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RESUMEN

Mundialmente, los plásticos son consumidos a escala masiva y son los productos más demandados en el mercado, Ecuador no está exento de esta tendencia. En los últimos años, se ha creado una conciencia ambiental acerca de los problemas actuales respecto a desechos plásticos con nuevas iniciativas creadas para su reutilización. La presente investigación explora cómo conceptos de economía circular y logística reversa se juntan para crear un sistema completo que beneficie a productores y consumidores. Específicamente, el presente estudio se centra en la aplicación de modelos de logística reversa como el Problema de Ruteo de Vehículos con Capacidad y el Problema de Ruteo de Vehículos con Capacidad y Ventanas de Tiempo. El estudio incluye una parte práctica en una empresa ecuatoriana productora de plásticos la cual está en busca de maneras de aumentar su circularidad mediante la recuperación y reutilización de producto desechado; a la vez de cumplir con la demanda requerida y asegurando una nueva producción sustentable. La investigación se enfoca en la integración de dichos modelos considerando las necesidades de la compañía al igual que la ubicación de un centro de reciclaje para el producto recolectado. Adicionalmente, un diseño por agrupaciones es implementado con el fin de identificar las ubicaciones más importantes basadas en el volumen y demanda del plástico recuperado. Los resultados de la investigación mostraron que la implementación de los dos modelos fue exitosa y, después de realizar diferentes análisis, una ubicación óptima para el nuevo centro de reciclaje fue determinada.

Palabras clave: Economía Circular, Problema de Ruteo de Vehículos, Cadena de Suministro Sustentable, Logística Reversa, Orquestación de Ecosistema Industrial, Cadena de Suministro de Ciclo Cerrado, Recuperación de Producto.

ABSTRACT

Worldwide, plastics are consumed on a mass scale and are the most demanded products in the market; Ecuador is not exempt from this trend. In the last years, an environmental conscience has been created about the current problems regarding plastic waste with new initiatives emerging to reuse them. The present investigation explores how concepts of circular economy and reverse logistics merge together in order to create a well-rounded system that benefits, both, manufacturers and consumers. More specifically, the present study focuses on the application of reverse logistic models, such as the Capacitated Vehicle Routing Problem and the Vehicle Routing Problem with Time Windows. The study includes a case study in an Ecuadorian plastics producer company, which is searching for ways to increase its circularity by recovering and reusing its finished products, while meeting demand requirements and ensuring a new sustainable production. The research focuses on the integration of said models considering the needs of the company and the requirements to implement a new recycling facility for the recovered material. Additionally, a Clustering Design is implemented in order to identify the most important locations based on the volume and demand of the recovered plastic. The results of the investigation showed that the implementation of the two models was successful and, after performing multiple analysis, an optimal location point for the new facility recycling was determined.

Key Words: Circular Economy, Vehicle Routing Problem, Sustainable Supply Chain, Reverse Logistics, Industrial Ecosystem Orchestration, Closed-loop Supply Chain, Product Recovery

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1. Introduction.

The use of plastics has become part of societies' lifestyle for the last 50 years (Gu & Ozbakkaloglu, 2016). Plastics have been used increasingly for the manufacturing of different products due to their advantageous properties, which include low density, high durability and low cost (Gu & Ozbakkaloglu, 2016). Since the 1950s, plastics large-scale production has been increasing (Geyer et al., 2017). Global production of resins and fibers, the two main components in plastic, has risen from 2.2 Tons in 1950 to 390 Tons in 2015, with a total of 7800 Tons in 65 years (Geyer et al., 2017). More than half of the amount of plastic produced is for one-time-use only products, which have a major impact on the environment because it takes them 1000 years to fully decompose. (Gu & Ozbakkaloglu, 2016). There are also immediate environmental problems related to plastics production and consumption that can be seen right away, such as urban contamination due to the lack of proper disposal of used plastics, which contaminates streets, lakes, and sewerage (Gu & Ozbakkaloglu, 2016).

These global problems also translate to every country in the world. In Ecuador, 304 Tons of plastic are being disposed every day, and of those, only 88,17 Tons are collected (INEC, 2018). Furthermore, it has become increasingly hard to collect plastics that have been thrown away because of the lack of environmentally friendly practices among Ecuadorian citizens; among the entire population, only 52% are aware of this problem and sort their waste (INEC, 2018). Provinces such as Galápagos and Loja are the ones with a higher waste sorting system, with 99.2% and 73.5% of garbage being classified, respectively (INEC, 2018). In Quito, 72,2% of the population sort their waste at home, but the number decreases to 22,07% in public areas such as streets, shopping malls and fast-food restaurants according to a survey conducted by Instituto Nacional de Estadísticas y Censos (INEC, 2018). The absence of enough specific recycling containers in public areas to place and classify waste, is the main reason for this behavior (INEC, 2018). Also, as mentioned before, one-time-use products such as plastic cups, cutlery and plates generate more waste (INEC, 2016). Therein, it is extremely important to work on initiatives to raise awareness among the population about how to handle these types of products and find out ways to collect them and reuse them.

Having this problem in mind, the concept of Circular Economy (CE) takes place. CE is a generative system in which the resources of a company and its waste are managed in a closed loop by designing, maintaining, reusing, recycling and remanufacturing its finished products (Geissdoerfer et al., 2017). The idea of CE is to translate this exclusive ecological term and apply it to the business model of a company to generate a more appealing and competitive concept (Parida et al., 2019). It is important to mention that the benefit of CE is not only to apply it to an individual company, but to a group that shares a specific goal in an effort to reduce costs and reduce the toll of industrial activities (Parida et al., 2019). Given the fact that CE aims to maintain its products and resources in the economy for as long as possible (Alamerew & Brissaud, 2018), methods to track, regain and relocate products that have reached their end of life (EoL) need to be taken into consideration. This is where Product Recovery Strategies (PRS) play a key role, as they focus on the collection of used products, and the reprocessing and redistribution of said reused products (Alamerew & Brissaud, 2018) in order to create a closed-loop economy. Having the term of CE taken into consideration, there needs to be a way in which the concept can be translated from a theoretical point of view to a useful tool that companies can take advantage of.

One of the PRS that has been widely used in recent years is reverse logistics (RL) (Alamerew & Brissaud, 2018). RL is the part of the supply chain management system which takes care of retrieving the products of a company from its numerous clients (Senthil & Sridharan, 2014). RL plays an important role in an organization's success because it has several benefits such as resource utilization and environmental protection (Senthil & Sridharan, 2014).

The management of products returning to the initial point of the supply chain represents a new challenge to organizations. RL has become a tool that helps companies reach economic circularity because it allows them to find solutions to connect end-customers to the initial manufacturing place (Banguera et al., 2017). RL takes into consideration different types of methodologies that assess diverse variables and scenarios in which a company can retrieve their used products. There is not a general model or formula that fits every company. RL's main objective is to design a network that takes into consideration used products, spare-part recoveries and how they can return them to a specific place in order to reuse them as raw material for the new products and decrease the amount of new material that the company has to buy (Banguera et al., 2017).

In this context, a company that is interested in CE is important for the wellbeing of the environment since it takes care of its own waste and, thus, generates less pollution. From a production perspective, it also helps them create an opportunity to relocate and reuse their finished products to reduce manufacturing costs (Andersen, 2007). The opportunity to explore and evaluate a RL model, applied to a supply chain of a company in order to support it in achieving circularity, represents an interesting challenge for a developing nation, such as Ecuador. For this reason, considering the problems mentioned before, a study that focuses on plastics retrieval and reuse is imperative as it could open new possibilities for different companies to adopt a CE system and to start tackling their environmental problems. The present study is focused on the research, design and adaptation of a RL model that helps an Ecuadorian plastics company identify, collect and allocate their used products at a strategic point in the city of Quito, in order to reutilize them in the manufacturing process to reduce the amount of new raw material used to create new products, thus, increasing its circularity.

More specifically, the present study focuses on company CP (named that way for confidentiality reasons), a producer of plastic hydrocarbon derivatives. The company aims to adopt a CE system in collaboration with its top client (Client A), that currently owns 19 of the 60 fast food franchises in Ecuador (Client A, 2020). Client A currently owns restaurants with two types of business models, the individual restaurants scattered in the city and restaurants inside the food courts of different shopping malls. The clients of these two combined restaurants use approximately 19 Tons of plastic each month. Their common goal is to achieve a more environmental-friendly economic model to reduce the amount of plastic waste that is currently thrown away without any kind of recycling method, and create an alliance that favors both companies in an economic and environmental aspect.

2. Literature Review.

The focus of the present literature review section is to identify and compare different case studies, researches studies and models to understand how concepts of circular economy and reverse logistics merge together in order to create a well-rounded system that benefits, both, manufacturers and consumers.

2.1 Circular Economy.

The creation of CE's initial associated concepts was attributed to Pearce and Turner (1989) and their studies of open-ended economic systems (Bocken et al., 2017), where they analyze the consequences of an excessive raw material extraction and irresponsible waste disposal. The main challenge society is facing is to find new practices in industrial production, creating a closed loop, where finished products can be utilized as raw material or can be processed to restore the environmental damage produced through the last centuries (Commoner, 1973). Stahel and Reday (1976) defined two loops/circles in the context of "economy loops", which will be later on, integrated in the principles of a circular economy.

The first principle refers to recycling materials and the second to reusing goods. Sadly, these two loops eventually end up producing waste, when reuse and remarketing is no longer available (1976). One step ahead, an environmental economist named Boulding (1966), introduced the idea of an economical circular system where sustainability was key for human development. Finally, all the former mentioned ideas gathered into the concepts that Pearce, Turner (1989) and modern studies utilize to define and shape CE and Industrial Environment (Alamerew & Brissaud, 2018; Bocken et al., 2017; Geissdoerfer et al., 2017; Ghisellini et al., 2016; Kirchherr et al., 2017).

CE is commonly perceived as a concept, where multiple practices, tools and methodologies are utilized to design and modify a system, that will work between theoretical, economical, and environmental boundaries (van Buren et al., 2016). The environmental boundaries are commonly framed by the concepts of classic 3R (reduce, reuse, recycle) to modern 9R (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover), differing from author to author (Kirchherr et al., 2017). As an overall frame, these concepts brought the importance of an integrated system, where organizational learning and change from tactical day-to-day planification to strategic levels and long term planification, were required (Mann, 2004). Physical observation of the usage and movement of energy, materials and products are the base for long-term waste reduction efforts, which are CE's main standpoint (Andersen, 2007). Common examples of the main benefits at a physical level are reduction of the raw material required or waste delivered to the environment (Andersen, 2007). This is the reason why a profound analysis of the interactions between the companies that belong to the complete Supply Chain (SC) are required.

Relevance of CE has been growing exponentially in the academic and theoretical field since 2015; however, not many companies have taken the step to a circular economy and organizational structure (Bocken et al., 2016). Some barriers and challenges must be considered when implementing CE. Tognato, et. al. mention that the main challenges that companies face are to reduce transportation costs due to reverse logistics, and to maintain the products' quality (2019). In regions like China, Japan, US, Brazil or EU, huge steps have been taken to stimulate the implementation of CE in the industry (Kirchherr et al., 2017). One big example is the Chinese CE promotion laws, which define a CE as "a generic term for reducing, reusing and recycling activities conducted in the process of production, circulation and consumption" (CCICED, 2008). Other countries, like China or members of the European Union, have been implementing similar initiatives, mainly focusing on waste management and application of the 4R principles (Van Buren et al., 2016). Some examples of these initiatives target the design of the product itself, carefully choosing more environmentally friendly materials and planning how its late end life will be. As an example, Bocken et al. used these initiatives for the recollection of discarded products (fishing nets) and their transformation into raw material for new products (plastic carpets); this practice is referred as "extending resource value" (2016) Other example is the inclusion of environmental effects of logistic operations in the management of freight delivery. Dutta et al. exemplify this by adding and minimizing an environmental objective function to the classic vehicle routing problem, not only considering the economic costs but also the transportation side effects (2020). Initiatives like the former are good examples of principles like waste reduction and increased trash classification, which are mostly complimented by environmental taxes for waste generation (Sakai et al., 2011). On the other hand, Gupta, et. al. considered that the challenges companies face when implementing CE initiatives are due to the complexity of the business operations and the stakeholder's engagement (2018). Finally, the barriers for implementing CE in companies are closely related to the lack of policies that facilitate and pressure them to have adequate waste management initiatives. Lack of knowledge, innovation, technology, culture, cooperation, and long-term vision, can create further limitations. (Zhang, et. Al., 2019). Parida suggests three main mechanisms to smooth the interaction between SC partners (2019). These mechanisms focus on the development of interdependence and solid give and take rules for the ecosystem. This can be achieved by giving economical or operational benefits to SC partners (Parida, 2019).

2.2 Reverse Logistics.

To implement CE in an industry, it is imperative to understand how to allocate finished products and search for techniques to retrieve them to a specific location, this is where reverse logistics takes place. Reverse logistics (RL) is the set of activities required to collect used products from customers with the objective to reuse, repair, recycle or dispose them (Agrawal et al., 2015). This term was not always the most accepted, it first began with Murphy and Poist (1989) referring to the reverse flow of goods. Later, Stock (1998), Dowlatshahi (2000) and Srivastava (2008) implemented the term environment to the definition. The definition of RL has been changing over time making its scopes and interests broader by researches (Agrawal et al., 2015). The RL process begins by the recollection of used or returned products, which are then sorted for recycling, remanufacturing, reuse or dispose depending on the purpose that has been set for said products or the condition in which they have been retrieved (Srivastava, 2008). This process can be separated in product acquisition, inspection and disposing (Agrawal et al., 2015).

RL can be implemented in almost every industry that wants to recollect and reuse their finished products. For example, Rubio & Jiménez-Parra (2014) implemented RL techniques in the return policy of an online store and managed to reduce the number of vehicles used to collect returned products. In the pharmaceutical industry, de Campos & de Paula (2017) reviewed how RL concepts and practices can be applied to medicines that have ended their life cycle. They identified where there was more concentration of soon to expire medicines and created a routing model to retrieve them. In Latin America, Dieste et al. (2009) evaluated different RL models for the collection of electronic equipment through the implementation of different software tools; they achieved a system of routes to collect all damaged equipment using a Travel Salesman Problem model. As mentioned by Guarneri & Streit (2015), in countries like Brazil studies of how to handle different types of waste have been conducted and all have the common denominator that working alongside municipal policies takes a long time to produce results. Guarneri et al. (2016) also stated that although working alongside governmental organizations might slow down results, the participation of individual companies that are willing to cooperate can bring faster results. Even though these investigations took place in another country, the reality of Ecuador is not that far from Brazil. One of the few relevant case studies in Ecuador performed by Kumar et al. (2011) mentioned that the Ecuadorian landscape scenario has not considered the recovery of its used products. One of the limitations of the research previously mentioned, is the implementation of a non-mathematical tool that was used to develop the study. The investigation used qualitative tools in order to solve the problem.

According to Grazia (2018), the study of RL problems have been present long before the use of computational models and, as well as a common logistics problem, that needed to be resolved in the most efficient way. Traditional Operations Research (OR) methodologies started to be applied to RL with the purpose of optimizing the use of resources and finding the fastest way to reach a specific location (Grazia Speranza, 2018). One of the first methods to tackle the problem of finding the fastest way from point A to point B, passing through different locations, is the Transportation Problem (TP) (Hillier & Lieberman, 2015). The TP main objective is to find the optimal route that passes by every assigned point of a delivery vehicle in the most efficient way (Hillier & Lieberman, 2015). Farahani et al. (2013) applied the TP in urban areas where they determined that this type of model can be applied in municipal transportation routes in order to facilitate the flow of traffic and minimize the overall time it takes a vehicle to go from one point to another. Another application of TP is the one proposed by Zhang et al. (2015), where they applied this model to a hospital in Hong Kong with the objective to find an optimal transportation route for disabled and elderly patients from different points of the city. Finally, Zeng et al. (2013), Lin (2016) and Samanlioglu (2013) stated in their respective reviews, that TP is the basis to understand how a logistics network works and how the implications of a correct application can improve the general performance of a company.

There have been different studies of RL in the plastics industry like the one conducted by Searcy et al. (2014), which identified places where there was a large concentration of plastic products and created a model to collect and reuse them for different purposes. Sellitto (2018) presented a study of a beverage company that uses plastic bottles to allocate and recycle their containers through a set of specific routes for their fleet, thus, minimizing the total cost of buying raw materials. Bing et al. (2014) redesigned the collection routes that a Dutch company uses to find and retrieve plastic waste, they found an optimized route where carbon footprint and the number of vehicles were considered to find the new route.

After the literature review, it is considered that the best method to solve a reverse logistics problem in a large industry, such as the plastics one, is the Vehicle Routing Problem. This model focuses on the assignment of a set of customers to a specific fleet of vehicles in order to complete the established demand in the most efficient way (Eksioglu et al., 2009). According to Eksioglu et al. (2009), the VRP can be classified in different ways depending on its applications and complexity. The main objective is to go through different points in the city and arrive at a fueling destination optimizing energy use. On the other hand, El-Sherbeny (2010), Tan et al. (2001) and Hsu et al. (2007) applied the Vehicle Routing Problem with Time Windows (VRPTW) in different types of stores, shopping malls and warehouses that had a scheduled delivery hour. They managed to classify and assign the best routes for a fleet of vehicles, thus minimizing the total traveled distance (Hsu et al., 2007). The principal constraint of these problems was to find the best route for a vehicle to deliver its goods within an established time period (Tan et al., 2001). This type of model fits for companies that need to deliver their products to stores or clients that have a limited amount of time set to receive products (Tan et al., 2001). Finally, the Capacitated Vehicle Routing Problem (CVRP) has been widely used in application papers because it takes into consideration the vehicle or location capacity and starts to solve the problem around that specific constraint (Barreto et al., 2007). Barreto et al. (2007), Kumar & Panneerselvam (2012), Roch & Langer (2019) and Carwalo et al. (2017) started implementing CVRP algorithms to enhance the number of products a single vehicle could deliver to a specific client. Roch & Langer (2019) recently applied this algorithm in a bin packing problem, where the vehicles responsible to deliver certain products had a volume constraint for said bins and needed to find the best route to its clients. The result was the creation of a route for small capacity vehicles that attend a large number of stores, but with low demand. Kumar & Panneerselvam (2012) conducted a literature review of the CVRP and encountered a problem that involves large sets of data. Even though solutions for CVRP can be found in a direct way, when you start incrementing data to its algorithm, the solutions become increasingly hard to find due to the fact that the VRP problem is NP-hard (Non-Deterministic Polynomial Time Hardness), which means that an optimal solution may not be found (Kumar & Panneerselvam, 2012). Therefore, the use of heuristics might take place in the development of the investigation because of the use of large datasets.

Therein, the present study is centered in a unique methodology which proves to be the first one to be implemented in Ecuador. It merges both qualitative and quantitative steps to reach a RL system that favors both, the customer and manufacturer using RL programming models and software tools such as Excel and Python.

3. Methodology.

Based on the literature review, the present study proposed a new two-phase methodology based on the principles of the second stage of Parida et. al. (2019) that evaluates, in a qualitative way, the CE ecosystem orchestration mechanisms. The main approach for these mechanisms is the creation of a restorative, regenerative industrial system by changing the assessed company business model and fitting them into the circular economy model (Rubio, 2014). In addition, the qualitative section of the methodology also includes a negotiation mechanism, that mentions negotiation activities and ecosystem partners needed to maximize the benefits.

The proposed methodology also presents a quantitative phase, to solve the proposed problem by developing an integrate mathematical model taken from the variations of the VRP modeling. This is one of the most widely studied topics in the field of operations research, supply chain management and computer sciences to optimize transportation, logistics, distribution and delivery systems (Khabou, 2016). It follows the operation research modeling approach methodology of Hillier & Lieberman (2015) in order to formulate an inverse logistic closed-loop supply chain model. Figure 1 introduces a graphical representation of the proposed combined methodology.

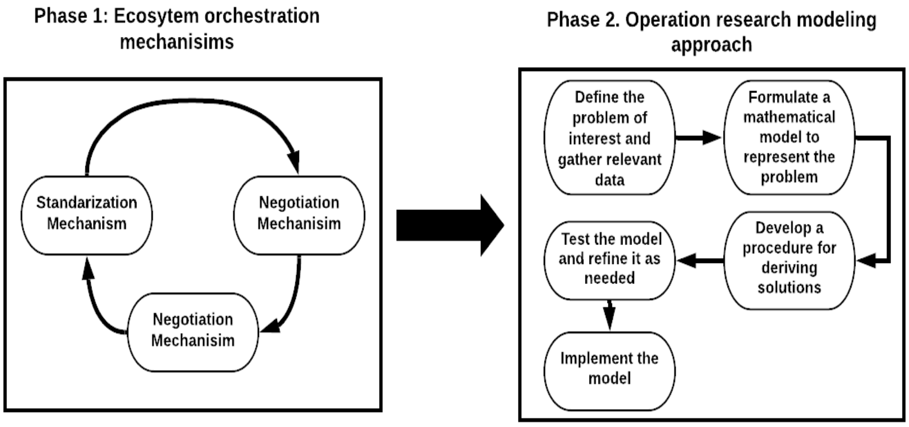

Figure 1. Proposed methodology.

The new methodology is focused on the evaluation of important mechanisms for implementing circular economy on manufacturing companies and complements it, with a deterministic model. The model helped the team in charge of each company, decide over the implementation of a suitable route that ensures the recollection of the maximum volume of products that have exhausted their life cycle. The role of each company was determined in previous meetings between both managers. Client A provides the plastic waste from all the stores, both individual restaurants and shopping malls, and the trucks for the routes of the individual restaurants. While CP will hire a third party logistic (TPL) to collect the plastic from shopping malls.

3.1 Phase 1: Ecosystem orchestration mechanism.

This phase is focused on the first steps needed to be applied to obtain real change in the company. It mainly includes Standardization, Nurturing and Negotiating mechanisms. In this phase several meetings where required to discuss with companies CP and Client A representatives.

3.1.1 Standardization Mechanism.

As mentioned by Parida et al. (2019), the study establishes industry standards associated with circular business models. Most of these standards and rules are defined by government entities. In Ecuador, there are not any formal laws regarding CE; therefore, policies designated for integral plastic handling (Ministerial Agreement No. 19, 2014), processed food transportation (Ministerial Resolution No. 67, 2017) and internal company regulations were used.

Through negotiations between the two companies involved, three statements were reached for this mechanism. These statements represent the interests of each company regarding how the CE mechanism should behave. The first, refers to sanitary concerns and refers to dry load (common nonorganic supplies) and recovered plastic, not being able to mix in the truck container. The second, refers to specific load and unload schedule that in the case of shopping malls, is defined by the mall and municipality. The third one, focuses on the recovered materials quality and the need that Client A should minimize the amount of non-plastic waste mixed with the desired plastic.

3.1.2 Nurturing Mechanism.

Nurturing activities, as defined by Williamson and De Meyer (2012) and Parida et al. (2019), are mechanisms that promote the development of the ecosystem and ease the transition towards CE. This often requires participants to bargain in early investment costs. Given the scope of the research, the resultant mechanisms focused on plastic waste recovery, associated costs, and initiatives. After the dialogue, Company CP, and Client A, agreed on investing resources to gather and transport recovered plastic material. Due to Company CP main focus being plastic manufacture, freight delivery to all its clients (including Company A) is handled by a third-party logistics company (TPL). Company CP will work with its TPL partner, picking up products from Client's A franchises located inside shopping malls. Client A will utilize its own fleet to recover products from individual restaurants. In addition, Client A agreed to invest in specialized trash cans and marketing campaigns to promote proper disposal of finished products in different trash cans.

3.1.3 Negotiation Mechanism.

The third key component towards CE is negotiation. Parida et al. (2019) described this mechanism as a give and take process, where the system orchestrator (company A) gives certain incentives to system partners. Given the fact that recovered plastic will be utilized as raw material for new products, an interdependent relationship between company A and B was created. These incentives and interdependent relationships are meant to promote a highly collaborative and motivated ecosystem.

Because of the project is in early stages, company CP was not able to define fixed economic incentives (discounts, exclusivity or preferential prices) for neither its third-party logistic partner nor Client A. However, this transition is meant to benefit economically and commercially all the stakeholders, by reducing financial expenses for both parties (environment taxes and sales permits) and improving public image. Once the qualitative phase defined the boundaries and mechanisms that will govern this new process, the next step to follow is the development of a quantitative model that will translate these mechanisms into mathematical constraints.

3.2 Phase 2. Operation Research Modeling Approach.

The following phase emphasizes on the planning and development of the reverse logistics model that can achieve the objectives of the study and business operational goals. This part is mainly based on Hillier & Lieberman (2015) operation research modeling approach. Following the steps of the aforementioned authors and considering some relevant data, and an integrated logistics model is formulated to seek equilibrated solutions. The goal is to maximize the volume of recollected finished products, while minimizing the travel distance to individual restaurants and visit every shopping mall within the established time windows. The scope of this investigation allows us to use the first four steps of the Hiller & Lieberman methodology (2015). Therefore, the steps presented below are the following ones:

1. Define the problem.
2. Formulate the model.
3. Develop computer-based procedure.
4. Test the model and refinement.

3.2.1 Define the problem of interest and gather relevant data.

Rubio & Jiménez (2014) found that, in practice, the most common approach in RL depends on the nature of the returned product (end of use or end-of-life) and the recovery process (remanufacturing, reuse, recycling). The objective of the present study is to retrieve 90% of the end of life cycle products that were sold to the Client A by obtaining the best collection route. As requested by the main client, Client A, the investigation's scope is mainly focused on individual restaurants and shopping mall restaurants located in the city of Quito. In addition, the facility location; capacity purchasing, production scheduling, inventory management, customer demand and transportation planning were also taken into consideration.

3.2.1.1 Possible industrial location sites for the new recycling facility.

Location decisions are strictly related to those of defining facility area boundaries (e.g. allocating demand to facilities). Outside the city limits, there are three main industrial yards that have potential properties for the creation of a recycling plant. These requirements where extracted from a former study allocated in the same city with the same legal boundaries and similar operational requirements (Cevallos, 2018). Two possible locations where defined, based on the following requirements: convenience, cost, industrial activities restrictions, location and land size (Cevallos, 2018). The third location was discarded due to excessive cost compared to the other two industrial yards. The following table contains information regarding each location.

Industrial Zone	Calacalí	Itulcachi
Types of activities in the area	Industrial, Heavy Industrial, Residential, Agriculture	Industrial, Heavy Industrial, Residential, Commercial
Available land >20.000 m2:	292,458 m2	332,308 m2
Distance from Company A to CP depot:	30.5 km	7.5 km

Table 1. Industrial parks locations.

3.2.1.2 Unit Load.

One important requirement for designing the reverse logistics models is the input demand of cutlery for each individual restaurant and the shopping mall restaurants. Since, this study is about a reverse logistic problem, the managed demand is going to be in terms of the expected quantity of cutlery recollected from each individual or shopping mall restaurant. This means the quantity of used product generated from each individual and shopping mall restaurant that can be recollected per month. Considering this information, to find an estimate of used cutlery that can be collected, a recovery factor of 31%, was obtained from the *Instituto Nacional de Estadísticas y Censos del Ecuador* (INEC) (2018). The factor is based on a study realized on 2018 in Quito (INEC, 2018). The study reveals that each month spawn *61,000 tons* of solid waste, and only *23,732 tons* could be recovered per month (INEC, 2018). From that, only 8% represent plastic waste, which amounts to *18,985 tons and is* equivalent to a *31 %* recovery index of the total solid waste in Quito. Hence, the recollected demand in each point is proportional to a recovery index multiplied by the total demand per month for each individual and shopping mall restaurants and ensure the recollection of the 80% annual production of cutlery by company CP. According to the information that company CP provided, it was found that each box represents one milliard of cutlery. Considering this information, alongside the recovery factor, the initial analysis that was centered on the milliards of recollected cutlery proved to be inefficient. Therefore, after discussing with company CP and Client A, it was determined that the recollection of the disposed product was going to be performed in a low-cost resistant plastic container called Totes Pan.

These plastic containers have the capacity to hold 925 units of cutlery each. Therefore, the measuring unit that was used in the investigation changed from the milliard units of cutlery to a plastic Tote. The dimensions of a Tote Pan are shown in Figure 2.

Length	45.5 cm
Width	30.5 cm
Depth	15 cm
Volume	20,816 cm3

Figure 2: Totes Pan dimensions.

The information of how many units fit in one Tote comes from calculating the number of forks and knives that fit in one Tote, based on the volume of the forks, knives, and Totes. Therein, it was determined that it is possible to fit 925 forks and knives inside of each proposed container. This result helped to determine an approximate quantity of Totes that could be recollected from the different restaurants and shopping malls. Then, another important result was to measure if the capacity load of the truck can bear the total recollected demand in Totes. To achieve that, it was considered the length and width of the Totes Pan and the truck's length of 3m and width of 2m. Thereby, the table below resumes the data obtained from the analysis of the demand and the dimensions.

	Data
Totes per layer	36
Layers per truck	6
Truck load Capacity (Totes)	216
Required Area (m^2)	5
Available Area (m^2)	6
% Utilization Area	83%
Total demand of Totes for local (monthly)	1814
Total weight of Totes (Tons) per month	5.47

Table 2: Result of the capacity load for each Truck and total monthly demand of Totes.

The table above ensures that the truck's capacity load of 216 Totes could satisfy the total demand with a utilization area of 83% for each truck, which represents a good percentage, since the recycling business is based on volume. Furthermore, according with the information given by the company CP, 55% of its total production of cutlery is destined to Client A (Company CP, 2019). This means that monthly, Client A receives *19.19 tons of product.* Table 2 above shows that the study can ensure a recollection of *5.47 tons* of used product per *month* with capacity truck of *216 Totes.* The tons collected represent the *28.54%* of the total cutlery produced per month destinated to Client A.

3.2.1.3 Assumptions and Limitations.

Based on the different locations, demands and restrictions of each individual restaurant and shopping malls, two different RL models were used. The first model for individual restaurants, in which only the truck's capacity was considered, and the other model for shopping malls, where time windows were considered in addition to the capacity. Furthermore, there were some assumptions that needed to be considered before going on with the study. First, because the individual restaurants are located in different parts of Quito, Client A had already established a delivery route. Also, Client A has a fleet of their own to fulfil these establishments, so the costs related to transportation are not taking into account and only the trucks' capacity was an important factor. Then, the restaurants inside shopping malls were evaluated with a different logistics approach because the shopping malls are restricted by time windows over the service schedule. Also, the delivery process was provided by a third-party logistics company, where the transportation costs associated per truck were considered.

General Assumptions:

- The overall demand for each individual and shopping mall associated restaurants, is deterministic.
- Only a single product is considered in the proposed model, the cutlery, as defined by Company A's representatives.

- There is a given return ratio of 31%. It is referring to the proportion of the quantity of used products returned from end-customers, and through the reverse logistics chain.
- There are only 2 possible locations to position the recycling depot.
- The distance from the distribution center of Client A between to the restaurants and shopping malls it is not considered.
- The costs of the reverse logistics do not consider processing at the distribution center, and fixed costs of the establishment for the proposed disposal.
- Due to lack of information, the time windows for each shopping mall were not available for this investigation. Therefore, two types of schedules were used, just the traffic on the morning and the traffic on the night.

Individual restaurants assumptions:

- Client A has their own pre-established facilities, a 1 level distribution center (DC). They supply to their restaurants using their own logistics management fleet.
- For the reverse logistic actions, the transportation fleet provided by Client A is homogeneous. This means that the group of trucks have the same capacity (Khabou, 2019)
- The transportation costs between the proposed recycling plant and every successor node is proportional to the Euclidean distance between the depot (recycling facility) to the different nodes (individual restaurants).

Shopping Malls restaurants assumptions:

- On this case a third-party fleet will provide the reverse logistics management. This fleet it going to be hired by the company CP.
- The quantity of collected used products from end-customers is given at any time inside the time windows intervals.

- The demand of collected product for each shopping mall is treated as the combination of several restaurants that belong to Client A.
- The shopping malls are treated like one point even though there are multiple restaurants that belong to Client A inside the mall.

3.2.2 Formulate model to represent the problem.

To implement a mathematical model, it is important to create an objective function (Hillier & Lieberman, 2015) and to understand the main approach over the benefited companies. According to Shue et. al. (2005) there is a lack of appropriate models that can be used as valuable and effective tools. Previous methods seem limited to specific applications for a single firm or a limited number of chain members, rather than focus on optimization across a reverse logistics flow (Shue et. al. 2005). Thereby, considering the limitations of applying the existing models for RL management, the present study proposes an integration and modification based on two well-known routing optimization models to adapt them into the reverse logistic context. The first modified model for individual restaurants is an adaptation based on the logic of the Capacitated Vehicle Routing Problem (CVRP) and the known Vehicle Routing Problem (VRP). The second model for restaurants inside the shopping malls, is based on the CVRP modified model and the Vehicle Routing Problem with Time Windows (VRPTW) logic.

The indexes of the different parameters used, the decision variables, the objective functions, and constraints for the modified CVRP are explained below.

Notations & Index CVRP.

$n \quad set\ of\ nodes\ (restaurants)$
$n = 1,2, \dots n$
$i \quad index\ of\ individual\ restaurants\ 'i'$
$j \quad index\ of\ individual\ restaurants\ 'j'$
$k \quad index\ of\ vehicles\ that\ cross\ through\ i\ and\ j, \qquad k = 1,2 \dots k$
$K \quad set\ of\ vehicles \qquad K = \{1,2, \dots, |K|\}$
$A \quad set\ of\ arcs \qquad A = \{(i, j) \in V \times V : i \neq j\}$
$N \quad set\ of\ destinations\ \ N = \{1,2, \dots, n\}$

$r \quad set\ of\ sequences\ of\ routes$
$r = (i_0, i_1, \ldots, i_s, i_{s+1}), i_{s+1} = n.$
$i_0 \quad last\ restaurant\ from\ the\ direct$
$logistics\ route.$
$i_{s+1} \quad final\ facility\ location.$

Parameters.
$D_{ij} \quad set\ of\ the\ minimal\ distances\ between\ the\ node\ i\ to\ j.$
$S \quad cluster\ with\ the\ set\ of\ restaurants'i'.$
$S = \{i_0, \ldots, i_n\} \subseteq N$
$u_{ik} \quad amount\ of\ collected\ demand$
$from\ the\ node\ i\ served\ by\ the\ vehicle\ k.$
$Q \quad vehicles\ capacity.$
$q_i \quad aproximate\ amount\ of\ collected\ demand$
$from\ restaurants\ and\ Shopping\ Malls.$
$q_0 \quad demand\ of\ final\ facility\ location. q_0 = 0.$
$u_{jk} \quad amount\ of\ collected\ demand$
$from\ the\ node\ j\ serve\ by\ the\ vehicle\ k.$

Decision Variables.
$x_{ij}^k \quad 1\ if\ and\ only\ if\ a\ vehicle\ k\ traverses\ an\ arcs$
$(i,j) \in A, 0\ otherwise.$
$y_{ik} \quad 1\ if\ customer\ i\ es\ served\ by\ vehicle\ k\ and$
$takes\ 0\ otherwise.$

The modified CVRP was structured as a directed map with $M = (V, A)$, where $V= 0 \cup N = \{1,2, \ldots, n\}$ is the set of n vertices (or nodes) (Bräysy & Gendreau, 2005), represented by the individual and shopping malls restaurants. Where point 0 is the last restaurant from the route of the initial direct logistic route given by Client A. Also, the structure includes the set of arcs $A = \{(i, j) \in V \times V: i \neq j\}$, and a final depot, the proposed recycling facility, denoted as point n. The amount that must be collected from the restaurant $i \in N$ is the restaurant's forecast collected demand, $q_i \geq 0$, with qo = 0 for the depot. The fleet $K = \{1,2, \ldots, |K|\}$ is assumed to be homogeneous, meaning that $|K|$ vehicles are available at any time, all have the same capacity $Q > 0$. A vehicle moving from node i to node j incurs the travel cost $c_{ij}$for $(i, j) \in A$. However, as explained in the assumptions, the cost of travel will be the Euclidean distance between every successor node making $c_{ij}= D_{ij}$for better understanding. On the other hand, the sequence on a route is represented as $r = (i_0, i_1, \ldots, i_s, i_{s+1})$ with i_{s+1} = n, over the cluster S = $\{i_0, \ldots, i_n\} \subseteq$

N that contains the restaurants visited. Finally, the model uses two binary variables x_{ij}^{k} and y_{ij}^{k}. The first one, x_{ij}^{k}equals 1 if and only if a vehicle k traverses an arc *(i, j)* ∈ A, and 0 otherwise. The second one, y_{ij} takes 1 if customer i is served by vehicle k and takes 0 otherwise. The mathematical formulation can be stated as follows:

$$Minimize \; = \sum_{(i,j)\in A, k\in K} D_{ij}\, x_{ij}^{k} \qquad (1.1)$$

The objective function (1.1) aims to find an arrange of routes that minimize the overall routing distance ensuring that each vehicle passes through all individual restaurants just once.

Subject to constraints:

$$\sum_{k\in K} y_{ik} = 1 \quad \forall\, i \in N \qquad (1.2)$$

$$\sum_{k\in K} y_{ok} = K \quad \forall\, i \in N \qquad (1.3)$$

$$\sum_{i=0, i\neq j}^{n} x_{ij}^{k} = 1 \quad j = 0, \ldots, n \qquad (1.4)$$

$$\sum_{j=0, j\neq i}^{n} x_{ij}^{k} = 1 \quad i = 0, \ldots, n \qquad (1.5)$$

$$\sum_{j\in V} x_{ij}^{k} = \sum_{j\in V} x_{ji}^{k} = y_{ik} \;\forall\, i \in V, k \in K \qquad (1.6)$$

$$u_{ik} - u_{jk} + Q\, x_{ij}^{k} \leq Q - q_j$$

$$\forall\, (i,j) \in A, k \in K \qquad (1.7)$$

$$q_i \leq u_{ik} \leq Q \quad \forall\, i \in V, k \in K \qquad (1.8)$$

$$x_{ij}^{k} \in \{0,1\}, \quad \forall\, (i,j) \in A, k \in K \qquad (1.9)$$

$$y_{ij} \in \{0,1\}, \quad \forall\, i \in V, k \in K \qquad (2.0)$$

Where constraints (1.2) and (1.3) impose that each customer is visited exactly once and that $|K|$ vehicles leave the first restaurant. Constraints (1.4) and (1.5) are taken from the Travel Salesman Problem (TSP) restrictions in order to ensure that there is exactly one departure from what is defined as point zero. Those constraints allowed the model to define the start and end points of the routes due to the fact that on reverse logistic modeling, the initial point of the reverse routes is the last point from the direct logistic routes (Client A, 2020).

On the other hand, constraint (1.6) represents the flow connectivity constraints, i.e. the same vehicle enters and leaves a given restaurant. Constraint (1.7) is for the elimination of any subtour over a non-empty cluster subset $S \subseteq N$ (S ≠ 0). The creation of the variables u = (u_{1k}, …,$u_{nk})^T$ is to indicate the accumulated demand u_{ik} already recollected by the vehicle k when arriving at customer i ∈ N. constraint (1.8) is the capacity constraint, which states that the demand cannot exceed the capacity of each vehicle. Finally, constraints (1.9) and (2.0) impose binary conditions on the decision variables.

In order to develop the model for the shopping malls' restaurants, the same logic used for individual restaurants model was used since this problem also requires the consideration of capacity, demand and subtours constraints. Taking into account that a new model is developed based on the previously presented CVRP model adding some modifications. The new additions were three new constraints and a set of new variables which are going to be presented further in the reading.

First of all, constraints (1.4) and (1.5) presented on the modified CVRP are not going to be considered for the development of the modified CVRP with time windows because, both, initial and final points are going to be the same this time. So, the depot was established as point 0 as well as *(n + 1)*, with each arc *(i, j)*, where $i \neq j$. Thus, the start and destination depot nodes become identical because the depot is split so the vehicle routes are no longer circuits, but paths from the start depot node to the destination depot node. Therefore the sequence on a route is represented as r = (i_0, i_1, …, i_s, i_{s+1}) with i_0= $i_{(s+1)}$ = 0, in which the set of points (shopping malls) is represented in the cluster S = {i_0, …, i_n} ⊆ N2. The proposed model has a set of new different parameters used, decision variables, an objective function, and three more constraints that are explained below.

Notations & Index CVRPTW.

$n \quad set\ of\ nodes\ (Shopping\ Malls\ )$
$n = 1{,}2, \ldots n$

$i \quad index\ of\ Shopping\ Malls\ 'i'$
$j \quad index\ of\ Shopping\ Malls\ 'j'$
$0 \quad index\ of\ final\ facility\ location.$
$N2 \quad set\ of\ destinations\ with\ starts\ \&\ ends$
$the\ final\ facility.$
$N2 = V \backslash \{0, n+1\}.$
$M \quad really\ big\ constant.$

Parameters.

$c_{ij} \quad set\ of\ minimal\ asociated\ time$
$between\ node\ i\ to\ node\ j.$
$[a_i, b_i] \quad the\ interval\ defined\ by\ the\ time\ window$
$t_{ij} \quad the\ existing\ time\ traveled\ between\ the\ node\ i$
$to\ j\ (i,j) \in A, served\ by\ the\ vehicle\ k\ .$
$[E, L] \quad the\ time\ window\ of\ the\ final\ facility$

Decision Variables.

$x_{ij}^{k} \quad take\ 1\ if\ and\ only\ if\ a\ vehicle\ k\ traverses\ an$
$arcs\ (i,j) \in A, 0\ otherwise.$
$y_{ik} \quad take\ 1\ if\ customers\ i\ is\ served\ by\ vehicle\ k\ and$
$takes\ 0\ otherwise.$
$w_{ik} \quad the\ service\ time\ for\ each\ node\ i\ served$
$by\ a\ vehicle\ k.$
$w_{jk} \quad the\ service\ time\ for\ each\ node\ j\ served$
$by\ a\ vehicle\ k.$

The structure of this modified model is seen on the notation and index above (CVRPTW). The model now establishes that each customer i is restricted to a time window $[a_i, b_i]$. A vehicle must arrive at customer before b_i, but the customer will not be serviced before a_i. The depot also has a time window [E, L], which defines the earliest possible departure from the deposit and a possible later arrival at the deposit. To complement the model, it is assumed that Q, a_i, b_i, q_i, c_{ij} are non-negative integers, while the t_{ij} are assumed to be positive integers. Finally, the model contains three sets of decision variables x_{ij}^{k} and w_{ik}. The mathematical model is stated as follow:

$$Minimize\ = \sum_{(i,j) \in A, k \in K} c_{ij}\, x_{ij}^{k} \qquad (2.1)$$

Where new the objective function (2.1) aims to minimize not only the number of vehicles required, but also the total travel time, waiting time, and total travel distance incurred by the fleet of vehicles. The constraints are the following ones:

Subject to constraints:

$w_{ik} + t_{ij} + M(1 - x_{ij}^{k}) \leq w_{jk} \quad \forall\, (i,j) \in N2, k \in K$ (2.2)

$a_i \leq w_{ik} \leq b_i \quad \forall\, (i,j) \in N2, k \in K$ (2.3)

$E \leq w_{ik} \leq L \quad \forall\, (i,j) \in N2, k \in K$ (2.4)

Where constraint (2.2) establishes that a service cannot be started at j if the customer i has not been attended and vehicle k has not reached customer j. Constraint (2.3) defines that the service time must start within the time window of each shopping mall and the time window for the depot (in this case the proposed recycled plant).

The two models are suitable because they include transportation capacities, the volume of the returned products, collecting points, time restrictions of different locations and final disposal locations. Furthermore, as Sheu et al (2005) suggested, the present study considered the best potential scenario that considers effects from corresponding governmental regulations, environmental restrictions, and end-customer behavior, e.g., willingness to return the product.

3.2.3 Development of computer-based procedure for deriving solutions.

With the mathematical models ready and all constraints taken into consideration, the next step of the study was to develop a functional tool that gives relevant results. For the development of the RL model, Google’s Operations Research tools (OR-tools), Google’s APIs and the software Python were implemented. OR-tools is an open source software specialized in the optimization of vehicle routing problems and constraint programming (Google developers, n/d). The decision to use this specific software, alongside Python, is due to the fact that it showed a wider range of investigation from different perspectives. It showed how to integrate and implement them into a new model, and it is also available for anyone to use, thus, it does not require licensing from a third party. On the other hand, Google's APIs helped to obtain the distance and time matrices for all the locations; this made the task of obtaining distances and times easier.

3.2.4 Test the model and refinement.

3.2.4.1 Initial testing.

After obtaining a functional model, the initial testing was performed with all the locations placed into a single matrix. This gave no results, meaning that there was no feasible answer. The reason for this initial result was that the amount of data that the model received was too big to process. This is because the integrated model derives from an original VRP, which is an NP-hard type of problem. As mentioned before, the more data placed into the model, the less likely it is to obtain a feasible solution. Further analysis had to take place in order to obtain a feasible answer. According to Barreto et al. (2007), a heuristic approach needed to take place in order to obtain a feasible solution, the approach is called group first, model second, which means that every location point had to be placed into a cluster and then the model could be implemented in each group to find the best routes.

3.2.4.2 Cluster analysis.

For the first model, a cluster analysis within individual restaurants was developed. The locations of the restaurants can be seen in the figure below.

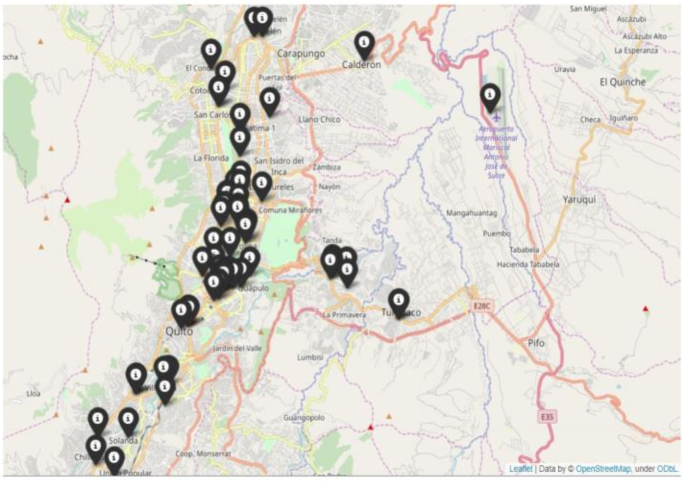

Figure 3. Locations of individual restaurants.

The K Means clustering technique was used alongside the Python software which allowed the use of the elbow curve technique to determine the number of clusters. As shown in Figure 4, the number of clusters to use is represented at the point where the curve starts to flatten, in this case 8 clusters were selected.

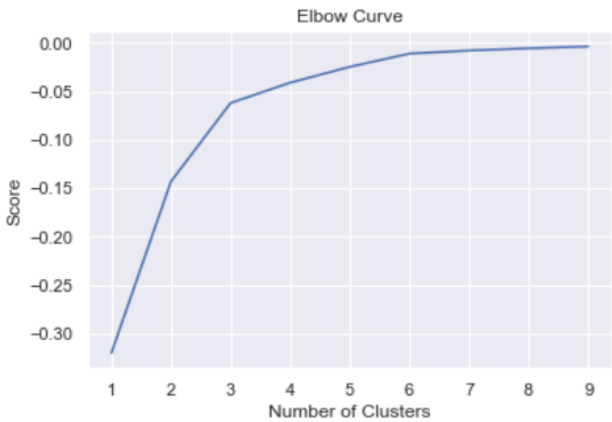

Figure 4. Elbow curve.

After analyzing the curve, the determined number of clusters to make was set to 8 as it shows more stability in the curve. The resulting clusters are shown on the next figure.

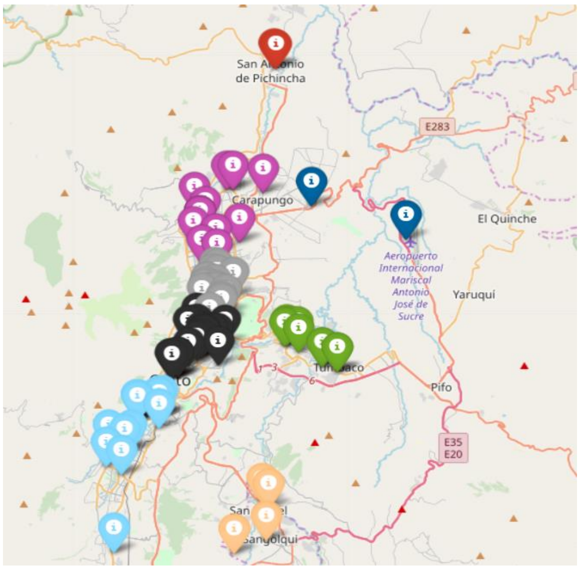

Figure 5. Locations points after cluster analysis.

As shown in Figure 5, there are 8 distinct clusters that were identified, but after further analysis the number decreased. First, the red cluster at the top of the figure was not considered in the development of the model because it is a location where the demand is low, and the delivery trucks do not go there as often as the other points. Then, the dark blue clusters were separated because they represent only two isolated points and creating an additional route is not worth it. The first location is now part of the pink cluster and the remaining point, located inside Quito’s international airport, was deleted since it follows airport rules and does not act as an individual restaurant. After these analyses, the final clustered map is shown in the figure below.

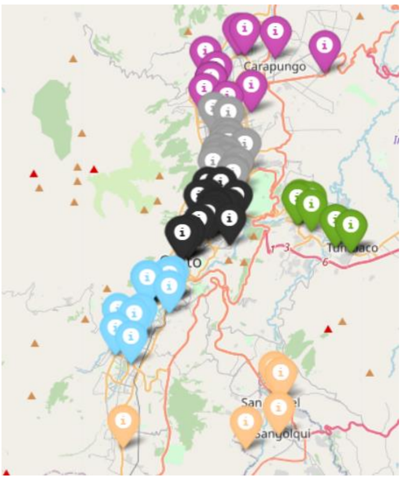

Figure 6. Locations points after final cluster analysis.

After clustering, the mathematical model could be implemented in each cluster with the objective of finding the best route to collect the used plastic. Another problem appeared when the model was tested in both black and gray clusters. The data among these two clusters was still too big for the model to give a feasible solution, therefore a sub-clusterization was performed on both clusters. The first sub-clusterization was performed on the black cluster. The figure below shows the initial size of the cluster and how it changed once the aggrupation was finished.

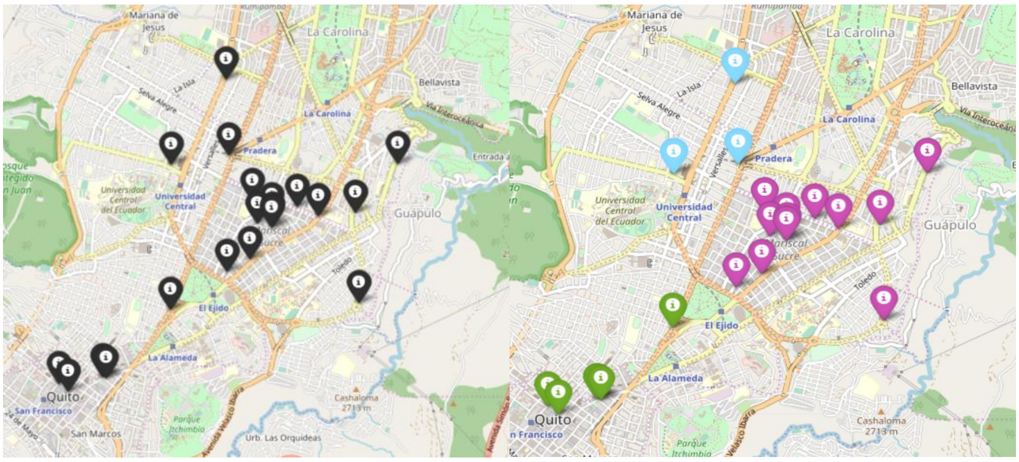

Figure 7. Sub-clusterization of black cluster.

The same process was performed for the gray cluster.

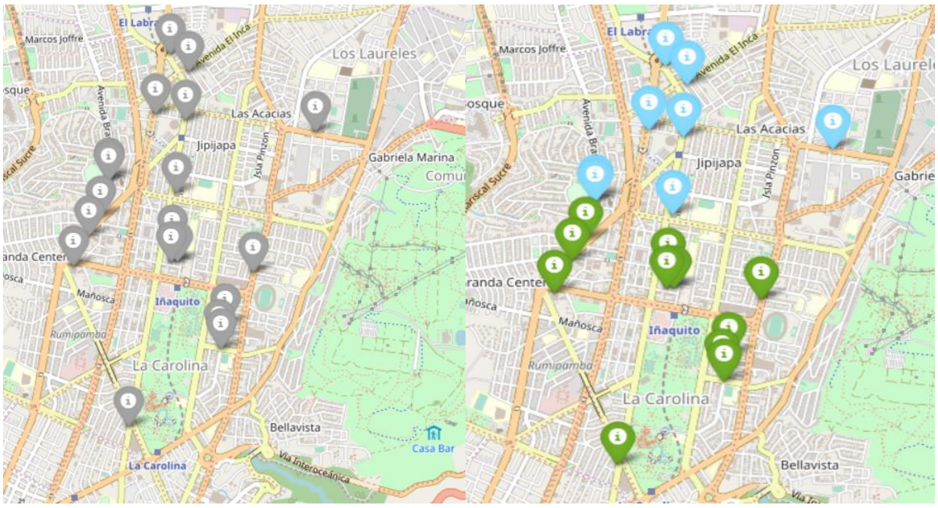

Figure 8. Sub-clusterization of gray cluster.

After the sub-clusterization, the model had to be changed as well. Now, the initial point was the same defined earlier, but the final point of each sub-cluster had to be an initial point of the next sub-cluster, and not the final location. Only in the last sub-clusters of each main cluster the two locations points were tested.

The analysis for shopping malls is almost the same as the one for individual restaurants. The figure below shows all the shopping malls located in the city of Quito.

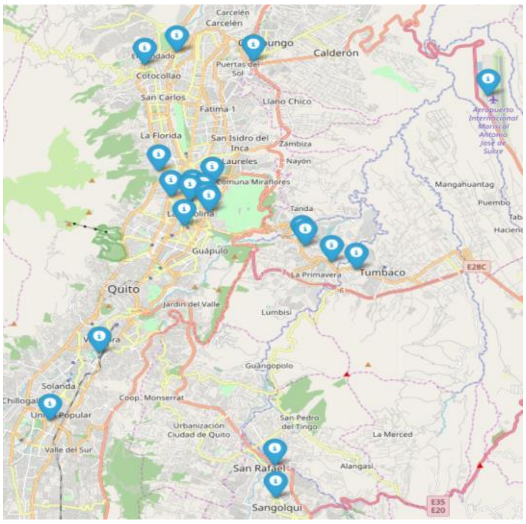

Figure 9. Locations of shopping malls.

These locations were also clustered, this time only by regions, as shown in the figure below.

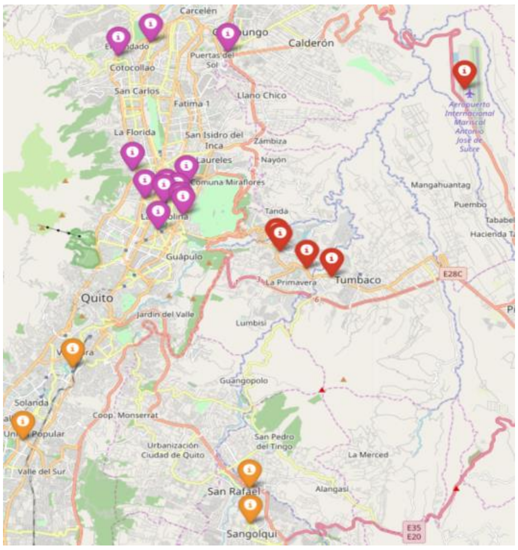

Figure 10. Clusters by regions for shopping malls.

As it is shown on figure 10, there are 3 main regions in the map. The purple cluster represents the Center-North region, the red cluster represents the region of Cumbaya and Quito’s International airport. Finally, the orange cluster represents the South-Valley region.

After the clusterization for the second model, another assumption had to be made regarding the time windows to be used. For the morning time window, the hours allowed for the retrieval of the finished products were set from 6 to 9 a.m. and for the night shift, the hours were set from 9 to 11 p.m. Finally, for each point inside the clusters, the hours in which the truck could make a visit were randomized in order to have a model which is as robust as possible and could adapt to any scenario.

4. Results.

After performing all the analysis required to obtain an adequate dataset for both, individual restaurants and shopping malls, the CVRP model for individual restaurants and the CVRPTW for shopping malls were implemented for their respective datasets and the results obtained are the following:

4.1 Individual restaurants.

After the clusterization and sub-clusterization of the locations, the first CVRP model was tested and it gave the following results.

	Distance traveled (KM)						
Location	Black Cluster	Gray Cluster	Light blue Cluster	Green Cluster	Purple Cluster	Beige Cluster	Total distance traveled (KM)
Zone 1: Calacalí	44.73	41.66	69.59	50.49	61.08	64.91	332.46
Zone 2: Itulcachi	47.63	48.68	70.32	37.12	79.6	30.71	314.06
Vehicles	1	1	1	1	1	1	

Table 3. Total distance traveled for individual restaurants.

Table 3 shows the total distance traveled in each cluster and the overall distance. Also, for each cluster the same amount of trucks was used; 6 in total, 1 for each cluster. The final result shows that Zone 2, located in the region of Itulcachi, is the best point to serve as a recycling center since it is the location where the vehicles travel the least distance. Finally, the table below shows how many totes each route from each cluster is set to retrieve. It is worth mentioning that the number of totes retrieved is not influenced by the location.

Totes retrieved per cluster						
Black Cluster	Gray Cluster	Light blue Cluster	Green Cluster	Purple Cluster	Beige Cluster	Total totes retrieved
35	29	33	22	30	12	161

Table 4. Total totes retrieved per cluster.

With these results obtained, we assure that all the finished product is retrieved from each individual location. The results also showed that each truck's capacity is more than enough to fulfill the routes because each truck only reaches an 83% of its capacity. Therefore, there is room to increase the volume of finished product that can be obtained from each restaurant.

4.2 Shopping malls.

The same procedure was performed for all the shopping malls. For the distance traveled, the same comparison with the two regions was conducted and the results are shown in the table below.

	Distance traveled per cluster [km]			
Location	Red Cluster	Purple Cluster	Orange Cluster	Total distance traveled [km]
Zone 1: Calacalí	128.82	239.85	115.21	483.88
Zone 2: Itulcachi	142.53	276.53	96.91	515.97
Vehicles	1	2	1	

Table 5. Total distance traveled for shopping malls.

In this case, Zone 1 located in the region of Calacalí, is the optimal location. Also, a total of 4 trucks were used in this model. One for red and orange clusters and two for the purple cluster.

The results for the total number of totes retrieved for the shopping malls is presented in the table below.

Totes retrieved per cluster			
Red Cluster	Purple Cluster	Orange Cluster	Total totes retrieved
83	217	169	469

Table 6. Total totes retrieved for shopping malls.

As the table above shows, the number of totes retrieved from the shopping malls is greater than the number for individual restaurants because the amount of people who visit these malls outnumbers the restaurants, thus, the percentage of recovered plastic of restaurants located in malls is 291% higher than individual restaurants.

After comparing the results of the two models, the next step was to select the final location for the recycling facility. Zone 1 was the selected one for the CVRP model, but the difference in distance is considered to be low (18 km difference). On the other hand, Zone 2 was selected on the CVRPTW model with a difference of 32.09 km from Zone 1. Apart from this result, the number of totes retrieved from each model also weights in the selection of the new location. A difference of 308 totes in favor of shopping malls alongside the difference in distance, makes Zone 1 located in the region of Calacalí, the optimal and strategic place for CP to locate the new facility.

5. Conclusions.

After doing the respective analysis of information, conducting meetings with company CP and Client A and conducting an investigation about reverse logistics models, the development of two reverse logistic models was successful. A CVRP model for individual restaurants and a CVRPTW model for shopping malls proved to be the right course of action to take due to their different characteristics and requirements. After developing the models, and the comparison between the two candidate locations for the recycling facility, it was determined that the appropriate zone to locate the recycling facility is Zone 1 in the region of Calacalí. This decision was determined after comparing the total distance traveled to each possible ending point and the number of possible Totes retrieved for, both, individual restaurants and shopping malls.

Even though, at the beginning it was initially concluded that Zone 2 located in Itulcachi was going to be the selected one because it gave the least distance traveled for individual restaurants, the second model proved to be the most efficient one in terms of distance and number of retrieved totes. For the second model, due to unforeseeable events, the time windows had to be randomized due to a lack of information; the results obtained may vary once the correct time windows are applied, but the results obtained at the moment were satisfactory enough to conclude that this model is robust enough to changes, for example increasing the demand of each restaurant, number of trucks used or the amount of new restaurants added in the map. With the total amount of retrieved Totes, it was calculated that the routing model could be recover an estimated amount of 76% of the total annual demand for Company CP. This means that the main objective of retrieving 80% of the total demand from Client A could not be fulfilled, but this result could change if a pilot test is conducted in order to increase the percentage of product recovered and apply it to the calculations.

Finally, from a technical point of view, the implementation of the two models was successful with both models giving realistic results. It was determined that the amount of data that is used to run the models influences on the results. The more data used in the model, the less likely it is to find a real result. As it was mentioned early in the investigation, the implementation of the 'model first, program second' heuristic proved to be the most effective approach for this case study. As the new two stage methodology implemented in this investigation presents, a company that is willing to implement CE to their day-to-day activities needs to join forces alongside RL methodologies in order to create a well-orchestrated system where both, clients and manufacturers work together to reach a common goal. The model has proved to be an efficient tool to determine an estimate of how much disposed product a RL route could retrieve from different places. The present investigation is an important step into the development of techniques for companies to start considering moving to a CE model. Not only because it will benefit the company's interests, but it could change the way people understand how important the environment is and how we could help to preserve it.

6. Limitations of the present study:

- Due to political constraints a pilot study could not be performed. This pilot would help to determine a more real recovery percentage of plastic that can be retrieved from the individual restaurants and shopping malls. The recovery percentage that was used is an approximate percentage of 31% obtained from the *Instituto Ecuatoriano de Estadísticas y Censos* on 2018.

- For the second proposed model which focuses on shopping malls, it the recovery demand considered was only from restaurants that belong to the Client A’s brands.
- Other restaurants inside the shopping malls are not considered because the information was not available.

7. References.

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