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Supply Chain Modelling and Simulation of Hemp Fiber Production in Ireland

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Abstract: With the growing concerns of environmental issues and awareness of sustainable materials and energy, industrial hemp has been proposed as one of the strategies to react to the ecological crisis and challenges that are caused by the transition from the original power plant to a sustainable ecosystem in Midland Ireland, with the support Just Transition Funds which the Irish government introduced. Industrial hemp has a wide range of applications and commercial value, and it is a choice that benefits both ecology and the economy in Ireland. However, a very limited focus has been put on hemp fibre production, compared to Cannabidiol-related products. Few studies have established a hemp production and management framework from raw materials to sales. Few studies can provide auxiliary information for the feasibility analysis of growing industrial hemp. This study aims to contribute to the feasibility study of hemp fibre production in Ireland by modelling and simulations of the supply chain of hemp animal bedding in Ireland. This paper establishes the supply chain framework for hemp production. It presents the results of the supply chain simulations in 5 scenarios for hemp animal bedding in Ireland. The supply chain modelling visualizes project structures, provides relevant simulation data results to aid decision-making, and establishes the basis for subsequent models. It is concluded that there is still potential for hemp fibre production, and it is feasible to adapt hemp fibre production in Midland Ireland from both sustainable and economic aspects.

1 INTRODUCTION

With the growing emphasis on sustainable agriculture and the potential economic benefits of hemp production, there is an increasing interest in exploring the feasibility of hemp fibre production in Ireland. Industrial hemp has a long cultivation history and a wide range of applications across fields, such as bioplastics, building materials, food and beverages, textile, paper, composite for the automotive industry, biofuels and others. Hemp farming enhances thermal balance and air quality through its strong carbon sequestration and absorption abilities. Hemp farming can also reduce soil toxicity, improve soil quality, prevent soil erosion, help clean up nuclear spills and remove harmful materials from contaminated soil(Barrett et al., 2005).

However, a minimal focus has been put on hemp fibre production. A small number of studies have established a framework for hemp production and management from raw materials to sales. Few studies can provide auxiliary information for the feasibility analysis of growing industrial hemp. A framework and feasibility analysis of hemp fibre production in Ireland would be helpful for the local government through the transition.

This research work aims to conduct a feasibility study of hemp fibre production as a new solution for local farmers in Midland Ireland, by developing the potential supply chain model of hemp fibre production, conducting simulations in multiple scenarios, and evaluating the feasibility of hemp fibre production business. Thus recommendations can be made based on the study results.

The remainder of this paper is organized as follows. Section 2 presents the related reviewed literature. Section 3 described the materials and methods used to conduct this work. This is followed by Sections 4 and 5, which present the implementation ef-

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forts and results. Sections 6 and 7 present the discussion and conclusions.

2 LITERATURE REVIEW

Hemp is one of the oldest and easiest crops to grow for centuries in human history, it is regarded as an agricultural commodity and used for its industrial properties in many countries rather than its medical and recreational effects with its negligible quantities of Tetrahydrocannabinol (THC), the active ingredient inducing psychoactive effects. Its versatility makes it a valuable crop for farmers and manufacturers.

However, challenges are faced by hemp fibre production, including the lack of modern processing machinery, lack of financial study, low profitability, a generation gap in the workforce, and the optimization of the environmental impacts of the entire value chain (Zimniewska, 2022) (Ingrao et al., 2020). Rudimentary supply chains have been developed for Cannabidiol (CBD) production, but areas such as fibre and grain segments are immature or non-existent. Today's retail supply chain is much more complex than the traditional supply chain with stronger collaborations with manufacturers and raw material suppliers (Ge et al., 2019).

The challenges of the Industrial Hemp Supply Chain (IHSC) include the high level of complexity and variability, data tampering, and the lack of an immutable information tracking system (Wang et al., 2020).

Both producers and buyers are seeking a balance between supply and demand that will result in profitable industrial-scale fibre production in the United States. Studies have shown that the primary obstacle to in-effectively executing the complete end-to-end process of IHSC (Industrial Hemp Supply Chain) lies in the absence of established guidelines and adequate knowledge concerning critical aspects such as seed selection, fertility, harvesting, and large-scale handling. The management of IHSC as a cyber-physical system is confronted with substantial challenges due to its intricate and variable nature, the dearth of comprehensive information, the potential for data manipulation, issues of scalability, and challenges related to data and information tracking. The hemp fibre supply chain has been compared with the traditional cotton production supply chain, indicating that both chains have similar processes, especially in agricultural activities (Duque Schumacher et al., 2020).

Many researchers have applied Industry 4.0 technologies in the supply chain models (Lezoche et al., 2020). Blockchain has been used to increase traceability in agricultural supply chains, which allows better evaluation of supply chain performances (Ronaghi, 2021) (Wang et al., 2020) (Kamble et al., 2020). IoT and digital twins are also used as more data-driven technologies in supply chain modelling to improve the performance and efficiency of supply chains (Yadav et al., 2020). Meanwhile, the use of computational tools has also drawn a lot of interest from corporations and scholars. Supply chain modelling and simulation have been carried out using digital and computational methods. With the help of computational tools, researchers can investigate various situations, assess risks, and improve supply chain networks using simulation-based methods. Many recent studies focus on supply chain risk management, mitigation and resilience evaluation regarding COVID-19 disruptions by running simulations in different scenarios (Yu and Rehman Khan, 2021) (Achmad et al., 2021) (Muralidharan et al., 2022) (Shahed et al., 2021). It is important to integrate modelling and simulation by using complicated models to depict the network dynamics. Studies in agricultural areas involve the durian supply chain analysis with modelling and simulation, the distribution network analysis of table grapes production (Sembiring and Sipayung, 2020) (Vitorino et al., 2022), etc. However, few studies have applied supply chain modelling to hemp fibre production.

Developing robust supply chain models and infrastructure for hemp fibre production could provide insights into the potential for hemp production in Ireland, as well as provide a basis for the establishment and modelling of the supply chain for the cultivation and utilization of industrial hemp fibres.

3 MATERIALS AND METHODS

A combination of quantitative and qualitative data collection techniques was used in this research. Four main steps are followed, namely, problem identification, solution definition, data collection, and implementation & evaluation.

3.1 Case Study: Interview

In order to have more accurate and firsthand information about hemp cultivation and production in Ireland, a case study was conducted with a local farmer in Wicklow, Ireland.

According to the provided data and information, there are several findings that can be categorized into 4 groups, namely, hemp cultivation and production, Sales and market, potential hemp fibre productivity,

and Challenges & Recommendations. Basic and cultivating information is shown in table 1.

According to the interview, about €6000/acre would be achieved for oil sales on retail and €3000/acre for sales on wholesale -just for hemp oil, excluding protein and dietary fibre. In the context of Ireland, hemp fibre would primarily find application in animal bedding, insulation products, and the production of hemp dust for pellets and briquettes. The prospect for the textile industry using hemp in Ireland may face challenges due to the potentially high processing costs in comparison to sales. This could result in hemp textiles produced in Ireland being considerably expensive. Table 2 shows the main expenses for hemp fibre production on farms.

3.2 Data Collection

The supply chain for hemp fibre production modelling and simulation mainly involves three steps, the Greenfield Analysis experiment (GFA), the Network Optimization experiment (NO) and the final simulation for further statistical analysis. For each step, certain types of data are needed.

The Greenfield Analysis experiment (GFA) will be conducted first to generate the best locations for a certain quantity of facilities that can satisfy the demand of all customers. Besides, the GFA experiment can optimize the number of facilities within the specified service distance maintaining the required service level. To conduct a GFA experiment, the following data should be considered and specified: Customers, Locations of the customers, Products, Demand for each customer and product, and Direct distance between customers and Distribution Centers. 65 customers are taken into consideration, including the big chain stores in Ireland, such as Maxi Zoo, Pet World, and Pet Stop, as well as small businesses in multiple Irish regions. The location information is determined by the existing geographical materials such as online resources, including online maps and websites. Figure 1 is the map of pet stores that sell animal bedding in Ireland.

Based on the market research and the findings from the case study, the end product for the simulation is Hemp Animal Bedding. To produce the bedding, the hemp plant's stalk, or hurd, should be decorticated with a decorticator, dried out, and mulched into a straw-like structure. The parameter settings for the demand are mainly based on purchase records and anticipated data. Hemp pet bedding products normally have a long shelf life. It is advised to change animal bedding at least once per week. However, animals that create a lot of excrement or have respiratory

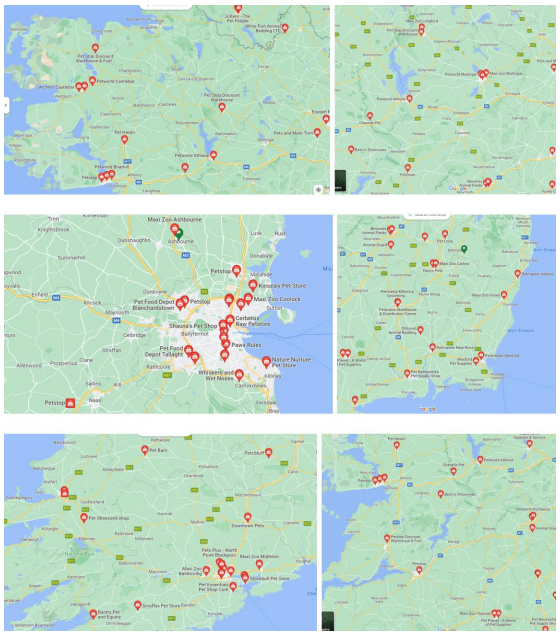

Figure 1: The map of pet stores that have animal bedding sales in Ireland.

problems might need to have their bedding changed more frequently. It is assumed that the demand is of a repetitive nature and is higher in bigger cities. In other words, the order interval of stores in highly populated cities will be shorter than stores that are located in less populated cities. The 65 retail stores are in 21 counties across Ireland, the population statistics are gathered from the Central Statistics Office of Ireland as of 2021. Based on the population, all 65 customers are ranked according to the population and divided into three groups with Group 1 including the most populated regions. The estimated Demand, order interval and total quantity are shown in Table 3. The names in the table are abbreviations of the first three letters of Irish city names.

NO experiment is then explored as an analytical tool to improve the efficiency of supply chains. The research uses a number of experiments to identify the ideal locations for things based on data obtained from GFA's conclusions. The actual roads that are accessible, the actual transportation expenses, the infrastructure, and the operational costs are all presented in relation to the determined optimum locations. Table 4 shows the parameters and settings for the NO experiments.

The final simulations are done based on the previous results generated by GFA and NO experiments. In the pursuit of finding the optimal balance between inventory volume and service level quality, businesses often turn to simulation experiments to test different scenarios. However, to achieve accurate results,

Table 1: Hemp Cultivation Infomations.

Parameter	Info
Farm Location	County Wicklow, Ireland
Farm Size	7 acres
Method	Organic (Animal Slurry)
Hemp Type	Finola
Main Use	Hemp Seeds
Number of workers	3-5
Seeds Yield	300-400 kg/acre
Main products	Seed oil and hemp cake
Sales Market	Ireland, UK and Czech Republic
Oil sales	€3000/acre (wholesale); €6000/acre (retail)

Table 2: Expenses in Hmep Fibre production on farm.

Expense	Cost (€)/acre
Seeding	18
Cutting	60
Renting and turning (twice)	60
Rowing	30
Bales	4
Transportation	Varies
Total (excluding labor)	**172**

proper configuration of sourcing and inventory policies is crucial. The sourcing policy for this case includes the distribution between the suppliers and distribution centres and logistics between DCs and customers.

Key performance indicators can be used for supply chain simulations to gauge the efficacy, efficiency, and general performance of the simulated supply chain. The KPIs should be the most relevant to this feasibility study of the hemp fibre production project in Longford County to align with the business goals and objectives of this project. Therefore, the selected KPIs of the supply chain simulation include financial statistics such as profit, cash, revenue, total cost, facility cost, and production cost. Time factors such as lead time. Demand and Orders should be monitored, such as Demand Received. Besides, service level by orders, service level by revenue, and service levels will be monitored as well.

4 SIMULATIONS

The implementation of this study involves supply chain modelling and final simulations in multiple scenarios, using AnyLogistix. The model performs a two-year simulation, from 01/01/2023 to 31/12/2024 considering 5 scenarios in total which include 3 scenarios for the GFA experiment and based on the GFA results, 2 scenarios are considered for the NO experiment and simulation.

GFA experiments are first conducted in 3 scenarios. The requisite settings and experiment results are shown in Table 5. For scenario 1, three DCs are generated. The first one is located near Dublin, which serves the group of customers that are around the Dublin area. The second DC is in between Galway and Longford, which is in charge of the customers in the north and west parts. The third one is located near Cork and covers customers from Cork to Limerick and the southwest part of Ireland. For scenario 2, only one DC is needed for the market of Ireland within the service distance of 200km between the DC and customers. The ideal location of the single DC is on the border of County Laois and County Offaly, which is about 1-hour driving distance from Dublin. For scenario 3, The result shows that the ideal location for the single DC would be at a nearby place as the result of scenario 2 which has a service distance of 200km within Ireland.

Based on the results of GFA experiments, two scenarios are considered for the following NO experiments. Namely, scenario A with 3 DCs, and scenario B with only 1 DC.

GFA conducted a basic assessment of distribution centre placements without considering key factors like proximity to roads cities, and other geographical peculiarities. The purpose of NO is to optimize the network generated by GFA considering the facts such as actual roads, initial costs, processing costs and other expenses. Multiple potential locations were identified on a GIS map, serving as options for optimal distribution centres. Criteria for selection include proximity to highways and safety in densely populated areas. In Scenario A, extra potential locations were suggested in Longford, Naas, and Cork, totalling seven marked locations. For scenario B, two more sites are added to the map within the county region.

The simulation experiment uses time as a pertinent factor in supply chain optimization. The data and results that are generated by GFA and NO exper-

Table 3: Demand Parameters for the Hemp Bedding.

Group	Cities	Demand	Order Interval	Quantity
1	Dub, Cor, Gal, Kil, Lim, Mea	35	7	525
2	Don, Tip, Wex, Wic, Ker, Mayo, Cla, Wat	25	14	750
3	Kil, Wes, Lao, Sli, Ros, Car, Lon	15	28	900

Table 4: Parameters settings for NO experiments.

Parameter	Setting
Cost Calculation Policy	€0.00005 / kg
Cost of the Product	€12 / package (15kg)
Facility Expenses	€5-7 million

iments are used in the simulations. Two scenarios are simulated finally based on the optimal networking results from NO.

5 RESULTS

- GFA results: A summary of the GFA experiments' results is shown in Table 6, with information about the number of customers for each DC, the total product flow, the distance, and the estimated flow cost, km*kg.

The distribution network of scenario 1 divides its demand into three distribution centres, which leads to a relatively low distance and low product flow. The total product flow is 1,407,455 kg, and the distance is 3,192 km in total. However, there is an uneven trend in the number of customers for each DC. Distribution centre 3 has 31 customers while there are only 12 customers for DC 2 to take care of. This could lead to overload and shortages in DC 3 while excess inventory in DC 2. For scenario 2, a level of service distance of a radius of 200km reveals that only one distribution centre is needed for all the customers in Ireland. The product flow and distribution distance increase dramatically from the results of scenario 1 with 3 DCs. The total flow is 2,846,450 kg for all 65 customers and the distribution distance is 6,402 km, which is double of having three distribution centres. Scenario 3 also has only one distribution centre which is the same as scenario 2 which has a radius of customer service distance of 200km. The total product flow is 2,870,750 kg, which is close to what is obtained from scenario 2, and the distance is 6,511km in total, which is the biggest among all these three scenarios.

- NO results: Table 7 shows the summary of the statistical results of NO experiments in two scenarios. Figure 2 shows the visual results of the NO for these two scenarios. Scenario A has 3 DCs, namely Newbridge DC, Athlone DC, and Mallow DC. The total profit is €17,341,554, and the amount of the flow is 5,741,500 kg. Scenario B has one DC in Athlone, with a total profit of €29,343,500 and 5,741,500 kg of product flows.

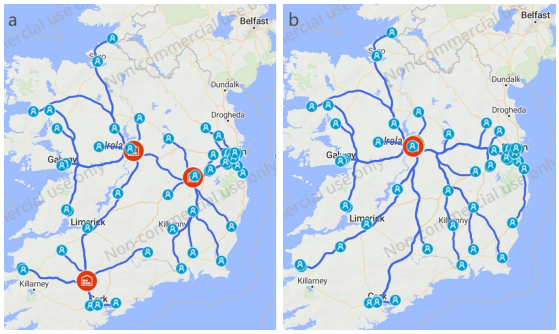

Figure 2: (a) The GIS map of the optimized network for scenario A with 3 DCs; (b) The GIS map of the optimized network for scenario B with 1 DC.

- Simulation results: Table 8 shows the comparison of the results of the simulations of two scenarios with the defined KPIs

As can be seen from the table, the lead time and travelled distance for Scenario A with three DCs is lower than that of having one DC. A service level scenario A of above 0.97 indicates a very high commitment to on-time delivery and a lower tolerance for order fulfilment delays. Meanwhile, the service level of scenario B is just about 0.5, which indicates roughly half of the order fulfilment. It is clear that scenario A has a better customer service level, thus, a better chance to reduce inventory holding and better responsiveness to changes in demand, market trends or other unforeseen events. Scenario A is better with flexibility, agility, and customer satisfaction level. However, scenario A shows some drawbacks when it comes to financial performance. In scenario A, the total cost is €52,565,779, while the total cost of scenario B is €39,890,505, which is €12,675,274 less than scenario A. Scenario B has a bigger number for the transportation cost with a longer travelled distance. The travelled distance of scenario B is 300,642 more kilometres than scenario A and the transportation cost of scenario B is just €3,274.04 more than in scenario A, where 3 DCs are included. It is worth noting that the initial site cost of scenario A is €12,000,000 more than scenario B, which is also the difference between

Table 5: Scenarios parameters and results for GFA experiments .

Scenario	Limited Service Distance	Limited No. of DCs	Needed DC
1	100	no limit	3
2	200	no limit	1
3	no limit	1	1

Table 6: The products flow and distance summary of GFA experiment for 3 scenarios.

Scenario	DCs	Customer	Flow, kg	Distance, km,	Flow Cost
1	DC1	22	847,550	1,318	49,177,187
	DC2	12	558,575	546	20,982,479
	DC3	31	1,330	1,330	59,657,846
Total		65	1,407,455	3,193	129,817,512
2	DC1	65	2,870,750	6,475	283,068,407
Total		65	2,846,450	6,402	281,303,534
3	DC1	65	2,870,750	6,511	282,806,934
Total		65	2,870,750	6,511	282,806,934

the profits. Opening new DCs is expensive and it is the main cost of the total cost, which also has a huge influence on the financial performance.

6 DISCUSSION

The findings of this research are relevant to the supply chain of hemp fibre production in Ireland as an original case project. The simulation results outline the best networking of the supply chain, including the optimal number of DCs for the animal bedding market of Ireland based on the GFA, NO experiments and the 2-year-long supply chain simulations. The results show that 1 DC is enough to reach a service distance of 200 km, and three DCs could realize a service distance of 100 km which leads to a high service level. Three DCs are located in Athlone, Newbridge, and Mallow, where each of them is in charge of 12-30 customers. In this 2-year simulation, the fibre processing business still generates great revenue. The KPIs show that the scenario that has three DCs has a lower lead time and a much higher service level, while the scenario that has one DC has a higher travelling distance for distribution, and higher transportation cost but still a lower total cost.

The results indicate that the performance of the supply chain does not depend on a single element. When it comes to the number of DCs in Ireland, having three DCs could achieve better service levels and agility with lower transportation costs. However, considering that there are currently no existing distribution centres and factories, every new site has its high initial cost including the expensive processing machinery, the total cost of having more DCs and factories is much higher than having a single one at the start. In this two-year simulation, the reduced logistics costs due to multiple distribution centres did not offset the cost of opening DCs and factories over a two-year period. There is a difference of about 12 million euros in spending after two years between owning three centres and having one. However, according to the profitability shown by the simulation, in the long run, with higher customer stickiness and market growth, Scenario A has the possibility of making more profits.

Overall, the experiments demonstrate that there is a market and potential for deploying an industrial hemp fibre industry in Ireland. Two strategies can be summed up. In the short term, starting by opening a centre and the factory can save expenses and realize profits sooner. However, lower service levels and lower customer satisfaction levels may lead to a loss of customer stickiness and loyalty, resulting in the risk of reduced demand and revenue. The second strategy is to start by opening multiple centres and factories with high investment, which can achieve extremely high customer loyalty and stickiness, which is conducive to market development and can increase market demand. At the same time, due to the large amount of investment in the early stage, the cycle to achieve comprehensive profitability is longer, and there is a greater risk of suffering from uncertain changes in the market. Relevant decision-makers should use the research results of this experiment to assist decision-making according to the actual situation.

Table 7: Sumamry of the results of NO scenarios.

Sce.	DC	Sites	Profit, €	Flow, kg
A	3	Newbridge, Althlone, Mallow	17,341,554	5,741,500
B	1	Athlone	29,343,500	5,741,500

Table 8: The summary of the results of supply chain simulation scenarios a & b.

Statistics Name	scenario A	scenario B	Unit
Lead Time	3.4	5.9	day
Initial Site Cost	17,000,000	5,000,000	EUR
Profit	16,332,221	29,007,495	EUR
Revenue	68,898,000	68,898,000	EUR
Transportation Cost	22,656	19,382	EUR
Total Cost	52,565,779	39,890,505	EUR
Traveled Distance	333,158	633,801	km
Service Level by Orders	0.976	0.497	Ratio
Service Level by Products	0.977	0.505	Ratio
Demand Received (Products)	5,794,000	5,759,000	kg

7 CONCLUSION

This study shows that there is still a nascent market for hemp products, the hemp industry will usher in many opportunities, as industrial hemp is getting recognized and accepted by more and more people, associations and various countries have introduced more comprehensive management policies accordingly, new technologies broaden the application map of industrial hemp, the demand is predicted to grow in the following years. A rational and efficient supply chain for hemp fibre production can provide a clear blueprint for deploying hemp fibre production. The feasibility of hemp farming in Ireland is high. It is agriculturally, legally and financially feasible according to the study results. Simulation results propose two strategic options: a short-term strategy involving the construction of one initial distribution centre to save on opening costs, potentially compromising service levels but enabling quick profit. The long-term strategy entails opening three distribution centres initially, ensuring high service levels for enhanced customer loyalty, market expansion, and demand. However, it involves higher initial costs and a longer payback cycle, posing a greater investment risk. The significance of the hemp fibre supply chain modelling and simulation rests in its capacity to offer businesses insightful information, support informed decision-making, improve performance, reduce risks, and optimize costs. The methods and results of this study also laid a certain theoretical and experimental foundation for subsequent scholars who want to study the feasibility and supply chain of industrial hemp. Subsequent research towards this project can focus more on other aspects, such as biological, geographical and financial aspects. Future research can also be done with a more comprehensive data collection method, such as experimental surveys, and interviews with more participants to obtain more accurate and close-to-reality results, which could improve the comprehensiveness and persuasiveness of the feasibility study.

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