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Logistics optimization for Circular Economy: A vehicle route planning based analysis

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ABSTRACT:
The main aim of this dissertation was to create effective and budget friendly vehicle routes for the removal of animal byproducts which fall under the risk category one in response to the allegation made by the European Free Trade and Association (EFTA) court on Iceland for not following the protocols with regard to this matter. Furthermore, determining number of vehicles and finding the ideal location for factory set up were other main tasks in this research. In addition to this, primary research method was Open door logistics, a tool to create advance vehicle routing. The key methodology used was to create routed based on the one-day, two-day and three day-demand. This was done by first calculating the cycle time. Thereafter, cycle time was used to calculate the visit frequency by utilizing the randbetween function in excel to have the demand specific routes. Thereafter, 40 different scenarios were listed based on demand, number of vehicles, time limit within with each entire process should be finished and all scenarios were then simulated in ODL to test their feasibility. After running the simulation 7 scenarios were found out to be feasible which were then compared on the basis costs, vehicles used. However, since cost was most imperative key performance indicator the scenario with the least cost was selected to be the optimal solution which came out be scenario 16. Thus, it was concluded that the operations should run every three days, with six vehicles in use, costing roughly around 796,000 euros/year, whereas, Dysnes in the Northern Iceland was selected as the potential location for the factory installation.

KEYWORDS: Circular Economy, vehicle routing, Cycle time, Visit Frequency, Randbetween

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Abbreviations

CE	Circular Economy
EFTA	European Free Trade Association
SCM	Supply Chain Management
GSCM	Green Supply Chain Management
SSCM	Sustainable Supply Chain Management
CLSCM	Closed-Loop Supply Chain Management
UNEP	United Nations Environment Programme
TMS	Transportation Management System
ODL	Open Door Logistics

1 Introduction

This dissertation highlights the logistics planning problem that GMM Finland faced in pursuing a circular economy for animal by-product collection in consultation with an Icelandic company for their logistics operations in Iceland. The project revolves around the circular economy model, which helps minimize the use of materials, reuse, and recycle, reducing waste and environmental impacts (Skelton, 2013). Consequently, this research is motivated by the need to enhance conventional waste systems by reducing their environmental impacts in animal by-product processing and handling.

GMM Finland, a consulting group of Honkajoki Oy, is a pioneer in sustainable economy. As per Aho (2022), the company, which processes animal by-products, is a well-known example of a sustainable business and a way of achieving zero waste by turning waste into goods. This research concerns the logistics consulting by GMM Finland with a local Icelandic company, covering the animal by-products picking up, transportation, and processing to improve efficiency and sustainability.

The paper explores different planning scenarios for GMM Finland, which would make business processes easier, minimize environmental impact, and help to achieve a circular economy. An example of this problem and importance was the company's consultation with an Icelandic business on truck routing to establish sustainable collection routes for animal carcasses. Such collaboration is responsible for transporting high-risk animal by-products, e.g., category one, stressing the complexity of logistics planning in the face of tight legal and environmental requirements (Tapia et al., 2021).

These researches aim to identify the most suitable logistics systems for the local company to use when transitioning towards a sustainable and regenerative business model. This research discusses the industrial and environmental implications of circular economy practice above GMM Finland's business advantages. The current dissertation offers momentum to an industry that is gaining more popularity in academia, i.e., sustainable supply chain management and circular economy, which is done by unveiling the logistics planning scenarios and their challenges, opportunities, as well as the inferences they have on companies that are transitioning to the sustainability front. Consequently, the research authors (Arora et al., 2021) claim that logistics planning is the fundamental stage in the circular economy, as demonstrated by the GMM Finland case. The objective of the research is to inspire and provoke other sectors to carry out similar initiatives, which will help achieve higher levels of resource use that is more conscious and energy efficient for environmental conservation.

1.1 Research Background

The circular economy (CE) is the model that highlights resource efficiency, the minimization of wastes, and a closed-loop production and consumption system instead of linear economic models. It has been determined in the research of Barros et al. (2021) that the historical way of doing things, which is "take-make-dispose" and has been embedded into industrial operations for a long time, is ultimately the opposite of this principle. CE principles are that goods and resources should be used for as long as possible to exploit their maximum value, then recycled after use.

Moreover, GMM Finland, a Finnish processor of animal by-products, is not just a player in the circular economy but a pioneer. It sees the circular economy as a significant and challenging gain (Saha et al., 2022). GMM Finland transforms animal by-products from slaughtering and processing industries into valuable materials for medicines, pet food, and energy, showcasing an innovative approach to waste management. As anticipated in Camilleri's (2020) study, the business, though specialized, plays a crucial role in waste management and processing. The firm is at the forefront of the circular economy by taking measures to eliminate waste and reuse resources.

Therefore, Ciliberto et al. (2021) strongly recommended in their research that the company's contribution to the circular economy heavily relies on the collection, transportation, and processing of animal by-products. The role of logistics planning in this context cannot be overstated. It is about reducing costs and ensuring environmental conservation and safe and on-time delivery of raw materials (Reddy & Kumar, 2021). However, it is essential to note that implementation has challenges. These include following health and safety protocols, dealing with high-risk cargo, and maximizing transit routes and processing capacities.

GMM Finland collaborates with a local company to construct a factory and logistics for further product collection in Iceland, showing how logistics planning is essential to the circular economy (Orko et al., 2022). Iceland received criticism from the EFTA Surveillance Authority and the EFTA Court for not respecting the animal by-product treatment duties as concluded in the EEA agreement. In addition to this, Dutta et al. (2021) have emphasized in their study that as a follow-up measure, the Icelandic government and GMM Finland are working on a satisfactory animal waste collecting system that is well coordinated, environmentally safe, and conforms to relevant standards, regulations, and guidelines. Thoughtful logistics planning is necessary for international compliance and sustainability of waste management, which this attempt could notice.

Furthermore, this statement has been supported by Gupta and Singh (2021), who state that the logistics planning scenarios for the GMM Finland Company's circular economy approach to animal by-products are developed under environmental sustainability, legal compliance, and operational performance quality. The paper studies whether the company's logistics operations can be improved to contribute to the circular economy. This research focuses on carrying out the best material collection routes, appraising the consequences of alternative production sites to animal waste, and deciding the optimal number of trucks for animal waste transportation.

Moreover, some of the financial support is received from the global trend covering sustainable supply chain management and the problems and opportunities facing GMM Finland (Nandi et al., 2020). Green initiatives and the incorporation of circular economy concepts into its business model are the company's core values and make it a promising candidate for researching circular economy logistics and supply chain management. The research on the utilization of animal by-products in Iceland brings its specificity due to the legal and regulatory issues on the subject.

The study is based on detailed research in modern literature on the supply chain management (SCM) methodology and its harmonization with the circular economy principles. It has been seen in the context of environmental and social performance that various SCM approaches like Green Supply Chain Management (GSCM), Sustainable Supply Chain Management (SSCM), and Closed-Loop Supply Chain Management (CLSCM) are explored; however, there is still a lack of integration with the circular economy objectives in the literature. Through this study, one hopes to fill the gap between the current logistics planning mechanisms and the needs of a circular economy, which is especially important for the animal by-product industry, and the practical reality of GMM Finland.

1.2 Research Objectives

Logistics planning scenarios for processing and transferring animal by-products in a circular economy are critical for environmental sustainability, regulatory compliance, and operational efficiency. As per Mallick et al. (2023), society is the timing for the research as the circular economy model has become a widely applicable trend among global companies. The model focuses on sustainable corporate practices. This study discloses GMM Oy's complex issues and advantages towards implementing circular economy concepts in logistics, particularly in Iceland's animal by-product collecting and processing.

This study aims to pay attention to the circular economy as an innovative way for companies around the globe to reduce the waste of resources and maximize the process of repurposing and recycling materials. Among important environmental sustainability issues, one can point out animal by-product processing (Kouhizadeh et al., 2020). Considering word gathering, transferring, and recycling according to circular economy rules, one may practice this approach by other companies. Nevertheless, this study tries to optimize logistics planning and circular economy objectives by minimizing negative environmental impacts, improving resource productivity, and complying with the most stringent regulations.

GMM Finland, the Finnish company that has become known for its utilization of native animal waste, is the organization that started these endeavors. The organization's activities are a kind of menu that shows the problems and prospects of sustainable logistics. The investigation of the collaboration between the Icelandic company and GMM Finland (Neto & Correia, 2019) denotes the organization's strife in achieving operational efficiency and environmental policy. This agreement was made to provide a logistics base that would be convenient for implementing risk category one animal by-products by the guidelines set by the Icelandic Ministry of Food, Environment, Energy, and Nature (Hazen et al., 2021).

This study is based on the idea that the combined use of transportation routes and logistics with the circular economy goal can be a factor that accelerates the rate at which the circular economy advances. This research will evaluate logistics planning options in terms of their success in reducing carbon footprint, fuel usage, and emissions connected with logistics operations and their compliance with local and international environmental regulations. This study quantitatively measures logistics scenarios using analysis methods, including truck loading capacity, route efficiency, fuel pricing, and collection point time.

The operational advantages of GMM Finland are the benefit of this research and the whole topic. It contributes to the discourse on sustainability logistics and circular economy, offering policymakers, industry insiders, and academics all the required information. The study implies that logistics innovations can be responsible for curbing environmental degradation and improving operational efficiency by incorporating animal by-products in a cyclical model. In conclusion, this study analyses logistics planning scenarios for GMM Finland to achieve a circular economy in animal by-products by critically examining sustainable business practices, environmental legislation, and logistical efficiency. The research uses GMM Finland's Iceland operations to determine the best logistics techniques for a circular economy. This project might boost GMM Finland's sustainability and help the world manage resources more responsibly.

This research analyzes and optimizes logistics planning scenarios for GMM Finland, explicitly focusing on collecting and transporting animal by-products. One research question: How does the logistics analysis of raw material collection influence the decision-making process for selecting alternative locations for the factory setup? Determining the number of trucks required for the efficient and sustainable collection of animal remains and finding the optimal route for collection are other crucial aspects of this research.

1.3 Research Significance

The significance of the research on analyzing logistics planning scenarios for GMM Finland to advance towards a circular economy in managing animal by-products extends across multiple dimensions of environmental sustainability, operational efficiency, and regulatory compliance. It is based on the fact that industries must transition towards implementing a circular economy that mainly emphasizes recycling and re-using resources, thus minimizing waste and environmental impact. GMM Finland, the company leading in the animal by-product processing area, is demonstrably a business that can combine logistics operations with a circular economy approach (Gusmerotti et al., 2019).

Moreover, this study is undoubtedly crucial to sustainable supply chain management research. It deeply covers the issues of gathering sources of animal byproducts and their transportation, which are vital in the circular economy. However, academic research has not adequately covered this topic. This research deals with raw materials collection logistics and manufacturing site strategy. The aim is to contribute to the dialogue on logistics’ role in sustainability.

The study by Rajput and Singh (2022) anticipated that the correct number of trucks that collect and transport animal wastes would influence GMM Finland's operating costs and environmental impact. Hence, this result is significant for global efforts to cut greenhouse gas emissions and switch to more sustainable production and consumption systems. Such research may enable GMM Finland and its peers to increase logistics effectiveness and eco-friendliness.

It guides policymaking and also forms the foundation of academic and industrial practice. Research outcomes can provide policymakers and managers with the necessary recommendations for implementing the circular economy animal by-product management, mainly focusing on the logistical aspects. This is the case in Iceland, where GMM Finland actively engages in the development of a local economy as well as partnerships with local companies to navigate through complex regulations (Fitch-Roy et al., 2021).

Other firms may be motivated by the research's circular economy goals and incorporate such goals into their processes. The logistics planning scenarios will be analyzed in depth. The understanding generated from those analyses will be helpful in other scenarios. This will pave the way to sustainability in sectors across the board. Savini (2019) says it cooperates with sustainable initiatives by showing how logistics innovations are helpful and have applications in building a circular and resilient economy.

2 Literature Review

2.1 Circular Economy and its Relation with Logistics

The circular economy (CE) is an innovative economic model designed to replace the traditional linear economy's "take-make-dispose" approach with one that is regenerative by design (MahmoumGonbadi et al., 2021). One might be unable to recapture all the value from products, materials, and resources. However, one would design a system that enables prolonged life, reuse, refurbishment, remanufacturing, and recycling of products and materials. It is predicted by the studies of Immonen (2022) that the circular economy of economy focuses on the reduction of waste and the continuous use of resources. This, in turn, aims at achieving economic growth while maintaining the limits of natural resources.

Logistics, as a critical determinant of the circular economy, ensures the efficiency and sustainability of the movement of goods (Lahane et al., 2021). This includes planned and performed activities to transport and store goods, services, related information, and commodities from the point of origin to the point of consumption, meeting customer requirements. Kyriakopoulos (2021) further emphasizes the role of logistics in linking supply chain components, optimizing resource use, and reducing waste, underscoring the significance of the audience's work in this field.

The relationship between logistics and circular economy is undeniable, and the two are deeply intertwined. To achieve a circular economy, logistics systems must be molded to accommodate the reverse flow of resources through the supply chain (Kouhizadeh et al., 2020). It means repurposing used products for repair, refabrication, or recycling; then, it ensures their distribution to the people in need. According to the Ellen MacArthur Foundation, which is involved in innovations regarding the circular economy, resources and waste are designed at the logistic level, and goods are kept in use for a longer time while natural systems are regenerated. In their study, Liu et al. (2022)

suggest that animal by-product processor GMM Finland profits from the circular economy but also faces the same pursuit.

Therefore, the logistics department of GMM Finland should include these difficulties in planning the circular economy based on by-products from animals. In this paper by the team of Mallick (2023), it is seen that the ABPs are divided, and the distance they travel is increased until the market as they are transported from one processing plant to another. This is a problem. The circular economy model comprises three phases, each designed to reduce emissions, energy, and waste in general. Statistics show that the circular economy will be able to give in a lot.

The Ellen MacArthur Foundation and McKinsey & Company report paints a promising picture of the circular economy, indicating its potential to reduce material costs by €1.8 trillion. Simultaneously, it is projected to generate €0.9 trillion in new business revenues in Europe by 2030 (Gusmerotti et al., 2019). This optimistic outlook underscores the importance of logistics in realizing these benefits. Through effective logistic planning, GMM Ltd. could significantly reduce the transportation and processing cost of animal by-products, with a primary focus on environmental impact.

A circular economy approach, the main component of an environment-friendly economy, stipulates resource efficiency and waste reduction. Referring to the UNEP report, Oliveira Neto and Correia (2019), applying circular economy guidelines could bring up to 45% emission reductions by 2050. The supply chain management optimization of GMM Finland not only has its environmental targets but also allows the company to be a part of the global climate change initiatives. Logistics, which are at the backbone, will assist with the set objectives. For example, GMM Finland demonstrated the collection, transportation, and processing of animal by-products, which had very challenging logistics scenarios. They were dealing with collecting, transporting, and processing these materials sustainably, environment-friendly, and efficiency-oriented (Fitch-Roy et al., 2021).

2.2 Importance of Logistics Analysis for Companies

Logistics analysis is the most crucial element of present-time business operations, and business must be run under a circular economy. The article considers the intricacy of logistics analysis in terms of the nature of the circular economy approach used by GMM Finland, referring to animal by-products. The paper by Rajput and Singh (2022) revealed that logistics analysis is the basis of supply chain management and evaluating and optimizing flows from the origin to the consumer. The essential characteristic of a circular economy is the recycling and reuse of the materials for which the resources used are sustainable and renewable.

Furthermore, logistics become more challenging when it comes to waste management by animal by-product processing plants such as GMM Finland because there is more waste to be transported and disposed of in a way that is friendly to the environment. The enterprise's ambition to change animal by-products into valuable solutions for various market segments coincides with the circular economy principles and thus highlights the demand for sustainable logistics planning (Do et al., 2021). Circular economy ideology is designed to eliminate waste and pollution, reuse resources, and renew natural systems. This requires a logistics structure that is efficient, sustainable, and resource-conserving.

In this case, logistics analysis becomes more than just the shipment of goods. It thoroughly evaluates the supply chain to pinpoint the bottlenecks, inefficiencies, and improvement opportunities. Ripanti and Tjahjono (2019) have argued in their study that GMM Finland might look at animal by-product collection routes to lessen fuel use and CO_2 emissions and improve environmental sustainability. According to the Ellen MacArthur Foundation, by practicing circular economy practices, greenhouse emissions can be reduced by 45% in specific industries, showcasing the environmental role of logistics planning.

Logistics analysis also assists in choosing processing facility sites. Companies can reduce transit costs and time by placing these facilities near source points or markets, which is helpful for supply chain efficiency (Chen et al., 2022). This is very important for GMM Finland since choosing a new processing facility in Iceland involves numerous issues, including the location of the collecting sites, compliance with the regulations, and social effects. Scheduling of logistics analysis should also determine the fleet size and timing for animal by-product collection and transfer. To be more specific, Savini's (2019) research reported that it is necessary to run through complicated computations, walking a tightrope between the size of the fleet and quick collection and delivery. Thus, this is likely due to high prices, environmental problems, and disobeying regulations.

The performance of an organization can be increased with this possible logistic system as operational efficiency, cost savings, and environmental sustainability will increase, hence its support for the circular economy (Cao et al., 2021). In the business case of GMM Finland, the use of alternative fuels and complex route algorithms as a new solution that can be used for saving both economically and sustainably and increase efficiency is addressed. In Vege's words (2020), systems like route optimization and real-time tracking of vehicles will be the means to that end. Logistic analysis occupies a primal place in GMM Finland that will create a circular economy of animal by-products since it reveals how by-product reuse is to be introduced. This includes route optimization, facility placement planning, fleet management, and technology integration services. Logistics analysis is one of the instruments and the means to deliver efficiency in operation, economy related to the cost, and environmental protection that assures a circular economy (Braz & de Mello, 2022). Firms struggling with logistics management and focusing on sustainability need detailed analysis techniques; otherwise, they may close down their businesses.

2.3 Vehicle Routing and Transportation

The provision of transport services is a vital aspect of logistics, and vehicle routing allows businesses to plan their supply routes predictably and reliably. Using this driver, the roads set for trucks are reorganized, which eventually leads to fuel savings and operational cost reduction. At the same time, these routes satisfy service-level agreements and the norms of environmental sustainability. In the article, Aho (2022) introduces a Finnish company named GMM Finland that recycles animal remains. The company in question uses progressive vehicle routing and transportation techniques because of the two facts. Namely, they care about both environmental and logistic issues.

The circular economy will provide a viable option for advancing sustainable social development. The term alludes to progressively disentangling economic activity from the limited availability of resources and eliminating waste along the process. Renewable energy supports the circular economy model, which is based on the development of the economy, environment, and society (Bal & Badurdeen, 2020). The paradigm of the circular economy supports this model. This economic model relies on efficient logistical technologies, including route optimization and transportation, that make it possible to finish the recycling, remanufacturing, and reuse processes from beginning to end, ultimately resulting in the conservation of the environment.

In addition, the article by Arora et al. (2021) shows that GMM Finland must have efficient logistics. It should collect the animal by-products from diverse areas and then deliver them to the processing facilities to be turned into valuable products. Furthermore, ill-treatment or any delay may lead to poorer quality of by-products and can cause health and environmental issues that necessitate planning and execution to be done correctly. To ensure conformity with the animal by-product transportation regulation, sophisticated trucks, and enclosure systems are required to avoid contamination and make compliance even more complex.

This refers to vehicle routing as a strategic point in that it is essential in strategic terms (Ali, 2019). Vehicle routing reduces fuel consumption and CO2 emission by shortening the collection distances and time. This is significant because of the global effort to reduce CO_2 emissions by attempting to limit the transportation sector, which has become a significant contributor. The efficiency of routes that the vehicle takes leads to reduced operations costs like vehicle maintenance, fuel consumption, and drivers' hours, which in turn increases the company's profitability.

Barros et al. (2021) also discovered that TMS with real-time data analytics and GPS monitoring may help improve route efficiency. Using these technologies, GMM Finland can respond to traffic, truck breakdowns, or schedule changes by dynamically adjusting routes. Hence, by-product handling is one of the most efficient. Route planning and transportation is not just a logistics issue but also an intricate part of animal by-products' circular economy. The field of green logistics is environmental stewardship (Tapia et al., 2021). Using data analytics for route optimization can dramatically cut fuel use by reducing atmospheric gas emissions. Strategic vehicle selection, which considers load capacity, fuel economy, and emissions standards, is an excellent example of how logistics can become more sustainable.

Nevertheless, successful vehicle routing and transport systems take work to put in place. Camilleri (2020) stresses that it is a profound knowledge of animal by-product collecting, handling, transportation, and the ability to use technology. Logistic and environmental factors continuously change, which necessitates continuous development and innovation. In the end, the logistics strategy of GMM Finland in creating a circular economy of animal by-products is based on vehicle routing and transportation. These concepts can increase the effectiveness of operation, affordability, and environmental sustainability for the organization. These above logistics aspects are equally crucial for transforming into a green and circular economic model, thereby showing the significance of research, development, and implementation of innovative logistics solutions (Saha et al., 2022).

2.4 Factors Affecting Vehicle Routing

Logistics and supply chain management determines the best plan to deliver commodities on trucks over a well-coordinated route. Ciliberto et al. (2021) have stated that there is a chain of related elements and efficiencies in international trading, which makes it a highly complex process. Being well-acquainted with such features allows GMM Finland, a company devoted to recycling animal by-products into a valuable resource, to fulfill the idea of a circular economy (Reddy & Kumar, 2021). This research investigates the impact of vehicle load factor, fuelling costs, and collection point time on vehicle routing, which relates to GMM Finland's collection and recycling of animal by-products.

Vehicle loading capacity is of great importance for transportation logistics efficiency. Capacity determines how many goods can be transported per trip, how many trips are needed, when the cost is growing logistically, and the carbon footprint size (Orko et al., 2022). GMM Finland has to be keen on creating maximum loading capacity so that the number of trips to pick up animal by-products from varied sources is reduced. On the other hand, it has been argued in the study of Dutta et al. (2021) that optimal use of vehicles leads to fewer trips and fuel consumption and emissions, which in turn allows improvements in logistics sustainability, a vital feature of the circular economy. Overloading will end up in vehicles wearing out and may violate traffic rules, whereas underloading makes transport inefficient and causes an increase in per-unit transportation costs.

Besides, the route is closely connected to fuel prices. In their research, Gupta and Singh (2021) identified that fuel prices may abruptly affect transportation logistics costs. Create your journey to success and reach your financial goals with the power of a personal loan from a trusted lending institution. GMM Finland has to fetch and ship animal by-products over more considerable distances and, therefore, will have higher fuel costs that might make the profitability low (Nandi et al., 2020). On this basis, organizations must plan their routes to minimize extra trips and fuel use unnecessarily.

Advanced algorithms that analyze gasoline prices in real time and suggest cheaper routes may, in turn, decrease fuel consumption. Haezendonck and Van den Berghe (2020) also claim that using fuel-efficient or alternative-fuel cars will reduce the quantity of fossil fuel utilization and the environmental impact, an essential element of the circular economy.

Making up vehicle routes entails also taking the time to collect points into consideration. It has been anticipated in the study of Immonen (2022) that the effectiveness of transportation is directly determined by loading and unloading time, which is a crucial factor. To optimize collection efficiency, the odors from the animal by-product logistics of GMM Finland should be minimized. Frozen transport times can add to the number of idle hours per vehicle, increase fuel consumption, and reduce daily capacity, affecting the network's carbon footprint and efficiency (MahmoumGonbadi et al., 2021). Efficient schedule, loading, and way too endless training of collection point staff can be a solution to getting rid of the delays and ensuring trucks stay as little time as possible at every stop and keep the schedule in good shape.

In a nutshell, the vehicle loading capability, fuel cost, and the collecting point time can be examples to show the complexity of circular economy vehicle routing. On the other hand, Kyriakopoulos (2021) says that the biggest challenge that GMM Finland has to overcome to take on animal by-product logistics in an environmentally sustainable manner is overcoming the mentioned obstacles. As the company aims to successfully align with the circular economy concept, logistics planning, and optimization turn out to be even more than crucial. Telematics, in turn, can be used for vehicle tracking in real-time, in addition to route optimization, which considers traffic and fuel prices. Furthermore, algorithms will be developed for the circular logistics economy based on optimizing these (Lahane et al., 2021).

This method also achieves the objectives of decreasing waste, reducing the negative environmental impact, and getting more value from secondary products. To bring this discussion to a close, we must admit that choosing an efficient transportation routing system and synchronizing the circular economy for GMM Finland is difficult since it includes many intertwined aspects. Also, this statement has been proved by Liu et al. (2022) that one needs a strategic plan that combines technological innovation with sustainable management to achieve the optimal balance between sustainability and environmental concerns, as well as logistics.

3 Research Methodology

This study aimed to analyze and develop the potential vehicle routes for animal carcass removal in Iceland. The primary method employed in this study was to examine different farm locations in Iceland, including data regarding which was shared by the company, including the coordinates, number, and type of each animal on a specific farm. The missing coordinates were found with the help of Google Maps.

3.1 Open Door Logistics

The main tool used for vehicle routing was Open Door Logistics. ODL Studio is a free and open-source vehicle planning, territory mapping, and scheduling software. Furthermore, the application can generate delivery or pick-up routes, view locations on a map, and design sale territories. The workings of the ODL studio are quite simple and easy to comprehend. This study required three main components or input data tables to implement vehicle routing functions in open-door logistics. The first step was to create the stops table where the locations required to be delivered or pick-up points were listed with their respective quantities and coordinates.

id	job-id	Type	name	address	latitude	longitude	service-du	start-time	end-time	quantity
Stop-1		P	Dysnes		65.8292	-18.1879	01:00:00	08:00:00	17:00:00	
Stop-2		P	Melavellir		64.26731	-21.8572	01:00:00	08:00:00	17:00:00	46
Stop-3		P	Ásmundar:		63.8712	-20.5828	01:00:00	08:00:00	17:00:00	47
Stop-4		P	Hurðarbak		63.92057	-20.796	01:00:00	08:00:00	17:00:00	44
Stop-5		P	Nesbú hf		64.0062	-22.3595	01:00:00	08:00:00	17:00:00	42
Stop-6		P	Vallá		64.126	-21.8252	01:00:00	08:00:00	17:00:00	52
Stop-7		P	Móar		64.3111	-21.9864	01:00:00	08:00:00	17:00:00	12
Stop-8		P	Fagrabrekl		65.1333	-21.1	01:00:00	08:00:00	17:00:00	10
Stop-9		P	Teigur		64.1654	-21.6855	01:00:00	08:00:00	17:00:00	31
Stop-10		P	Saltvík		66.00797	-17.3911	01:00:00	08:00:00	17:00:00	16
Stop-11		P	Jarlsstaðir		65.5667	-17.4667	01:00:00	08:00:00	17:00:00	7
Stop-12		P	Oddsmýri		64.147	-21.9424	01:00:00	08:00:00	17:00:00	6
Stop-13		P	Krókar		64.0814	-21.9294	01:00:00	08:00:00	17:00:00	5
Stop-14		P	Sveinbjarn		65.7809	-18.0627	01:00:00	08:00:00	17:00:00	5
Stop-15		P	Eilífsdalur		64.2667	-21.6489	01:00:00	08:00:00	17:00:00	4
Stop-16		P	Rauðilæku		64.26614	-18.8158	01:00:00	08:00:00	17:00:00	4
Stop-17		P	Eskiholt 2		64.6164	-21.7554	01:00:00	08:00:00	17:00:00	4
Stop-18		P	Helluvað 6		65.58682	-17.1557	01:00:00	08:00:00	17:00:00	3

Figure 3.1 Explains the stops table for the route designed for picking up animal carcasses in some farms

Figure 3.1 shows the stop table required and necessary data inputs. ID was a unique stop ID given to each location in the software that needed to be served. The type also signifies the job category: delivery or pick up. Since this study requires picking up farm animal waste, the type is P. On the other hand, if the job requires delivery, the type becomes D. Furthermore, the name column shows different locations that need to be served along with latitude and longitudinal values, which are imperative for the vehicle, and shows map components to run.

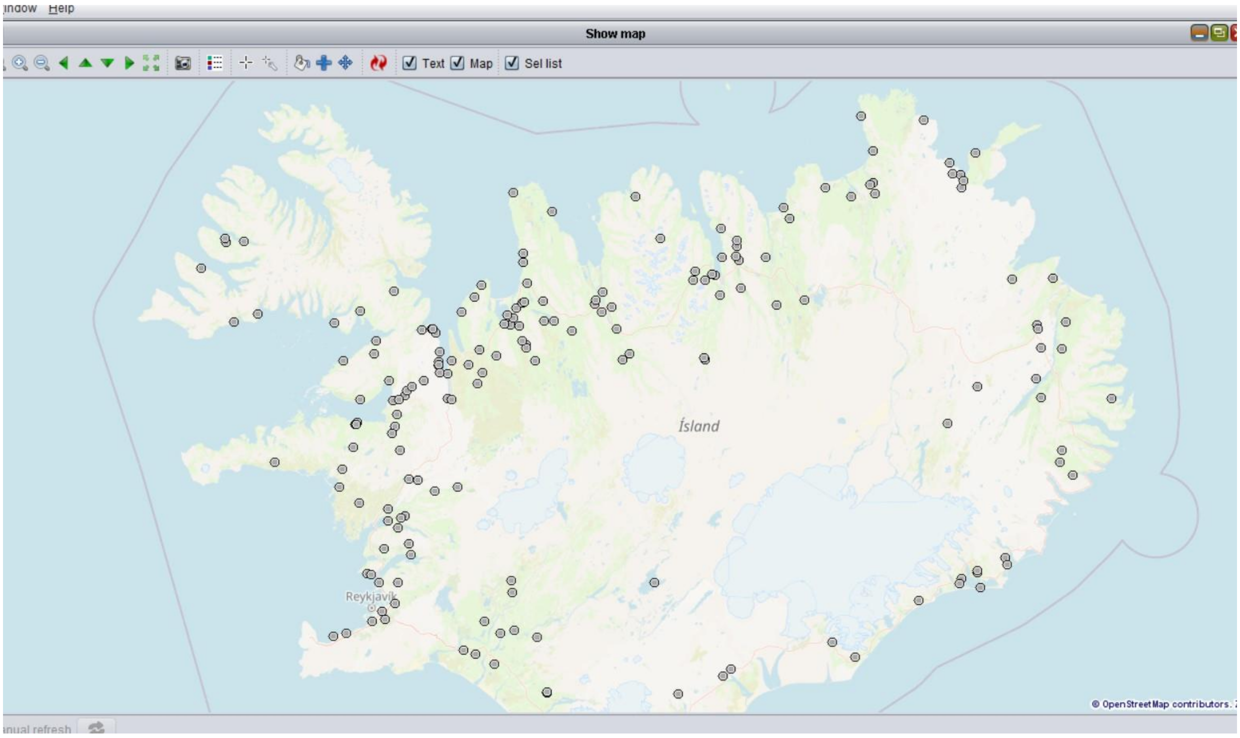

Figure 3.2 Demonstrates the location of 200 estates needed to be served.

Figure 3.2 signifies the workings of the show map component and geocoding of Open-door logistics, which was imperative for vehicle routing. Figure 3.1 also shows the time taken to serve each location, start and end time, and quantities required to be picked up from each farm. In addition to the stops table, the vehicle table was necessary to give input to the software about the number of vehicles available and the quantity of each vehicle.

vehicle-na	vehicle-id	start-latitu	start-longi	end-latitu	end-longit	start-time	end-time	capacity	speed-mul	cost-per-ki	cost-per-h	waiting-co	fixed-cost	p
Vehicle 1	Vehicle 1	65.829	-18.1879	65.829	-18.1879	08:30:00	18:00:00	10000	1	0.001	1	0.5	100	
Vehicle 2	Vehicle 2	65.829	-18.1879	65.829	-18.1879	08:30:00	18:00:00	10000	1	0.001	1	0.5	100	
Vehicle 3	Vehicle 3	65.829	-18.1879	65.829	-18.1879	08:30:00	18:00:00	10000	1	0.001	1	0.5	100	
Vehicle 4	Vehicle 4	65.829	-18.1879	65.829	-18.1879	08:30:00	18:00:00	10000	1	0.001	1	0.5	100	
Vehicle 5	Vehicle 5	65.829	-18.1879	65.829	-18.1879	08:30:00	18:00:00	10000	1	0.001	1	0.5	100	
Vehicle 6	Vehicle 6	65.829	-18.1879	65.829	-18.1879	08:30:00	18:00:00	10000	1	0.001	1	0.5	100	
Vehicle 7	Vehicle 7	65.829	-18.1879	65.829	-18.1879	08:30:00	18:00:00	10000	1	0.001	1	0.5	100	
Vehicle 8	Vehicle 8	65.829	-18.1879	65.829	-18.1879	08:30:00	18:00:00	10000	1	0.001	1	0.5	100	
Vehicle 9	Vehicle 9	65.829	-18.1879	65.829	-18.1879	08:30:00	18:00:00	10000	1	0.001	1	0.5	100	
Vehicle 10	Vehicle 10	65.829	-18.1879	65.829	-18.1879	08:30:00	18:00:00	10000	1	0.001	1	0.5	100	

Figure 3.3 depicts the vehicle table used for vehicle routing for all the routes.

Figure 3.3 shows input values for the vehicle table used for vehicle routing. The first and second columns show the unique ID given to each vehicle. In addition, each vehicle's start and end coordinates are also mentioned. In this case, the factory location was Dysnes, Iceland, so each vehicle's coordinates of Dysnes were used as starting and ending points. The table also shows the number of vehicles available, which is 10, and the capacity of each vehicle is 10 tons. Lastly, the stop order table was generated after implementing the vehicle routing function. Thus, the software created the stop order table after optimization.

vehicle-id	stop-id
Vehicle 1	Stop 12
Vehicle 1	Stop 4
Vehicle 1	Stop 30
Vehicle 2	Stop 32
Vehicle 2	Stop 8
Vehicle 3	Stop 15
Vehicle 3	Stop 24
Vehicle 3	Stop 1
Vehicle 3	Stop 33
Vehicle 4	Stop 2
Vehicle 4	Stop 9
Vehicle 4	Stop 18
Vehicle 5	Stop 17
Vehicle 5	Stop 21
Vehicle 5	Stop 26
Vehicle 6	Stop 10
Vehicle 6	Stop 23
Vehicle 6	Stop 14
Vehicle 6	Stop 34
Vehicle 6	Stop 16
Vehicle 7	Stop 20
Vehicle 7	Stop 5

Figure 3.4 illustrates that the stop order for Route 1

Figure 3.4 shows the stop order table after optimization. The software automatically generates the order in which stops will be served during operations and which vehicle number will be used to serve that particular stop. Another core step was creating a script to produce the desired road network maps with a clear routing direction. The first step in creating a script was to call the vehicle routing function in ODL and select the correct quantity type, which was one in this case. Furthermore, the stops and vehicle tables were provided as the input data. Another crucial step in creating the script was to select the digital road network graph instead of map dots to have clear routings.

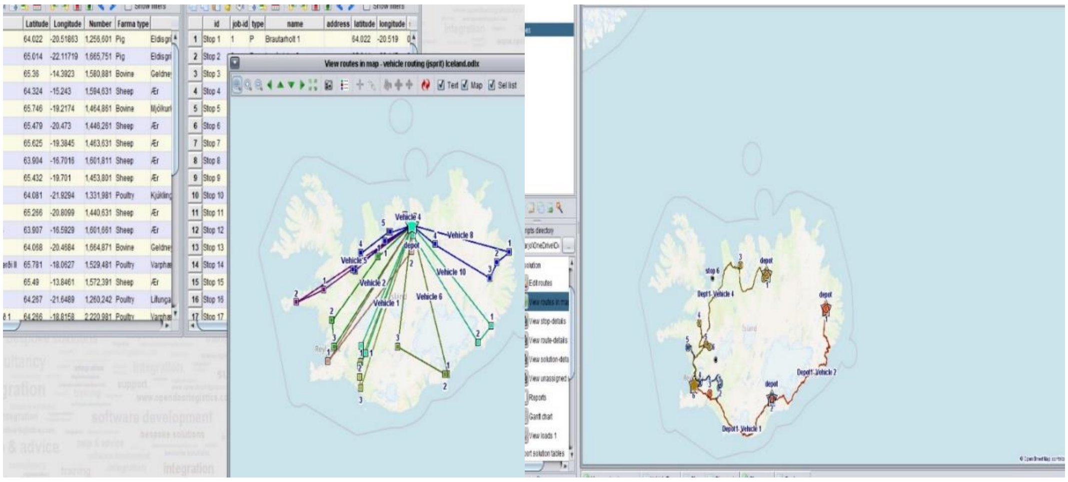

Figure 3.5 depicts the difference between digital road networks and map dot routings.

```
:\Users\harjo>cd C:\Program Files\ODLStudio-1.4.1-Win-64-bit\graphhopper

:\Program Files\ODLStudio-1.4.1-Win-64-bit\graphhopper>java -Xmx2G -jar graphhopper-0.4-SNAPSHOT-jar-with-dependencies.
jar config=config.properties osmreader.osm=C:\Users\harjo\OneDrive\Documents\iceland-latest.osm.pbf
'java' is not recognized as an internal or external command,
perable program or batch file.

:\Program Files\ODLStudio-1.4.1-Win-64-bit\graphhopper>
```

Figure 3.6 depicts the javascript required to use the road network graph.

Figure 3.5 clearly shows that the digit road network on the right showed a much clearer picture of the routes instead of map dots. Moreover, using the digital road network requires creating a Java script and downloading the pb extension file for Iceland, free to download from the software website. In addition, Open Door Logistics used the grasshopper function for geocoding and routing, which was again available on the software website for download. Figure 3.6 shows the creation of a JavaScript called the grasshopper function, the final step in creating a script for the routing. Figure 3.6 shows the steps in writing JavaScript. First and foremost, the grasshopper function was called from the directory where the file was stored. The next step was to call the Iceland file and initiate Java to read the OSM reader.

3.2 Calculation of quantities and obtaining random routes based on demand

There were approximately 1310 unique farm locations that were required to be covered. Moreover, there were six animal types on these farms which were Poultry, Horses, Pigs, Bovine, Sheep, and Mink. Apart from this weight of poultry was 3 Kg, Horse was 375 Kg, Pigs was 125 Kg, Bovine was 425 Kg, Sheep was 60 Kg and Minks was 1 Kg. Thus, in total, there were 768,947 poultry, 1683 Horses, 40,122 Pigs, 331,220 Sheep, 36,019 Bovines, and 9357 Minks across all farms. In the next step, calculating the correct quantities for each farm location was crucial to producing optimal and cost-effective routes. The main logic behind calculating the quantities was figuring out how many animals died on each farm for a year. Thus, according to statistics provided by the company, 2% of animals were estimated to die on each farm. However, for poultry, the average deaths for the entire year were 1.5%, and for sheep, 2.3% for the whole year. Figure 3.8 shows the animal distribution in some of the farms, and according to it, Teigur has 1335 pigs in the entire estate. Thus, using the above statistic, 2% of the pigs will die for the whole year, which was 26.7. Moving forward, the next step was to convert the number of animals dying to kilograms to get the demand for animal carcasses removed for the whole year. Figure 3.7, shows the general formula to calculate the daily demand for each farm.

Hence, the number of animals dying on each farm was multiplied by the weight of the animal dying. For example, 26.7 pigs will die in Teigur for an entire year, and to convert this into kilograms, the value was multiplied by the animal's weight, which was 125 KG for pigs. Thus, the amount to be picked up from Teigur was 3337.5 Kilograms for the entire year. Furthermore, the year can be divided by 365 to get daily demand.

$$Q = \frac{percentage\ of\ aninal\ dying * number\ of\ animal\ in\ each\ farm * weight}{365}$$

Figure 3.7 depicts the formula for calculating quantities for all animal types.

Estate	Latitude	Longitu	Numbe	Farma	Group	Numbe	D
Melar	65.833	-17.900	1337881	Pig	Eldisgrísir	7800	
Melar	65.833	-17.900	1337881	Pig	Smágrísir	3800	
Brautarholt 1	64.02208	-20.51863	1256601	Pig	Eldisgrísir	3000	
Melavellir	64.26731	-21.85724	1256551	Poultry	Kjúklingar	120000	
Hýrumelur	64.70	-21.24	1345081	Pig	Smágrísir	2080	
Ásmundarstaðir 1 3/5	63.8712	-20.5828	1652652	Poultry	Kjúklingar	101000	
Hurðarbak	63.92057	-20.7960	1331861	Poultry	Kjúklingar	101000	
Nesbú hf	64.0062	-22.3595	1308511	Poultry	Varphæns	98517	
Hraukbær	65.704	-18.1797	1525031	Pig	Eldisgrísir	1770	
Ormsstaðir	65.1348	-13.7649	1682711	Pig	Eldisgrísir	1750	
Minni Vatnsleysa	64.0216	-22.2197	1308691	Pig	Fráfærugr	1581	
Minni Vatnsleysa	64.0216	-22.2197	1308691	Pig	Eldisgrísir	1432	
Brautarholt 1	65.5677	-19.4755	1256601	Pig	Smágrísir	1400	
Teigur	65.6122	-18.0865	1528081	Pig	Eldisgrísir	1335	
Vallá	64.1260	-21.8252	1257622	Poultry	Varphæns	71000	
Lindartún	63.6682	-20.3734	1639571	Horse	Óskráðar	381	
Hofsstaðasel	65.7052	-19.372	1464071	Bovine	Geldneyti	327	

Figure 3.8 denotes the Excel file denoting each estate's type and number of animals.

The next step was to create random routes based on whether collection would be done based on one-day, two-day, or three-day demand to create optimal logical and cost-effective routes. Since the demand for some farms was relatively low, covering entire estates by one route was impractical. In addition, manually picking up the estates was impractical; therefore, the classification of estates was imperative to produce the desired outcomes. Thus, to overcome this obstacle, calculating cycle time was crucial to determine the optimal routes. Cycle time can be defined as the time taken for the animal to die in each farm. This was calculated by the formula shown the Figure 3.9.

$$Cycle\ Time = \frac{1}{daily\ amount\ of\ carcasses}$$

Figure 3.9 depicts the calculation of the cycle time of one animal dying on each farm.

=ROUNDUP(1/H2343,0)

B	C	D	E	F	G	H	I	J
atitude	Longitu	Numbe	Farma	Group	Numbe	Daily Demand	Daily demand (kg)	Cycle Time
3.9381	-20.926	1662811	Loðdýr	Aliminkar,	2200	0.120547945	0.120547945	9
4.2427	-15.2088	2161191	Loðdýr	Aliminkar,	1600	0.087671233	0.087671233	12
5.6844	-14.8538	1948391	Loðdýr	Aliminkar,	1100	0.060273973	0.060273973	17
4.08067	-20.69201	1682841	Loðdýr	Aliminkar,	1024	0.056109589	0.056109589	18
4.08067	-20.69201	1682841	Loðdýr	Aliminkar,	864	0.047342466	0.047342466	22
5.6998	-18.1455	1462161	Loðdýr	Aliminkar,	830	0.045479452	0.045479452	22
5.5887	-19.4670	1460301	Loðdýr	Aliminkar,	527	0.028876712	0.028876712	35
3.9381	-20.926	1662811	Loðdýr	Aliminkar,	500	0.02739726	0.02739726	37
4.2427	-15.2088	2161191	Loðdýr	Aliminkar,	320	0.017534247	0.017534247	58
5.6844	-14.8538	1948391	Loðdýr	Aliminkar,	212	0.011616438	0.011616438	87
5.6998	-18.1455	1462161	Loðdýr	Aliminkar,	180	0.009863014	0.009863014	102
					9357			

Figure 3.10 exemplify the calculation of the probability of one animal dying on each farm.

As mentioned earlier, manually picking up the farms was cumbersome and ineffective. Thus, by utilizing the randbetween function on cycle time we were able to calculate visit frequency which showed how many times each farm must be visited during the entire year as seen in Figure 3.10. Randbetween is a function in Excel used to get a random integer between two specific values. The visit frequency was then used to segregate the farms and create routes, based on whether we planned to run the collection daily, after two days, or after three days. To exemplify, farms with a visit frequency of one were categorized in route for daily operations. This step was repeated until all stops were categorized into their respective routes, demonstrating the accuracy of our approach as seen in Figure 3.11.

=RANDBETWEEN(1,J2343)

B	C	D	E	F	G	H	I	J	K	L
Latitude	Longitu	Numbe	Farma t	Group	Numbe	Daily Demand	Daily demand (kg)	Cycle Time	Number of Days to pick up	Visit Frequency
63.9381	-20.926	1662811	Loðdýr	Aliminkar,	2200	0.120547945	0.120547945	9	8.295454545	2
64.2427	-15.2088	2161191	Loðdýr	Aliminkar,	1600	0.087671233	0.087671233	12	11.40625	8
65.6844	-14.8538	1948391	Loðdýr	Aliminkar,	1100	0.060273973	0.060273973	17	16.59090909	14
64.08067	-20.69201	1682841	Loðdýr	Aliminkar,	1024	0.056109589	0.056109589	18	17.82226563	9
64.08067	-20.69201	1682841	Loðdýr	Aliminkar,	864	0.047342466	0.047342466	22	21.12268519	3
65.6998	-18.1455	1462161	Loðdýr	Aliminkar,	830	0.045479452	0.045479452	22	21.98795181	3
65.5887	-19.4670	1460301	Loðdýr	Aliminkar,	527	0.028876712	0.028876712	35	34.62998102	32
63.9381	-20.926	1662811	Loðdýr	Aliminkar,	500	0.02739726	0.02739726	37	36.5	19
64.2427	-15.2088	2161191	Loðdýr	Aliminkar,	320	0.017534247	0.017534247	58	57.03125	3
65.6844	-14.8538	1948391	Loðdýr	Aliminkar,	212	0.011616438	0.011616438	87	86.08490566	9
65.6998	-18.1455	1462161	Loðdýr	Aliminkar,	180	0.009863014	0.009863014	102	101.3888889	23
					9357					

Figure 3.11 depicts the randbetween usage to calculate each farm's visit frequency.

The last step was to create different scenarios based on certain constraints to test their feasibility that is whether we were able to cover the entire stops in one particular scenario. Adding further, constraints were several trucks to be used and, the time limit within which the farms could be served was either from 6:00 a.m. to 9:00 p.m. or 9:00 a.m. to 5:00 p.m., whereas the number of trucks can be from anywhere between 2 to 10. Apart from these two, the other constraint was whether we are serving the stops daily, with a two-day demand or a three-day demand since the maximum time we can allow the carcasses in the open was three days. Hence, considering all these factors a total of 40 scenarios were obtained which can be seen in Figure 3.12.

1	Demand	Trucks	Service Time	Stops to be covere	St
2	2 day demand	2	06:00 to 21:00	34	
3	2 day demand	3	06:00 to 21:00	28	
4	2 day demand	4	06:00 to 21:00	27	
5	2 day demand	5	06:00 to 21:00	35	
6	2 day demand	6	06:00 to 22:00	29	
7	2 day demand	9	06:00 to 22:00	31	
8	2 day demand	8	06:00 to 21:00	23	
9	2 day demand	9	06:00 to 21:00	25	
10	2 day demand	10	06:00 to 21:00	25	
11	3 day demand	2	06:00 to 21:00	24	
12	3 day demand	3	06:00 to 21:00	25	
13	3 day demand	4	06:00 to 21:00	25	
14	3 day demand	5	06:00 to 21:00	25	
15	3 day demand	6	06:00 to 21:00	30	
16	3 day demand	7	06:00 to 21:00	30	
17	3 day demand	8	06:00 to 21:00	29	
18	3 day demand	9	06:00 to 21:00	29	
19	3 day demand	10	06:00 to 21:00	29	
20	2 day demand	2	09:00 to 17:00	32	
21	2 day demand	3	09:00 to 17:00	27	
22	2 day demand	4	09:00 to 17:00	36	
23	2 day demand	5	09:00 to 17:00	33	
24	2 day demand	6	09:00 to 17:00	34	
25	2 day demand	7	09:00 to 17:00	29	
26	2 day demand	8	09:00 to 17:00	33	
27	2 day demand	9	09:00 to 17:00	33	

Figure 3.12 depicts the constraints for each scenario and the number of stops to be covered

4. Results

A total of 40 scenarios were obtained by randomly segregating the pick-up points. Moreover, 18 scenarios had a two-day demand, and another 18 had a three-day demand, whereas the rest had a one-day demand. In addition, the scenarios were then further distinguished based on the number of vehicles used and the time within which each route should be completed. Further, each stop and vehicle table was created for each scenario in ODL based on the constraints defined in Figure 3.12. To exemplify, scenario 16 had a three-day demand with eight trucks available to serve the stops, and the time within which the entire route should be completed was 6:00 a.m. to 9:00 p.m... Based on the above constraints, inputs were created in stops and vehicle tables, which can be seen in Figures 4.1 and 4.2.

id	job-id	type	name	address	latitude	longitude	service-du	start-time	end-time	quantity	requi
Stop-1	1	P	Melar		65.833	-17.9	00:15:00	06:00:00	21:00:00	125	
Stop-2	2	P	Hýrumelur		64.7	-21.24	00:15:00	06:00:00	21:00:00	125	
Stop-3	3	P	Skarðabor		65.9581	-17.3196	00:15:00	06:00:00	21:00:00	65	
Stop-4	4	P	Bjarnastað		64.7066	-21.0441	00:15:00	06:00:00	21:00:00	125	
Stop-5	5	P	Halldórssta		65.3146	-18.2506	00:15:00	06:00:00	21:00:00	65	
Stop-6	6	P	Stóri-Núpu		64.0545	-20.1643	00:15:00	06:00:00	21:00:00	425	
Stop-7	7	P	Holt		65.4924	-20.0335	00:15:00	06:00:00	21:00:00	65	
Stop-8	8	P	Ytra-Áland		66.2084	-15.548	00:15:00	06:00:00	21:00:00	65	
Stop-9	9	P	Stóra-Fjarð		65.5549	-21.4659	00:15:00	06:00:00	21:00:00	65	
Stop-10	10	P	Þykkvibær		63.7463	-17.9404	00:15:00	06:00:00	21:00:00	65	
Stop-11	11	P	Garpsdalui		65.4543	-21.8295	00:15:00	06:00:00	21:00:00	65	
Stop-12	12	P	Melar		65.07	-14.8946	00:15:00	06:00:00	21:00:00	65	
Stop-13	13	P	Steinnes		65.5192	-20.3784	00:15:00	06:00:00	21:00:00	65	
Stop-14	14	P	Ölkelda 2		64.8379	-22.9749	00:15:00	06:00:00	21:00:00	425	
Stop-15	15	P	Hamarssel		64.6703	-14.5615	00:15:00	06:00:00	21:00:00	65	
Stop-16	16	P	Svartagil		64.7557	-21.5299	00:15:00	06:00:00	21:00:00	1	
Stop-17	17	P	Þrándarlur		64.03465	-20.3578	00:15:00	06:00:00	21:00:00	1	
Stop-18	18	P	Melar 2		65.1183	-21.0962	00:15:00	06:00:00	21:00:00	65	
Stop-19	19	P	Litli-Kropp		64.6304	-21.4541	00:15:00	06:00:00	21:00:00	65	
Stop-20	20	P	Hamar 1 o		63.8396	-20.8208	00:15:00	06:00:00	21:00:00	65	
Stop-21	21	P	Högnastað		64.7537	-21.4034	00:15:00	06:00:00	21:00:00	65	
Stop-22	22	P	Klaufabrek		65.867	-18.75	00:15:00	06:00:00	21:00:00	1	
Stop-23	23	P	Reykir		65.25	-21.0983	00:15:00	06:00:00	21:00:00	65	
Stop-24	24	P	Hvammur		65.5874	-20.0545	00:15:00	06:00:00	21:00:00	65	
Stop-25	25	P	Dalbakki 9		63.6807	-19.4826	00:15:00	06:00:00	21:00:00	65	
Stop-26	26	P	Litlu-Reyki		63.9638	-20.8245	00:15:00	06:00:00	21:00:00	65	

Figure 4.1 denotes the stops input table for scenario 1

vehicle-na	vehicle-id	start-latitu	start-longi	end-latituc	end-longitı	start-time	end-time	capacity	speed-mul	cost-per-k	cost-per-h	waiting-co	fixed-cost	parking-co	skills	number-of-vehicles
Vehicle 1	Vehicle 1	65.829	-18.1879	65.829	-18.1879	06:00:00	21:00:00	10000	1	2	0	0	0	0		8

Figure 4.2 demonstrates the vehicle input table for scenario 1

The above step was repeated for each scenario to test their feasibility and whether it was possible to serve all the stops in one scenario within the set constraints. Then, all input tables were simulated in the ODL to get possible feasible scenarios, which were 7 out of 40. Figure 4.3 shows all the feasible scenarios where all the stops were served within time and vehicle limits, scenarios 7,8,9,16,17,18 and 37, respectively.

cenario	Demand	Trucks	Service Time	Stops to be covere	Stops Covere	Feasible
7	2 day demand	8	06:00 to 21:00	23	23	Yes
8	2 day demand	9	06:00 to 21:00	25	25	Yes
9	2 day demand	10	06:00 to 21:00	25	25	Yes
16	3 day demand	8	06:00 to 21:00	29	29	Yes
17	3 day demand	9	06:00 to 21:00	29	29	Yes
18	3 day demand	10	06:00 to 21:00	29	29	Yes
37	1 day demand	10	06:00 to 21:00	40	40	Yes

Figure 4.3 explains all the feasible solutions out of 40

Then, to get the best possible scenario, all the feasible solutions were compared based on the set: the lowest cost which amounted to 2 euros/Km which means for every kilometer run the incurred was 2 euros, fastest time, most stops covered, and a minimum number of vehicles used. Figure 4.4 shows the statistics for all KPIs set concerning the feasible scenarios. To elaborate further, scenario seven only required four vehicles out of 8 available; the distance traveled was 3326.826 km; time taken was roughly around 13 hours, and the cost was 6,653.652 euros per operation cycle with the yearly cost of 798,438.24 euros. Figure 4.5 shows the route for scenario 7.

Scenario	Demand	Vehicles Used	Distance travelled(km)	Costs in Euro	Time Taken	Cost(monthly)	Costs(Yearly)
7	2 day demand	4	3326.826	6653.652	13:05:00	66536.52	798438.24
8	2 day demand	5	4657.981	9315.962	13:36:00	93159.62	1117915.44
9	2 day demand	6	4996.257	9992.514	13:10	99925.14	1199101.68
16	3 day demand	6	4740.652	9481.304	13:10:00	66369.128	796429.536
17	3 day demand	6	4876.237	9752.474	12:35:00	68267.318	819207.816
18	3 day demand	6	4876.237	9752.474	12:35:00	68267.318	819207.816
37	1 day demand	7	5840.513	11681.026	13:40:00	350430.78	4205169.36

Figure 4.4 depicts the distance, costs (per operation, monthly and yearly), vehicles used, and time taken for each feasible scenario.

Figure 4.5 demonstrates the route for scenario 7.

Similarly, Scenario 8 required five vehicles to cover 4657.981 km in 13:36 hours, estimated to cost 1,117,915.44 for the year. In Scenario 9, only six vehicles were required to cover 4996.514 km in 13:10 hours, roughly 1,199,101.68 euros annually. Figures 4.6 and 4.7 show the routings for scenarios 8 and 9.

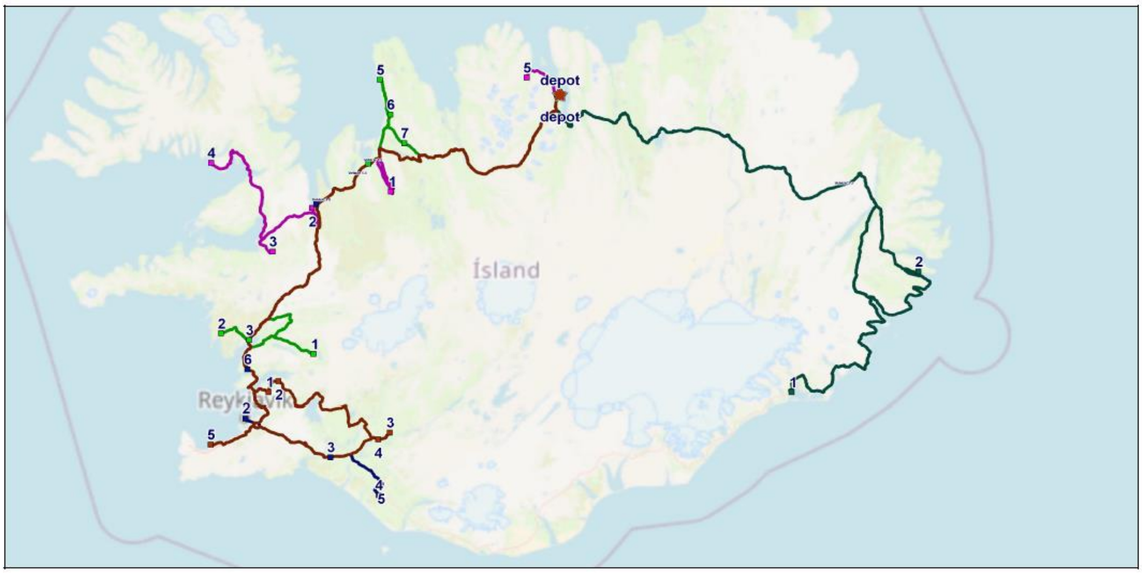

Figure 4.6 depicts the vehicle routing for scenario 8, covering 25 stops.

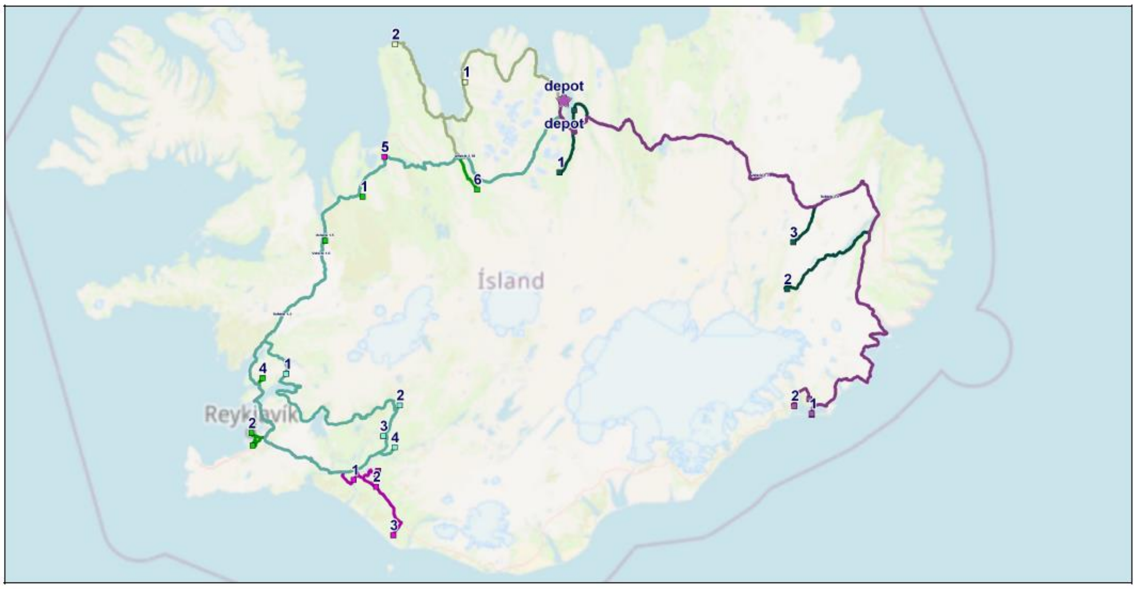

Figure 4.7 depicts routing for scenario 9, serving 25 pick-up locations.

Analyzing further, scenario 16 had 29 stops covered by six vehicles, and the distance traveled was around 4740.652 km, costing 796,429.536 euros yearly. In contrast, scenarios 17 and 18 also had 29 stops to be covered, with 4876.237 km traveled by six trucks in both scenarios. Moreover, the cost for both of them was 819,207.816 euros annually. Apart from these, scenario 37 shows that to cover the stops daily, the required number of trucks was 7, and the distance traveled to cover all the stops was 5840.513 km. Moreover, the daily cost of running the operations was 4,205,169.36.

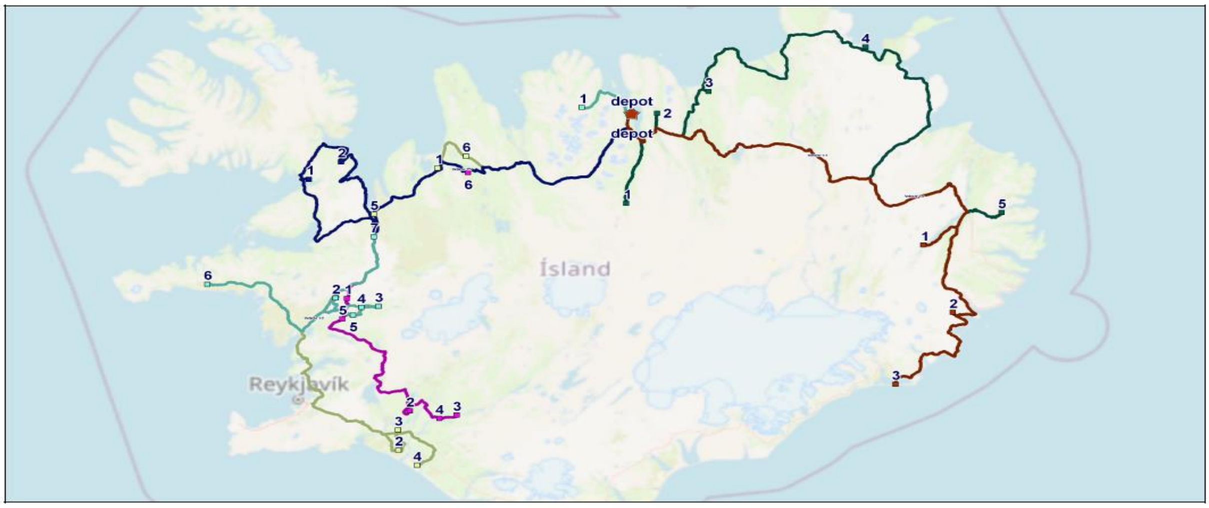

Figure 4.8 illustrates the routing for scenario 16

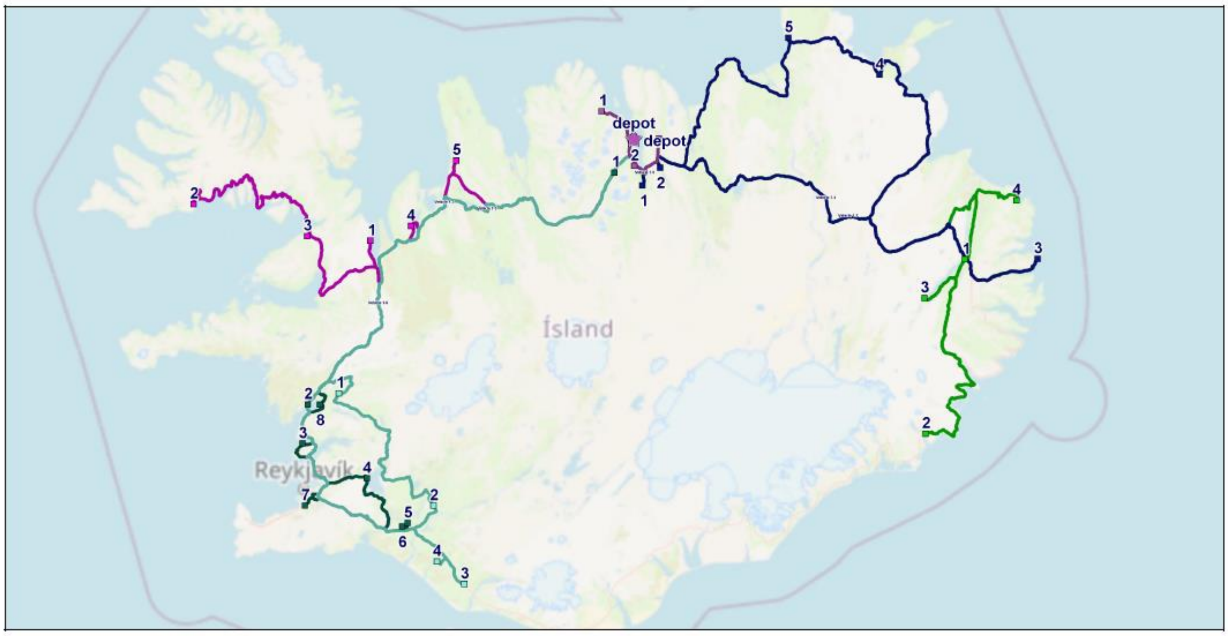

Figure 4.9 depicts the routing for scenario 17

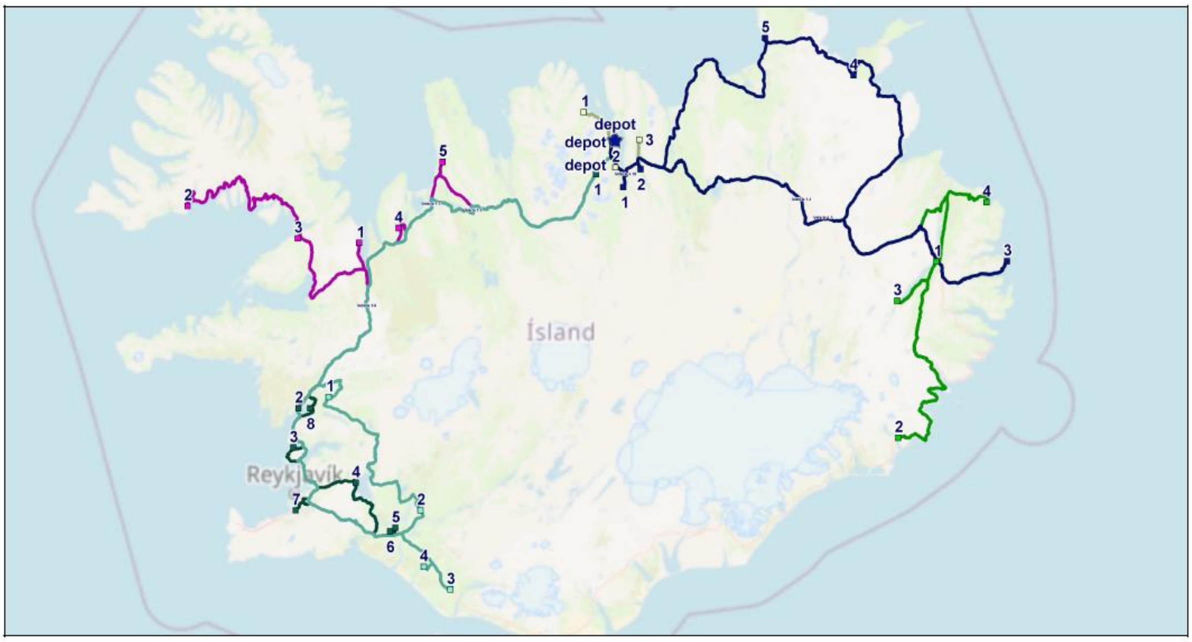

Figure 4.10 illustrates the routing for scenario 18

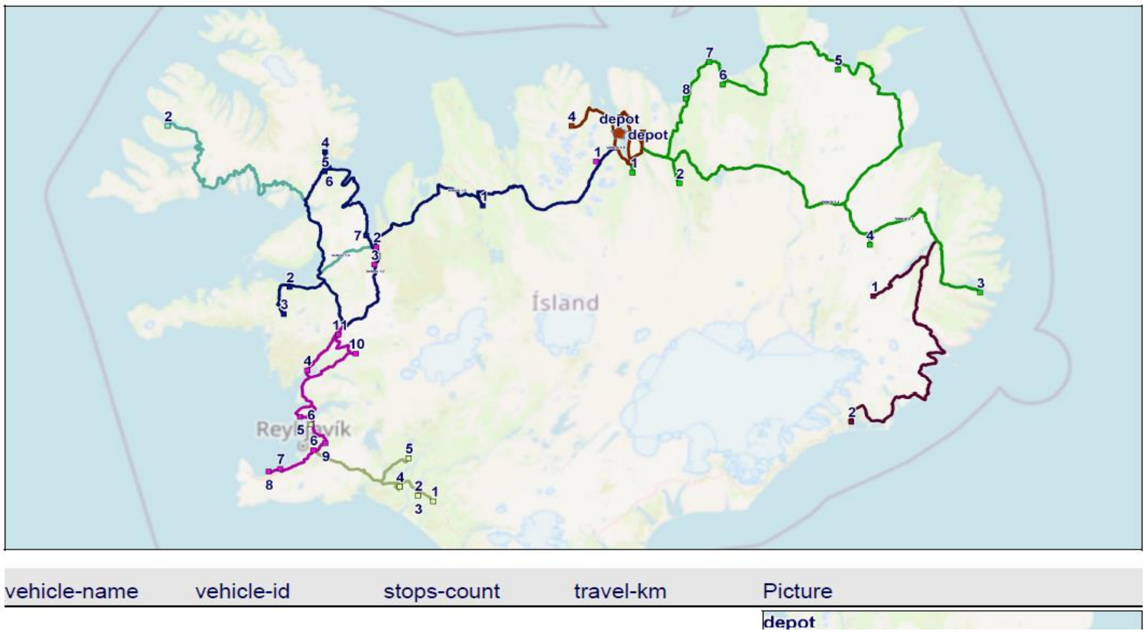

Figure 4.11 depicts the routing for scenario 37

However, cost was the most critical factor in selecting one scenario from the feasible solutions. Scenario 16 had the lowest possible cost of around 796,429.536 euros yearly. Hence, Scenario 16 has a three-day demand with an approximate quantity of 2465 Kg to be removed from 29 stops with 6 vehicles in use per operation.

5 Discussion

The main aim of this thesis was to create optimized logistics routes for the collection of animal carcasses in Iceland adhering to the circular economy principles promoting efficiency and sustainability. Apart from this, keeping the cost for the entire operation to a minimum, determining the number of vehicles required to cover all 1310 farms across Iceland efficiently. Moreover, comparing different locations for the factory set was also crucial to creating optimal routes to cover and remove animal carcasses, thus, preventing the mixing of materials that are hazardous to the environment.

Our results clearly show the optimum collection process, that is covering the entire stop with minimum costs while also ascertaining the number of vehicles required to carry out the process. Moreover, our recommendation was to carry out the collection operations every three days, since it was more budget-friendly, whereas, it was also feasible to carry out the operations daily, however, due to the significantly high cost of operations which amounted to 4.25 million euros with 7 vehicles required at the disposal to implement the process. In contrast, if we carried out the process every three days, with 6 vehicles in use which cost approximately 796,000 euros for the whole year. Thus, it was more practical to follow a three-day pattern which not only was cost effective but also required one less vehicle in the process. In addition, it was also feasible to follow a two-day pattern with four vehicles in use, which amounted to 798,000 euros, slightly higher than the three-day pattern discussed earlier. Hence, the most optimal way to implement the complete logistics process was to follow a three-day demand pattern with 6 vehicles in use and the time of the collection process from 6:00 a.m. to 9:00 p.m. for a single operational cycle.

Lastly, finding out the location of the factory set up where the processing of material would take place was another objective of this dissertation. Dysnes Harbour site, in the North of Iceland about 15 km from Akureyri, was selected as the prime location for the factory setup due to its accessibility. Moreover, Dysnes is a part of a green-field industrial area in Northern Iceland which is being actively developed to promote various industrial sectors like mining, oil factories, and other research work to grow different industrial sectors in the region. Thus, Dysnes was ideally suited to be the location for the factory required to process the dead carcasses. Thus, in conclusion, this research was not only crucial in devising a cost-effective process, but it was also vital to remove animal by-products that are harmful to the environment by adhering to circular economics practices, thereby, improving sustainability.

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