consumers can acquire genuine spare parts, for they carry the automaker's logo and have the highest quality in the market, assured by the company. Other companies that do not supply directly to OEMs can obtain the license to produce and distribute spare parts for a lower price; however, in this case, these parts are not warranted by automakers. Even though genuine parts are more costly compared to their counterparts, the tendency indicates that automakers will be able to further expand aftermarket activities in the next five to ten years, making it fundamental to incorporate sustainable practices into its supply chain (Breitschwerdt, Cornet, Kempf, Michor, & Schmidt, 2017).

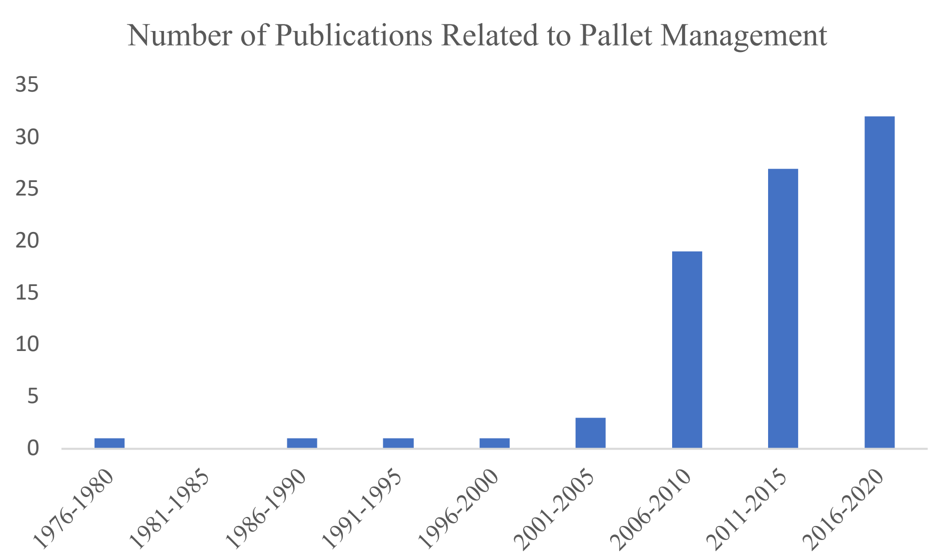
From a logistics perspective, there are many actors involved in an automotive supply chain. OEMs tend to outsource all their logistics needs to specialized transportation companies and then hire procurement specialists with profound knowledge of the complex interactions that occur in these intricate networks. To leverage the scale, automakers tend to negotiate global contracts with ocean carriers and freight forwarders in competitive bids. There are several components that build up the logistics costs in international transportation, which can be grouped into inland costs (in the country of origin), the port of export costs (handling fees and others), ocean freight costs, the port of import costs, and inland costs again (the country of destination). As will be discussed further, the introduction of returnable packing may involve additional freight transportation to relocate empty packing where it is required. Thus, these logistics costs need to be included in a cost analysis for this initiative.

2.2 Returnable Transport Items

Returnable transport items (RTIs) are reusable packing materials such as pallets, crates, and bottles. RTIs have been attracting attention in recent years as the interest to protect the environment increases. As depicted in Figure 1, the number of academic publications related to this topic increased from an average of 0.23 papers/year between 1976 and 2005 to an average of 5.2 papers/year since 2006 (Fabiana et al., 2021).

Figure 1

Number of Sampled Articles Published per Year



(Fabiana et al., 2021. Management and Logistics of Returnable Transport Items: A Review Analysis on the Pallet Supply Chain. Sustainability 13, 12747.)

Using RTIs can bring various benefits to companies, such as reducing CO_2 emissions. While expendable packing materials are disposed of after their use, RTIs are reutilized multiple times during their lifecycle and can therefore contribute to lower CO_2 emissions (Amienyo & Azapagic, 2016). As public awareness of sustainability issues continues growing, many companies are taking the initiative to protect the environment through different actions. RTI gained attention as one of the practical implementations to deal with the issue from an SCM perspective.

To consolidate the benefits of RTI implementation, Hellström & Johansson (2010) state that the choice of control strategy has a major impact on the investments and operating costs of an RTI system. A control strategy entails operational rules such as whether to use RTI for a single trip or a round trip, RTI handling policy, maintenance policies, etc. According to Christoph & Taebok (2015), shipment frequency influences the total number of RTI required in the system. Their research also points out that the size of RTIs has a significant impact on the efficiency of the system. When smaller RTIs are adopted, the transportation frequency increases along with the holding costs and repair costs.

Previous research has proven that the types of RTI to use and its operation policy impact the RTI introduction to the supply chain. This project should also define these points to take full advantage of RTIs.

2.3 Closed-Loop Supply Chains

Closed-loop supply chains (CLSC) incorporate reverse logistics to its already implemented forward logistics flow. Reverse logistics operations involve the activities necessary to recapture value or ensure the proper disposal of materials and products. Other operations that enable reverse logistics are reuse, repair, remanufacturing, and recycling. In most cases, the reverse process starts from the endpoint of the forward logistics supply chain – commonly the end-customers (Govindan, Soleimani, & Kannan, Devika, 2013). Companies that incorporate any of these functions need to ensure means for recuperating the materials and sending them to the origin nodes. The RTI implementation usually enforces the use of round trips, where the empty cases go back to origin in the same transport that delivered full cases. A number of idle RTIs is always required in these systems as a buffer.

The introduction of returnable packing aims to minimize the disposal of packing materials by introducing durable cases or containers that can be used for up to five years and are repairable. In addition, the materials used to build them can also be recycled at the end of life of the case. Introducing RTI redefines the company's aftermarket supply chain as a closed-loop supply chain, therefore explaining the importance of studying CLSC networks.

2.3.1 RTI Management in Closed-Loop Supply Chains

As mentioned in Section 2.2, RTIs are reusable, and it is possible to reduce packing costs when compared to expendable packing. However, there is a trade-off these two packing types as RTIs require return processes, which in turn involves additional operations and transportation costs. Thus, finding the optimal number of RTIs to introduce plays a key role in maximizing its benefits.

Soysal (2016) indicates that when finding the optimal total energy use (emissions), total driving time, total routing cost, total inventory cost, and total cost simultaneously in CLSC, the most environmentally friendly solution does not equal the most cost-effective solution. Soysal's research showed a nearly 7% decrease in total CO_2 emissions in return for a 59.7% total cost increase. Similarly, Biswajit et al. (2017) created a model and studied the impacts of transportation and carbon emissions costs in a CLSC. In the model, the manufacturer sends products to retailers, and the retailer collects used products and returns them to the manufacturer for remanufacturing. The result revealed that covering demand with remanufacturing will end up with a higher total cost compared to pure production with no remanufacturing. Although remanufacturing can reduce production costs, it incurs additional return transportation costs, accompanied by higher CO_2 emissions. In the study, the lowest total cost for the system was obtained with a hybrid policy of manufacturing and remanufacturing. The research shows the importance of considering transportation and CO_2 emissions costs in CLSC business cases.

Transportation lead time is also crucial to determine the optimal number of RTIs to introduce in the network. Taebok et al. (2014) pointed out if the RTI returns is stochastic and takes longer than the expected lead time, the receiver is more likely to be suffered from RTI shortage and will have to use expendables. Thus, uncertain return lead times constrain the introduction of RTIs.

2.3.2 RTI Inventory Policy

In order to utilize RTI, it is crucial to secure the placement of the required RTIs at any given site. Thus, inventory management is another critical operation for RTI management. There are some differences between a traditional supply chain where traditional flow is considered to be forward, linear, and non-complex, and a supply chain with reverse logistics. In a traditional supply chain, a sender can control supply, as it is mainly its production capacity that constrains it. However, in reverse logistics, the product returns to a sender as a partial substitute for regular supply. Uncertainties in return lead times, quantities, and the quality of product returns are commonly cited as major difficulties in reverse logistics (Fleischmann Minner, 2013). In addition, safety stock is another critical factor to consider in CLSC. Safety stock is a buffer that protects supply chains against backorder. The research of Christoph & Taebok (2016) also indicates the importance of using safety stock, especially in the case of high lead time uncertainty. According to their results, implementing RTI safety stock in combination with safety RTI return lead time outperforms where no safety measures are adopted.

As various entities are incorporated into a CLSC, controlling inventory levels gets more complicated. It is crucial to implement policies or systems for inventory control; therefore, an inventory review policy needs to be considered. Inventory review policies define the methods with which inventory will be monitored to ensure there will always be inventory available when needed. The research of Berman et al. (2012) suggests using a periodic review policy. Although this policy implies higher cost, its ease of implementation outweighs the marginal cost increase (less than 1%).

2.4 Network Design

The opportunity to replace expendable packing with RTI involves certain trade-offs that need to be considered, especially those discussed by Soysal's research (2016) in which a reduction in CO_2 emissions could only be achieved through higher costs. An optimization model for the network design may help determine the best solution to balance the possibly contradictory objectives.

Several authors proposed models to incorporate the sustainable dimension into the supply chain analysis. Fragoso & Figueira (2021) propose a multi-objective function that aims to maximize revenue and jobs created while minimizing total logistics costs and CO_2 emissions. Sahebjamnia et al (2018) perform a similar analysis in which they include economic, sustainable, and social dimensions into the model and propose metaheuristics algorithms to solve it.

Regarding the introduction of CO_2 emissions into the network design, the sponsoring company is not currently quantifying this information. Due to this lack of data, we found that Stojanovic et al. propose a model to quantify the cost of CO_2 emissions in international trade logistics (Stojanović, Ivetić, & Veličković, 2021).

2.5 Packing Cost Models

Since returnable packing is more expensive than expendable packing, its use is limited to supply networks that allow reverse logistics and therefore reuse. Because it is a necessary input to the network model, the cost of packing must be defined.

Akabane et al. (2018) define three types of packing costs: acquisition costs per year, replacement costs per year (understood as scrap or breakdown costs), and the increased logistics costs (the cost of the return flows). The first one, acquisition, is an attribute than applies to both expendable and returnable packing. The second and third costs are attributes that only apply to returnable packing. In the case of the logistics costs, the authors only included the difference in costs that emerged from the return flow of the returnable cases that the expendable cases did not present. The depreciation period considered was five years. No impact on handling costs is considered (Akabane, Pozo, & Galhardi, 2018).

Kathephap & Limnararat (2017) use a similar model to calculate total packing costs with different logistics arrangements. They define the total packing costs as the sum of the expendable packing costs, the depreciation costs for the returnable packing, the logistics costs (only incremental), and scrap costs. The logistics arrangements allow for a mix of both expendable and returnable packing. The difference with Akabane et al is the incorporation of the depreciation costs, which makes the model more precise. Although no impact on handling costs is considered, the authors emphasize that returnable packing requires additional handling efforts to prevent damage.

2.6 Conclusion

The RTI introduction is critical essential for the sustainable growth of the sponsoring company. The literature review shows that several factors are needed to be considered when introducing RTIs to a supply chain. Focusing on this, not only should the alternative packing costs be considered, but also additional costs, such as the costs of logistics return flow and CO_2 emissions. It is also important to identify the scope of the RTI introduction and define the RTI network within the closed-loop supply chain. To ensure a continuous operation in that network, inventory management at each depot is another critical area.

In the previous research, each of the topics above was studied separately. This study will create a network design model that focuses on the combined use of expendable and returnable packing in a closed-loop supply chain within multiple countries and propose a more practical solution to the sponsor company. Our model will also incorporate CO_2 emissions as a factor to minimize.

3 METHODOLOGY

In this chapter, a closed-loop supply chain model using RTIs and expendable packing for shipping is created to explore the opportunity to minimize the total logistics costs and CO_2 emissions.

As a first step, an overview of Nissan's trading network is discussed. Detailed operation process and trading conditions are studied by interviewing subject experts from Nissan. Following this, a series of mathematical models are formulated: single-period and single-objective, multi-period and single-objective models, and a multiple-period and bi-objective model. The models are increasingly complex in that order, and the reason for this is to start small and then scale as we validate our model and assumptions. The single-period, single-objective model represents the network as if it were only going to operate one period only and aims to minimize total logistics costs. The multiple-period, single objective adds time as a variable and is more representative of reality, given that it represents a continuous operation. A third model is created with the same constraints as the second model, but with a different objective function that aims to minimize CO_2 emissions. The fourth and final model, multi-period, bi-objective optimization model, is formulated to determine the optimal RTI introduction policy, where one objective function aims to minimize logistics and packing costs while the other aims to minimize CO_2 emissions. Each objective function and its weights are further explained.

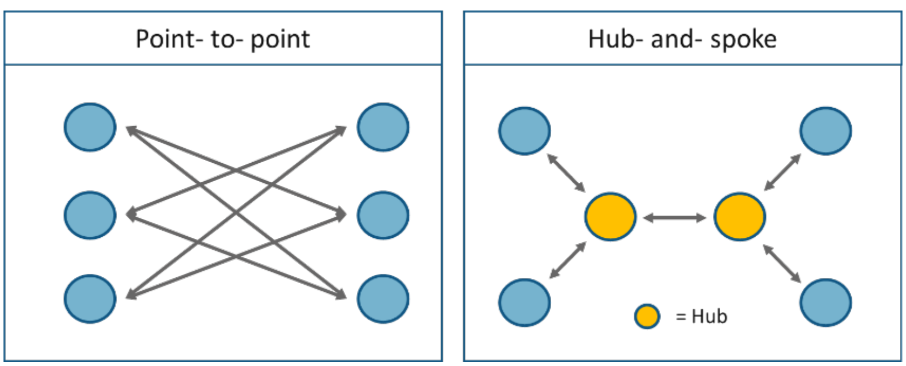
3.1 Network Conditions

3.1.1 Hub-and-Spoke System

Nissan's logistics network employs a hub-and-spoke system. In a hub-and-spoke system, some facilities serve as switching, transshipment, sorting, and distribution nodes, called hubs. Unlike the traditional point-to-point system, which directly connects shipper to destination, all shipments are gathered at hubs and transferred to another intermediate hub or final destination (see Figure 2). By consolidating items in the hubs, it is possible to reduce item handling and transportation cost per unit, since the network can take advantage of the scale economies of inter-hub connections (Camargo et al., 2009).

Figure 2

Point-to-Point and Hub-and-Spoke Network Models

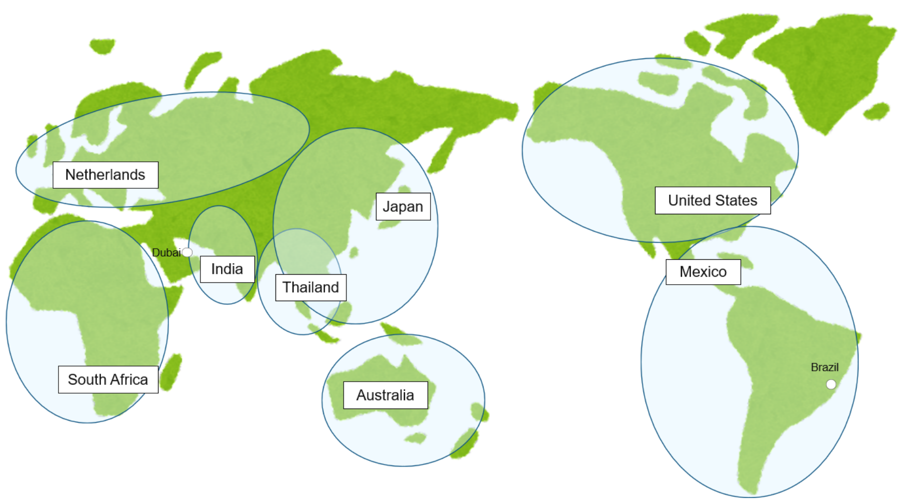


In Nissan's Aftersales logistics, the countries with high demand and supply capacity are set as hubs, and they transfer materials and parts to other, smaller demand/supply capacity countries. With this focus, facilities in ten countries are recognized as hubs: United States (North America), Mexico (Central and South

America), Netherlands (Europe), South Africa (Africa), Japan (East Asia), Thailand (South-East Asia), India (other Asia), United Arab Emirates (Asia), Brazil (South America), and Australia (Oceania). These hubs distribute shipments to other countries in their corresponding region. Figure 3 depicts an overview of Nissan's logistics network.

Figure 3

Overview of Nissan's Hub Countries, Their Area of Coverage, and Other Non-Hub Countries.



3.1.2 Transportation among Facilities

In general, hub-to-hub material flows are high in volume, whereas the other types of flows are low on volume. However, in Nissan's logistics network, some hub-to-non-hub shipments have large volume quantities, for instance some flows from Japan and the U.S. to countries like UAE and Canada. The model will incorporate these high-volume countries as separate nodes and include direct flows from them to other hub-countries different than their closest hub. Therefore, the model will treat hub and non-hub countries equally.

3.1.3 Difference between Expendable Packing and RTI

For shipping, two types of packing are used: RTIs and expendable packing. Expendable packing can accommodate various types of packing items with different sizes and weights. Carboard boxes and steel/wooden crates are considered as the two primary types. Steel and wooden crates need to be assembled with nails and require in-plant labor. They can be used for every destination and are regularly purchased from domestic packing suppliers, which allows the company to replenish materials in a short time. In practice, this means they can be replenished almost immediately. Multiple uses are not expected, and they are disposed of at their destination in most cases.

RTIs have different features. They are designed to fit the size of a shipping container and have fewer varieties. They are usually made from steel, aluminum, or other alloys, making them durable, recyclable, and less impactful on the environment. Their cost is higher than expendable packing, and they require a longer lead time for production. Thus, it cannot be replenished immediately, even when facing a shortage. They are designed to be used multiple times, making them a less costly option when compared to expendables that must be purchased in every use. Once RTIs with items arrive at their destination, empty RTIs are stored until enough amount to fulfill a container is accumulated and returned to the original location.

Packing is chosen based on shipping volume and mode of transportation. When the destination volume is low, expendable packing is currently preferred. For critical shipments, like those via air freight, expendable packing may also be preferred due to its almost immediate availability and its low weight. RTIs are used in both hub-to-hub and hub-to-non-hub ocean freight, although their use is restricted to countries with large trading volumes. For this reason, the model will focus only on ocean freight for this study.

3.1.4 The Proposed Network Design

RTI implementation is favored in those countries with a high transportation volume. Currently, RTIs can only have bi-directional flows between two countries. Our model will allow for RTIs to flow between all the nodes of the model, and thus will be an expanded version of the current situation. Between any pair of nodes (i, j), there will be material flow and its corresponding packing flow that cannot be less than the required demand. In addition, empty RTI flow will be allowed in case some countries need to balance inventory. All flows account for lead time, that is, the time material or packing takes to arrive at their destination after an order has been placed. In addition, every flow will have a cost associated. Every origin will have an RTI inventory balance equation that will serve as a constraint.

In the following sections a series of mathematical models with increasing complexity will be described. These models are intended to represent the current company's logistics network and then incorporate our redesign features so that we can contrast results.

3.2 Mathematical Models

3.2.1 Problem Description

The mathematical models that we developed are increasingly complex. The first model includes all nodes and focuses on fulfilling demand for one period at the lowest cost possible. The second model expands the time dimension into multiple periods. Time can be naturally divided into known intervals, such as days and months. For the sake of this second model, we divided it into periods of one month. The objective is still to minimize total costs. In the third model, the objective function is switched, and the program has the objective of minimizing CO_2 emissions. In the fourth and final model, these two objectives are considered simultaneously: minimizing 1) total costs and 2) CO_2 emissions.

The proposed network is considered as a closed-loop supply chain between a set of countries, including hub and non-hub countries. Countries are modeled with one node each. When hubs or destination warehouses at non-hub countries receive material, RTIs are put back into available inventory. Therefore, even though the material will continue flowing downstream to dealers and clients, RTI inventory will remain at these warehouses and therefore it is not necessary to include additional flows in the model. Let us look at each model progressively in the following sections.

3.2.2 Single-period, Single-objective Model

As a first approach, the network was designed in a single-period frame, with no account for lead time.

Single-period means the model includes the demand of one period alone. This model aims to establish a cost baseline for the operation. Demand is only fulfilled with expendable packing.

The following assumptions are used in the single-period, single-objective programming model:

a) The planning horizon is finite and single period.

b) Transportation is instantaneous (no lead time considered).

c) There is an unlimited and instantaneous supply of packing.

d) RTIs are non-collapsible when returned empty.

e) The different materials transported from plant to plant are modeled as a single material measured in cubic meters.

f) The demand is considered as stochastic and uniformly distributed between the minimum and maximum values of aggregated demand data for each arc (i, j).

g) All materials have to be transported inside a case, either expendable or returnable.

h) Transportation is modeled as only ocean shipping.

i) Expendable packing is one-time use, purchased at the beginning of every period they are used, and they are instantaneously available. RTI packing is one-time purchase at the initial period only and used in all periods. No deterioration or failures are expected during transit.

This is an initial model that will serve as a baseline. The decision variables determined for this first model are material flows, packing flows, and RTI inventory at the set of nodes.

3.2.2.1 Mathematical Model Formulation

In the following lines, we describe the indexing sets, parameters, decision variables, objective function, and constraints of the mathematical model.

Sets:

$i =$ origin plants ($i \in I$)

$j =$ destination plants ($j \in J$)

$k =$ packing type ($k \in K = \{e = 'Expendable', r = 'Returnable'\}$)

Parameters:

$d_{ij} =$ demand of material required from plant i to plant j (m^3)

$f_{ijk} =$ transportation costs from plant i to plant j in packing mode k

$c_k =$ acquisition costs for one unit of packing mode k

$m_k =$ capacity of packing mode k (m^3)

Decision variables:

$x_{ijk} =$ amount of material shipped from plant i to plant j in packing mode k (m^3)

$y_{ijk} =$ number of cases shipped from plant i to plant j with material in packing mode k

$\pi_i =$ number of RTIs purchased at origin plant i

Objective Function:

The objective function is to minimize the total transportation costs of shipping materials between plants i and plants j using packaging mode k, the total cost of acquiring the expendable packing to ship materials between arcs (i, j), and the total cost of acquiring returnable packing at each plant i to ship materials between arcs (i, j), formulated as follows:

$$\min Z = \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} f_{ijk} x_{ijk} + \sum_{i \in I} \sum_{j \in J} \sum_{k = e} c_k y_{ijk} + \sum_{i \in I, k = r, t = 0} c_k \pi_i \quad (1)$$

Constraints:

$$\sum_{k \in K} x_{ijk} \geq d_{ij} \quad \forall\, i, j \quad (2)$$

$$x_{ijk} \leq m_k y_{ijk} \quad \forall\, i, j \quad (3)$$

$$\sum_{j \in J} y_{ijk} \leq \pi_i \quad \forall\, i \wedge k = 'Returnable' \quad (4)$$

$$x_{ijk} \geq 0 \quad \forall i, j, k \quad (5)$$

$$y_{ijk} \geq 0 \;\&\; int \; \forall i, j, k \quad (6)$$

Constraint (2) indicates that the total amount of material shipped between the plans with any packing mode has to be equal to or exceed the minimum required quantities d_{ij} at any given arc (i, j). Constraint (3) links the material flow variables to the packing flow variables, to ensure the packing capacity is higher than the shipped amount for every arc (i, j, k). Constraint (4) represents that the number of returnable packing cases flowing from plant i to any other plant j cannot exceed the quantity purchased at each plant i. Constraint (5) ensures that all material flow variables are restricted to real and non-negative, and constraint (6) that all packaging flow variables are restricted to integer and non-negative values.

3.2.3 Multiple-period, Single-objective Model

In a second stage, a multi-period network will be considered. The period length spans one month of operations. Movements between nodes will take at least one period and can also take multiple periods. The demand and inventory constraints will be readjusted to fit the new time frame. The objective of designing a multi-period network is to analyze the behavior of the RTIs inventory at each node throughout time. We expect higher utilization of RTI in this model since they are only purchased at the first period and can be reutilized in the following periods. Expendable packing will still be allowed, as the model may find it better to operate with RTIs just as a fraction of total packing.

Lead time will also be accounted in this model. The minimum lead time between nodes is considered one period; however, some freight transportations take up to three periods. The first three periods will be considered as transitional (with minimum demand), to allow the flow to adjust to lead times.

The assumptions established in Section 3.2.2 adjusted to the following:

a) The planning horizon is finite and spans T periods of one month each.

b) Transportation is not instantaneous (lead time is considered).

c) There is an unlimited and instantaneous supply of expendable packing.

d) Returnable packing can only be purchased in the first period and can be reutilized in the following periods. Expendable packing is one-time use and has to be purchased at every period it is required.

e) Returnable packing downtime or failure is not allowed.

f) RTIs are held in inventory at the end of any period unless they are in the transportation pipeline. The incoming RTI inventory in any period is available for use at the beginning of the following period in the same location.

g) RTIs are non-collapsible when returned empty.

h) The different materials transported from plant to plant are modeled as a single material measured in m^3.

i) The demand is considered stochastic and uniformly distributed between the minimum and maximum values of aggregated demand data for each arc (i, j).

j) All materials have to be transported inside a case, either expendable or returnable.

k) Transportation is modeled as ocean shipping alone.

3.2.3.1. Mathematical Model Formulation

Sets:

The same sets presented in Section 3.2.2.1 are used with an additional set as shown below:

$t = Periods\ (t \in T)$

Parameters:

All of the parameters included in Section 3.2.2.1, with the addition of the following.

l_{ij} = lead time from plant i to plant j

cn_{ij} = transportation costs from plant i to plant j for empty RTIs

w_f = average weight of an RTI with material (in kg)

w_e = average weight of an empty RTI (in kg)

dst_{ij} = distance from plant i to plant j

α = emissions factor (in $gCO_2 / \frac{ton}{km}$)

Decision variables:

x_{ijkt} = amount of material shipped from plant i to plant j in packing mode k ($m3$) *in period t*

y_{ijkt} = number of cases shipped from plants i to j with material in packing mode k *in period t*

n_{ijt} = number of empty RTIs shipped from plants i to j in period t

π_{it} = number of RTI purchased at origin i in period t

I_{it} = inventory of RTI at location i at the end of period t

Objective Function:

To obtain the solutions for this model, one of the objective functions presented below must be chosen as the single objective. If the objective function (7) is chosen, then the solution will minimize total costs, and if the objective function (7) is chosen, then the CO_2 emissions will be minimized. Function (7) minimizes the total transportation costs of shipping materials between plants i and plants j using packaging mode k in each period t, the total cost of acquiring the expendable packing to ship materials between arcs (i, j) in each period t, and the total cost of acquiring returnable packing acquisition costs at each plant i to ship materials between arcs (i, j). Function (8) indicates the total CO_2 emissions generated by both material flows and empty packing costs at each period t, that are proportional to an ocean freight emission factor, the weight of the freight and the distance traveled. The solutions are found by running the model one objective function at a time.

$$\text{Min } z = \sum_{t\in T}\sum_{i\in I}\sum_{j\in J}\sum_{k\in K} f_{ijk}x_{ijkt} + \sum_{t\in T}\sum_{i\in I}\sum_{j\in J}\sum_{k=e} c_k y_{ijkt} + \sum_{i\in I, k=r, t=0} c_k \pi_{it} + \sum_{t\in T}\sum_{i\in I}\sum_{j\in J} cn_{it} n_{ijt} \tag{7}$$

$$\text{Min y} = \alpha * \left(w_f * \sum_{i,j,k,t} dst_{ij} * y_{ijkt} + w_e * \sum_{i,j,t} dst_{ij} * n_{ijt} \right) \tag{8}$$

Constraints:

$$\sum_{k\in K} y_{ijkt} \geq d_{ijt} \quad \forall\, i, j, t \leq 3 \tag{9}$$

$$\sum_{k\in K} y_{ijk(t-L_{ij})} \geq d_{ijt} \quad \forall\, i, j, t > 3 \tag{10}$$

$$x_{ijk} \leq m_k y_{ijk} \quad \forall\, i,j,k \tag{11}$$

$$I_{it} = I_{i,t-1} - \sum_{j \in J}(y_{ijkt} + n_{ijt}) + \sum_{j \in J}(y_{jik(t-l_{ij})} + n_{ji(t-l_{ij})}) \qquad \forall i,t \geq l_{ij} + \ \wedge\ k = r \tag{12}$$

$$\sum_{j \in J}(y_{ijkt} + n_{ijt}) \leq \sum_{i \in I, k=r, t=0} I_{it-1}\ \forall\, i,j \tag{13}$$

$$\sum_{j \in J}(y_{ijkt} + n_{ijt}) + \sum_{j \in J}(y_{jik(t-l_{ij})} + n_{ji(t-l_{ij})}) \leq \sum_{i \in I, k=r, t=0} \pi_{it}\ \forall\, i,j,t \tag{14}$$

$$x_{ijk},\ y_{ijk}, I_{it}, \pi_{it}\ \geq 0\ \forall i,j,k,t \tag{15}$$

Constraint (9) represents the minimum shipped amount from every plant i to every plant j in all packing modes k required to satisfy demand in periods 0 to 3. Constraint (10) represents the minimum shipped amount from every plant i to every plant j in all packing modes k required to satisfy demand after period 3. Constraint (11) ensures that the shipped amount of material to every node in any packing mode k do not exceed the packing capacity, since every m^3 required of material must be transported inside a packing container of any k mode. Constraint (12) represents the RTI inventory balance needed at each period in each node: the available inventory of RTIs at the end of period t depends on the available inventory of RTI at the end of the previous period $t-1$, the number of RTIs that were shipped out of plant i to any plant j in period t, and the number of RTIs that were received at plant i at period t (adjusted for lead time). Constraint (13) presents that the outflow of RTIs from any plant i in period t cannot exceed the inventory available in that same node at the end of period $t-1$. Constraint (14) ensures that the number of RTI available and in pipeline is limited to the amount purchased for every shipment made from plant i to plant j at period t. Constraint (15) imposes non-negativity constraints on all variables.

3.2.4 Goal Programming

The fourth and final model is a bi-objective mixed-integer linear program. Goal Programming (GP) is used to find a feasible solution by handling the multi-objective model as a multi-criteria decision-making problem. In GP, the objective functions are converted to constraints that have to meet a certain target, either a minimum or a maximum threshold, therefore becoming the goals to achieve. Deviation variables are included in constraints to convert them from "hard" to "soft" constraints. GP then aims to minimize the overall sum of deviations between the target and the actual results of each function. The deviation variables can be either positive or negative, representing overachievement and underachievement of the goals (Tozanli et.al, 2019). The presented model has two objectives: minimizing total logistics cost and total carbon emissions. As both objectives intend minimization, underachievement does not occur. Thus, the negative deviation is not restricted, and only the positive deviation ρ_k should be considered in this model.

GP can be categorized into two subsets: lexicographic GP (LGP) and weighted GP (WGP). In LGP, all objectives are prioritized and minimized sequentially while maintaining the minimal values reached by all higher priority level minimizations (Tamiz et al., 1998). At WGP, weights according to the relative importance to the decision-maker are assigned to each deviation, and a solution with a minimum sum is considered optimal (Tamiz et al. 1998). Weight at WGP is equal to the penalty of target violation. In this study, LGP is adopted since it is challenging to define an adequate penalty. The LGP model is described in Section 3.2.5.

3.2.5 Multiple-period, Multiple-objective Model

This model aims to minimize both total costs and CO_2 emissions. The two objectives were formulated into two separate objective functions. The first attempt to solve the following model found no feasible solution, hence the use of goal programming to relax the constraints and find the deviations with which a solution could be found. The two objective functions were re-written as constraints with an upper threshold that cannot be exceeded and with deviation variables, and the new objective function to minimize is the sum of deviations. The upper thresholds were obtained by running the mathematical model presented in Section 3.2.3.1 one objective function at a time.

3.2.5.1 Mathematical Model Formulation

Sets:

The sets defined are the same as in Section 3.2.3.1, with the addition of the number of goals:

g = number of goals ($g \in G$)

Parameters:

The parameters are the same as in Section 3.2.3.1, with the addition of the following:

U_g = desired target for goal g

Decision Variables:

The variables are the same as in Section 3.2.3.1, with the addition of the following:

d_g^{+-} = positive or negative deviations for goal g

Objective Functions:

In this case, we are using the deviations as the variables that make up the objective function, and the objective is minimizing the sum of those deviations:

$$\min U = \sum_{g\ in\ G} (d_g^+ + d_g^-) \tag{16}$$

Constraints:

The defined constraints are the same as in 3.2.3.1, with the addition of two.

$$\sum_{t\in T}\sum_{i\in I}\sum_{j\in J}\sum_{k\in K} f_{ijk} y_{ijkt} + \sum_{t\in T}\sum_{i\in I}\sum_{j\in J}\sum_{k=e} c_k y_{ijkt} + \sum_{i\in I,k=r,t=0} c_k \pi_{it} + \sum_{t\in T}\sum_{i\in I}\sum_{j\in J} cn_{it} n_{ijt} + d_1^- - d_1^+ \le U_1 \tag{17}$$

$$\alpha * \left(w * \sum_{i,j,k,t} dst_{ij} * y_{ijkt} + w_e * \sum_{i,j,t} dst_{ij} * n_{ijt} \right) + d_2^- - d_2^+ \le U_2 \tag{18}$$

Constraint (17) aims to keep total logistics and packing costs under a certain target, allowing for over or under deviations. Constraint (18) aims to minimize total carbon emissions for the network, based on an emissions factor for ocean shipping, the gross volume of cases with material, the gross volume of empty RTIs, and the distance travelled for all cases.

4 RESULTS

This chapter will discuss the data collection process and then present the results of the models presented in the methodology chapter. Three models, single-period single-objective model, multiple-period single-objective model, and multiple-period, multiple-objective model, are analyzed with and without introducing RTIs, to understand how RTI introduction impacts the costs and emissions objectives. The results indicate the optimal logistics flows and RTI purchasing quantities to introduce in order to obtain to optimize the network.

4.1 Data Collection

The data below is collected from the sponsor company to serve as inputs for the model. Due to confidentiality concerns, the actual data for demand, lead time, and costs cannot be provided in this report. However, for every critical input we explain its purpose, define the data collection, cleaning, and preparation techniques.

a) Demand: Fiscal Year monthly average export volume (m^3) among hub countries from 2014 to 2020 was used. The monthly average export volume is calculated by dividing the annual export volume by 12 months. Since there is no individual month data, we cannot capture monthly fluctuations or seasonality; therefore, we randomized demand (d_{ijt}) assuming that the demand at each node follows a uniform distribution ranging from the minimum and maximum values observed from data between

2014 and 2020, $d_{ijt} \sim U\ (Min\ Demand\ for\ (i,j), Max\ Demand\ for\ (i,j)$.

In the model, this demand data is converted from volume (m^3) to number of cases by dividing monthly average export volume by case size. The purpose of this data is to determine the demand constraints for every pair of nodes in every period.

Some combinations of (i,j) do not have demand associated. This means there is no material flowing through these nodes. However, they were still included in the model as empty RTIs might flow between these countries.

b) Leadtime: lead time is assumed based on the shipping lead time agreement with shipping companies in 2021 and the discussion with the company. Lead time for the return trip is considered as same as its outward trip. Lead time is measured in multiples of t periods, from one to three.

c) Flow cost: Shipping costs are calculated based on contracts between the sponsoring company and other shipping companies. The cost of most lanes between origins and destinations is defined as a flat rate per container. Other lanes or routes were not found in the contracts because they are currently inexistent for the sponsoring company. In these cases, the cost information is estimated based on the distance of each route. The contracts specify a cost per container. We translated this cost into cost per case (dividing the total cost per container by the capacity of the container measured in number of cases). Every model has an objective function based on these costs.

4.2 Single-period, Single-objective Model

This model examines only a single period of demand and neglects lead time. All materials arrive instantaneously in their destination country after being shipped. Since only one action is allowed in a single period, each country can only do shipping to fulfill the demand. The list of origin and destinations countries are summarized in sets $I = J =$ {Japan, United States, Mexico, Australia, Netherlands, Thailand, India, South Africa, United Arab Emirates, Brazil}. There are two types of packing allowed, either expendable or returnable, summarized in the set $K = \{e =' expendable', r =' returnable'\}$. No extra activities such as RTI return can be carried out because there are no variables defined to that objective. Table 1 summarizes the result of the RTI/ Expendable packing usage rate against the demand. Each country ships the exact same

Table 1

Expendable Packing and RTI Import Ratio in a Single-period, Single-objective Model.

	Austra lia	Brazil	Dubai	India	Japan	Mexi co	Nether lands	South Africa	Thail and	United States	Avg
Expendable	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
RTI	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

amount as demanded to minimize shipping costs. No returnable packing will be purchased, given that for a single use it presents higher costs when compared to expendable packing. The total logistics costs for this operation are $2,994,731, and 13,086 expendable cases are purchased. The result of the single-period, single-objective model provides the baseline for future comparison. The values for the set K are either 'Returnable' or 'Expendable' and they also apply to the subsequent models.

4.3 Multiple-period, Single-objective Model

In this model, shipping has been performed for multiple periods to fulfill corresponding period demands. RTIs only make financial sense when the planning horizon includes several periods, so that the higher upfront acquisition costs can be offset in the following periods. Lead time was also considered, with countries having an expected lead time of up to three months. Specific RTI return variables were included to distinguish RTIs that carried materials from those that did not. The prices for these returns are lower when calculated on a per case basis, given the fact that empty RTIs are collapsible and occupy significantly less space when transported. Due to the design of our model, we sought to minimize those empty returns by allowing multilateral trading and creating a "shared pool" of RTIs. Demand was estimated by randomizing the estimated distribution for every plant following a uniform distribution, as explained in Section 4.1.

In the following sections we expand the model into a longer planning horizon and present two scenarios, one with five months of demand and another with twelve months of demand.

4.3.1 Multiple-period, Single-objective Model (Five months)

The objective of this model is to minimize total costs by optimizing for function z (objective function (8) in Section 3.2.3.1). To test if the inclusion of more periods would lead to higher savings, we calculated a new scenario with five periods of demand ($T = \{0, 1, 2, 3, 4, 5, 6, 7, 8\}$, where periods 0 to 3 have no demand and serve as transitions necessary for lead time). We also calculated a scenario restricted to only expendable packing to have a baseline that could serve as comparison.

In a five-month planning horizon, as depicted in Table 2, the RTI introduction reduces the use of expendable packing in 22% when compared to a scenario with all-expendable packing scenario, introducing 4,240 RTIs with no empty returns as well. The RTI introduction ratio for this solution calculated as the proportion of RTIs over the total packing required is 7.6%.

Table 2

Expendable Packing and RTI Import Ratio over a Five-Month Scenario

	Austr alia	Brazil	Dubai	India	Japan	Mexico	Nether lands	South Africa	Thail and	United States	Avg
Expendable	93%	88%	97%	11%	22%	27%	90%	88%	3%	87%	78%
RTI	7%	12%	3%	89%	78%	73%	10%	12%	97%	13%	22%
Empty RTI (Cases)	0	0	0	0	0	0	0	0	0	0	0

4.3.2 Multiple-period, Single-objective Model (Twelve months)

In this section, we explore the results of a model with an operation period of 12 months ($T = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15\}$ where periods 0 to 3 have no demand and serve as transitions necessary for lead time) while keeping all of the other conditions the same and examining its impact on RTI introduction, logistics flow, and costs. RTI use varies per country. India, Japan, Mexico, and Thailand are the countries with higher adoption of RTI use and fewer empty returns. The worst performing country is Australia, with a continued high use of expendables.

Table 3

Expendable Packing and RTI Import Ratio over a Twelve-month Scenario

	Australia	Brazil	Dubai	India	Japan	Mexico	Netherlands	South Africa	Thailand	United States	Avg
Expendable	76%	3%	64%	0%	1%	4%	64%	70%	0%	55%	48.6%
RTI	24%	97%	36%	100%	99%	96%	36%	30%	100%	45%	51.4%
Empty RTI (Cases)	2043	5596	5938	0	0	0	1203	1721	2	11804	2830.7

4.3.3 Models Comparison

The results of both five-month and twelve-month scenarios are summarized in Table 4. It shows the average total costs per period of demand, the total expendable and returnable packing required, and the number of empty packing returns needed. There is a clear difference compared to the five-month scenario. Firstly, empty RTI flow increases. In the five months model, the model designed the logistics flow, which can avoid empty RTI shipping to fully utilize the RTI in five months. However, the twelve months model has empty RTI shipping, and it allows the countries importing less than they ship (Australia, Brazil, Dubai, Netherlands, South Africa, and the United States) to introduce RTIs.

Table 4

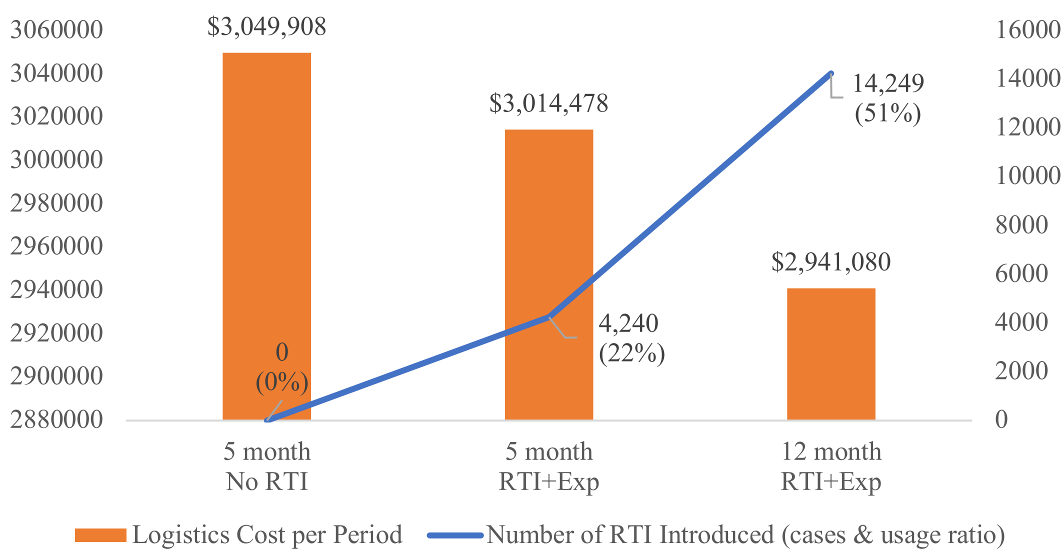
Comparison of Results Among Models

	MULTIPLE-PERIOD, SINGLE-OBJECTIVE (COST MINIMIZATION) MODEL			
	All Expendable 5 months	**3 Months Transition + 5 Months Demand**	**All-Expendable 12 months**	**3 Months Transition + 12 Months Demand**
Total Costs Per Month ($)	3,049,908	3,014,478	3,157,655	2,941,080
Total Expendables (# Cases)	66,282	51,637	162,271	78,784
Total Purchased Rtis (# Cases Cases)	-	4,240	-	14,249
Empty Flows (# Movements)	-	-	-	28,307

Furthermore, according to Figure 4, the average RTI usage ratio, defined as the number of returnable cases shipped over the total number of cases shipped, increases from 22% to 51%. This can also be calculated as the number of expendable packing cases no longer needed over the total expendable packing cases needed in the all-expendable scenario. This is reasonable, as the initial cost of RTI introduction can be depreciated for a longer time, making it less expensive for countries to introduce more RTIs.

Figure 4

Costs and RTI Introduction Ratio Among Multiple-period, Single-objective Models



A longer planning horizon of twelve months leads to higher RTI use and lower costs per period when compared to both all-expendable and five-month models.

Table 5 summarizes the number of countries that each country imports RTIs from. As the planning horizon increases, there is a tendency of receiving RTIs from more countries. Hence, multi-lateral trading is promoted when the study contemplates more periods.

Table 5

Number of Countries that Each Country Imports RTI from.

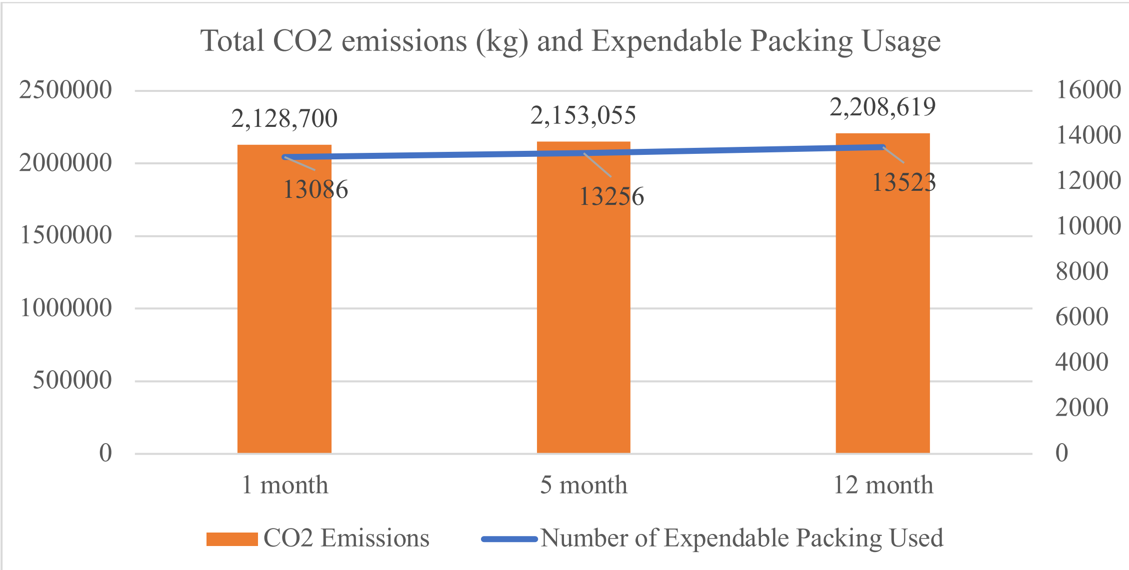
		Australia	Brazil	Dubai	India	Japan	Mexico	Netherlands	South Africa	Thailand	United States	Avg
Single-period Single-objective	1 mo.	0	0	0	0	0	0	0	0	0	0	0.0
Multi-period Single-Objective	5 mo.	1	2	1	3	6	4	5	3	3	2	3.0
	12 mo.	4	5	5	4	8	5	6	5	6	3	5.1

4.3.4 Multiple-period, Single-objective model for CO_2 Emissions

This model focuses on CO_2 emission minimization, performed by minimizing the model in Section 3.2.3.1 using only the objective function y (8). This function estimates the total emissions generated by the transportation activities in the model, whether it is from freight transportation or empty RTI returns. The drivers of CO_2 emissions are weight and distance in a positive relationship (the greater these factors are, the higher the emissions). The results for different planning horizons (different sizes of T) are shown in Figure 5. CO_2 emissions increase slightly the longer the planning horizon is.

Figure 5

CO_2 Emissions Comparison among Models



4.4 Multiple-period, Multiple-objective Model using Goal Programming

In the previous sections, we discussed the results for models that either minimize costs or minimize CO_2 emissions separately. In this section, we show the results of a multiple-period, multiple-objective model that captures trade-offs between both objectives at the same time.

There is no feasible solution for a model that minimizes both cost and CO_2 emissions at the same time. Therefore, the approach was to use goal programming and deviations to find how much the model would need to be relaxed in order to find a feasible solution. Targets needed to be set for both functions. The approach was to minimize one objective at a time and obtain what the minimum values for each are. The results are shown in Table 6 and also match with the results shown in Section 4.3.2 and 4.3.4.

Table 6

Results of Multiple-period, Multiple-objective Models

	Cost ($/month)	CO2 (kg/month)	Packing usage ratio	
			RTI	Exp
Cost Minimization model	2,941,080	2,237,628	51.40%	48.60%
CO_2 Minimization model	3,157,655	2,208,619	0%	100%

In the next step, deviations are introduced to the model. Deviations are variables that represent how much each result needs to deviate from its target, either above or below, to obtain a feasible solution. The objective is to minimize the sum of these deviations with the previous cost and CO_2 emissions functions now introduced as constraints. The results are summarized in Table 7. In terms of the best solution found for each objective separately, the goal programming results found a solution at a point in which total logistics costs are 0.1% higher than optimal, and CO_2 emissions are 0.99% higher. This result is understandable since there is a trade-off between the cost and CO_2 objectives, where the minimum of one can only be obtained through an increase of the other. However, it is still a very minor increase.

Table 7

Multiple-period, Multiple-objective Model Results Comparison

	Actual		Difference (Vs Goal Programming)	
	Cost	**CO_2**	**Cost**	**CO_2**
Cost Minimization Model	35,292,964	26,851,532	-0.10%	0.32%
CO_2 Minimization Model	37,891,862	26,503,423	7.25%	-0.99%
Goal Programming Minimum Cost & CO_2	35,329,627	26,767,131	-	-

In Section 4.3.2, we found that when we only focus on minimizing costs, the solution requires empty RTI flow, whereas only minimizing CO_2 emissions would not have any empty returns. This can be deduced from the fact that expendable packing requires no returns and are therefore the least CO_2-emitting option. Thus, when aiming to minimize both objectives at the same time, the goal programming model should relax its constraints, resulting in both higher costs and emissions. In fact, the average number of empty RTI flow is 2,799 cases in this model - lower than the cost optimization model - while it is higher than in the CO_2 optimization model. Overall, as shown in Table 8, average RTI usage ratio is 49%, being higher than in the CO_2-optimization model (0%) but lower than the cost-optimization model (51.4%).

Table 8

Expendable Packing and RTI Import Ratio in Multiple-period, Multiple-objective Model.

	Austra lia	Brazil	Dubai	India	Japan	Mexico	Nether lands	South Africa	Thailand	United States	Avg
Expendable	72%	17%	64%	0%	0%	4%	62%	65%	0%	57%	49.1%
RTI	28%	83%	36%	100%	100%	96%	38%	35%	100%	43%	50.9%
Empty RTI (Cases)	0	0	0	4894	2346	17427	0	3	3325	0	2799.5

This goal programming mixed solution is 3.4% lower in costs and 0.99% higher in CO_2 emissions when compared to an all-expendable scenario.

5 DISCUSSION

In this chapter, we will explain the implications of the results shown in Chapter 4 and comment the insights gained on the sponsoring company's business.

5.1 Main Findings and Implications

The single-period and single objective model that only minimizes costs will only procure expendable packing. This makes perfect sense in terms of packing costs. Since expendable packing is 65% less costly than returnable packing, it will be preferred for one-time use as the model implies.

When we incorporate a planning horizon (i.e., demand for the following t periods) into the problem scope, savings begin to appear. Savings of 1.7% are expected in only five months of operation by reducing expendable packing use in 22% and incorporating 4,240 RTIs. A longer planning horizon of twelve months leads to greater savings of 3.4%. In addition to these savings, we also found that a twelve-month planning horizon leads to RTI flowing through more network arcs than before, meaning that all countries receive RTIs from more countries with a longer horizon. However, with these added flows in the twelve-month model, there is also increased empty RTI flow. Although it is still cheaper, there is cause for concern in terms of CO_2 emissions, as there is a slight increase in emissions as seen in Figure 5, Section 4.4.

When we tried to minimize both objectives at the same time, we found that there was no feasible solution. Relaxing the constraints on the model helped reach a solution that involves trade-offs. This means that it is impossible to obtain the least costs without harming the CO_2 emissions, and vice-versa. However, the 0.99% increase in CO_2 emissions do not appear to be significant, and it does not consider the positive impact generated by the great reduction in expendable packing. In fact, for this solution, the average use of RTI return trips decreases, the RTI introduction ratio – as defined in Section 4.3.2 is maintained.

5.2 Managerial Insights

According to the results shown in Figure 4, Section 4.3.3, there is a clear benefit of introducing RTIs in a long planning horizon. Those benefits can already be captured from a short timeframe of five months but can be increased with an extended length of time, as we saw in the twelve-month model. In addition, it is clear that the network expansion from bilateral to multilateral trading is feasible and actually reduces costs. However, there are still countries with unbalanced demand that, if rearranged, could help drive costs down even more, starting from India and Australia, which are the slowest adopters of RTIs.

To determine if the company should make an investment in RTIs or not, however, they must disaggregate the costs calculations to account for the time in which costs are actually incurred. Our model does not take into consideration the time value of money, which is something that any Finance team will want to look into before making any investment. However, a normal depreciation period for an asset like an RTI will amount to two or three years and our model only goes through one year. We have established that the costs reductions in this model increase with longer planning horizons so we are confident that the financial analysis will yield even more positive results for the company. Furthermore, transitioning to multilateral trading with a standardized RTI means that the procurement of those packing cases can be done centrally and will allow for a stronger bargaining position in terms of acquisition price, further increasing costs reductions overall. Since the model quantifies the amount of CO_2 emissions at every arc in every period, this will allow the company to set up specific goals for CO_2 emissions reduction. The model can be fine-tuned by pruning unnecessary arcs and redefining demand forecasts, thus providing a quick way to estimate the impact on emissions that multiple network scenarios would yield. Although beneficial in costs, the results of the final model still showed empty RTI returns, proving that even with the improved design these inefficiencies are still unavoidable. However, the model does indicate in which specific arcs will empty returns be needed, pointing the company in the right direction for finding demand planning opportunities that could improve the results.

The company has been struggling with delays in RTI returns, and this is the one of main reasons RTI implementation has been postponed or avoided for so long. Multilateral trading improves RTI availability by creating a shared pool of RTIs between multiple countries, but it presents a new challenge to inventory planners: how to decide when and where RTIs should be shipped. Shipping decisions are made on a daily or weekly basis whereas our model assumes a monthly plan. The new shipping rules for supply chain managers will have to uphold the model's suggested shipping volume proportions for any given hub or plant to not generate stagnation or excess of RTIs in any given node, especially in those countries that have low RTI introduction. Increased communication and collaboration will be required between countries for this implementation to be successful. At the same time, this could provide further opportunities to include other currently overlooked countries or hubs into the network, increasing savings opportunities.

6 CONCLUSION

The use of returnable packing for freight transportation in automotive manufacturing companies is widespread due to the overall reduction in costs they provide and the significant contribution they make to environmental sustainability. However, there are certain conditions that may constrain the implementation of such closed-loop supply chains. In particular to our sponsoring company, in the spare parts business, there is high demand variability and imbalance between trading countries. Demand variability negatively impacts freight planning, causing delays or higher inventory levels to compensate uncertainty. Imbalances between trading countries means that some countries import far more material than they export, meaning that if returnable packing were to be implemented, then empty packing returns would be guaranteed because of this imbalanced demand. To avoid these challenges, the use of expendable packing is extensive, with the corresponding impact on the environment due to its single-use nature, in addition to the materials used to produce them such as cardboard or wood. Through our research, we found there is an opportunity for us to contribute to the sponsoring company's sustainability targets by redesigning their spare parts network design in order to enhance the use of RTIs.

The current network design that Nissan holds for their spare parts or Aftersales business only allows bilateral trading. This means that returnable cases can only flow to a country and then return to origin. However, Nissan has hubs and markets in many countries. Most of them do not utilize RTIs. Our hypothesis is that we can expand the network possibilities and allow multilateral trading - that is, any given country can export RTIs to any other country and that receiving country will hold RTIs in inventory. Our approach to this problem was to model their network as a mixed-integer linear program that calculates the required number of expendable and returnable cases based on forecasted demand, but also contemplating our assumption. The resulting model allows freight transportation among all countries involved. In addition, we know that RTIs are more expensive to purchase upfront but are reutilized multiple cycles, so that their real value can only be captured over time.

Our first step was to observe the results of a model that operates for one period only. This allowed us to validate our initial variables and obtain an initial result in which all packing selected was expendable due to its lower price. To test our assumption, we then proceeded to expand the model by adding time, inventory, and empty returns as variables for the model, as well as lead time, inventory constraints, and also CO_2 emissions calculations. We analyzed two timeframes, one of five months of operation and another one with twelve months, and then calculated the minimum costs incurred and with how many of any given case. The results show that just with five periods the model will select to start operating with RTIs, reducing expendable packing use in 22% when compared to the all-expendable scenario. The twelve-month model showed an even greater reduction of expendable packing use around the 51% mark. In addition, every country received RTIs from five other countries on average, supporting our hypothesis that multilateral trading would be beneficial for the network design.

6.1 Recommendations

In this section, we will share recommendations on how the company can apply our findings to their business.

First, we recommend the company to introduce RTIs and expand their aftersales logistics network from bilateral to multilateral trading. In their current operation, RTIs have not been introduced in countries with low trading volume due to the possible effects of long return lead times and costs. However, as long as demand conditions remain stable, the expanded use of RTI will lead to lower costs per period.

Second, the company must look for demand-balancing opportunities. Countries like Australia and Netherlands present very low RTI usage rates, possibly due to the difference in demand when compared to other countries like Japan. A different network design study could be carried out where the hub locations are analyzed. If these hubs were to consolidate more demand from other countries, it is possible to reiterate our models with these new data to find the impact on RTI usage and overall costs.

Lastly, the company must be comprehensive in their emissions measurements. As stated in Section 1.1, reducing CO_2 emissions is a crucial objective for the company, however we had difficulty measuring emissions for all transportation-related activities, such as expendable packing manufacturing emissions. The SCM department in Nissan is still paying more attention to cost reduction alone, and they will be required to take some action for CO_2 reduction in the future, or else they might not meet the company's global goals. This research showed that the current state of the company's network might reduce costs at the expense of increasing emissions, an impact that could be avoided with more information on currently overlooked activities. The model provides them with a way to measure CO_2 emissions related to transportation and find alternatives to reduce them, for instance by showing the countries that generate empty RTI returns.

6.2 Limitations

While the results of this project derive practical suggestions for the company, there are some points that could not incorporated into the design. These challenges are listed below:

a) This model assumes there is a unique and equal size for both RTI and expendable packing. However, in the actual operation, different packing sizes are used based on the characteristics of the products (like size and weight) and the actual volume to be packed. Thus, a model that incorporates different packing sizes can yield near real-life results. This, in turn, can increase complexity n-fold, n being the number of different existing sizes.

b) In this model, lead time only represented ocean transit time, and it was considered as deterministic data. However, actual ocean shipping transit times are highly variable, making lead times stochastic variables. In addition, materials also go through other transits, such as inland operations, warehouse, drayage, demurrage, and export country distribution, that were not included in our measures, because they are on average not as lengthy as the ocean transit time. However, since all operations are sequential, any delay in one of them may cause a ripple effect that might severely impact the total transit time and pose a risk to RTI supply.

c) We assumed the packing had a capacity of 3.75 m^3 under full utilization. However, in the actual operations, it is practically impossible to use full capacity since the mix of products carried within a case have different sizes and weights, making it highly unlikely to "cube out" a case, that is occupy the entire space. To contemplate this, we assumed an 80% capacity utilization. This measure may present differences between countries and should be revisited before implementing the model for different countries.

d) We also assumed maximum utilization of a container space when we calculated our material and packing flow costs. At full container capacity, the cost per case is the lowest possible. A more realistic calculation could significantly impact the results, particularly for the empty RTI return flows, where sometimes out of necessity a container might be shipped out underutilized although paying full rate for its transportation.

e) Our model does not include all the activities that drive CO_2 emissions in the supply chain. The literature is not clear on how much CO_2 emissions are derived from the manufacturing of cardboard boxes, so we felt it best to exclude this angle from our analysis. However, our results show that there is a reduction of expendable packing use, leading to unquantified gains on these manufacturing emissions. There are also CO_2 emissions in other segments of freight transportation such as inland operations. If we could have included these aspects, the results of total CO_2 emissions might have changed significantly.

6.3 Future Research

Following the lines of the limitations of our research, the results shown in this work can be further improved by increasing the planning horizon, analyzing multiple sizes of RTIs, improving the forecast of demand, and including the impact on emissions due to expendable packing use. Our hypotheses are that longer planning horizons would reveal increased cost reductions, as was shown by our research. Furthermore, multiple sizes of RTI would more accurately reflect reality and could provide further insights as to whether other packing sizes would be convenient for the network. The limited data available on forecasted demand did not allow us to observe the effect of seasonality in the results. The recommendations made could vary significantly with an accurate forecast, but it is difficult to predict if it would lead to lower or higher adoption of RTIs in the system. Lastly, the emission gains generated by the reduction in expendable packing are not captured in this model, which could explain why the results actually show an increase of emissions in the optimal solution. We recommend the company to find a way to measure the impact of the expendable packing manufacturing operation in an end-to-end approach, quantifying the emissions upstream in their expendable packing suppliers. One possible approach for this is to request suppliers for estimate emissions per kilogram of expendable material manufactured, and then quantify total emissions generated by considering the total packing weight utilized.

In a complementary line, the models developed in this study can be implemented in similar network strategies that other industries may have, such as consumer-packaged goods companies with high volume of production in only a few manufacturing sites and a significantly relevant aftersales business. Electronics goods companies are an industry that present similar manufacturing strategies.

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