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Data-Driven Environmental Sustainability of Supply Chain for Medical Equipment

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Abstract

Sustainable supply chain of medical equipment is challenging due to the inherent importance of having health-related components in-stock whilst balancing the economic and environmental impact of that. In general, to minimize the environmental impact of inventory management, physical inventory space and transportation amount can be lowered. However, in medical equipment, shortage of medical materials, and supplies could cause delays in providing adequate healthcare services. Therefore, effective inventory management is required to maintain a steady supply while minimizing the environmental and economic impact of supply chain. This study is aimed at assessing the environmental and economic impact of inventory for a medical equipment manufacturer. Inventory classification of the medical equipment manufacturer is performed using ABC analysis. After inventory classification using ABC, safety stock analysis is performed. Obtained inventory results are analysed both in terms of environmental sustainability using Life Cycle Assessment (LCA) approach and in terms of economic impact calculating cost of holding safety stock. An LCA model is created based on transportation of procurements. Impact assessment is performed to define most environmentally and economically impactful suppliers of the medical equipment manufacturer.

Keywords: Environmental sustainability; supply chain; inventory management; medical equipment; Life Cycle Assessment

1. Introduction

Supply chain management is an essential component of any business that involves the process of managing the flow of goods and services from the point of origin to the point of consumption. It includes all activities related to the conversion of raw materials into finished products and their distribution to customers. Supply chain is particularly critical for medical industry as it is related to human health and well-being. In the medical industry, timely access to medical equipment can be a matter of life and death, and any disruption to the supply chain can have serious consequences. Therefore, a reliable and efficient supply chain is necessary to ensure that medical equipment is available when and where it is needed to deliver adequate healthcare [1]. Effective supply chain management requires coordination and collaboration across various departments and stakeholders, including suppliers, manufacturers, distributors, retailers, and customers. The goal is to ensure that goods and services are produced and delivered in a timely, cost-effective, and high-quality manner.

Sustainability of supply chain on the other hand, is an emerging and increasingly important issue. As consumers and regulators become more environmentally and socially conscious, there is growing demand for companies to adopt sustainable practices in their supply chains [2]. Sustainable supply chain management for medical equipment is challenging

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due to the importance of having critical health-related components in-stock, as well as the need to balance economic and environmental impacts [3]. To address these challenges and achieve sustainability, inventory management and logistics are important elements of supply chain management that need to be optimized.

Inventory management is critical for medical equipment companies to optimize their inventory levels by ensuring they have the right amount of safety stock at the right time to meet customer demand. The primary goal of safety stock is to protect the supply chain from unanticipated events; maintaining an adequate level of safety stock is critical for an efficient inventory management, while maintaining an excessive level of safety stock increases inventory carry costs [4]. Demand of the product, average lead time and standard deviation are factors that affect safety stock. Inventory classification is a technique used in inventory management to group and prioritize items based on their importance for an effective safety stock management. There are several methods that focus on the classification of the inventory based on data, such as ABC analysis, FSN (Fast Moving, Slow Moving, Non Moving) analysis, HML (High, Medium, Low) analysis and XYZ analysis [5]. Although these classification methods are similar in terms of grouping the items into three categories, they use different criteria for classification. ABC analysis categorizes suppliers and their inventories by unit cost and amount of stock (per year), FSN analyzes by frequency of use, HML analyzes by unit price of the product and XYZ by the variability of their demand [6, 7]. The ABC inventory classification system is one of the most commonly used methods of inventory classification [8]. It implements inventory control policies and techniques, narrow down group of items that require more managerial monitoring and control, prioritize a storage location plan, minimize the time, and labor cost of put-away, picking, and packing, and dictate when products should be reordered or replenished. In this system, items are grouped into three categories: A, B, and C. Class A items are considered the most important, as they have the highest value or demand, while Class B items are considered to be of moderate importance, and Class C items are considered to be of low importance [9]. Overall, an ABC inventory analysis can help a medical equipment manufacturer to balance the amount safety stock and environmental and economic impact of safety stock.

Logistics is another important element of supply chain management that needs to be optimized in terms of sustainability issues. Logistics implies the transportation and storage of raw materials, spare parts, and finished products in a supply chain. It includes all inbound and outbound activities moving to and from warehouses, as well as the internal and external transport and materials handling operation [10] Logistics is impactful on environment sustainability as it includes all transportation operations and increase greenhouse gas emissions.

For the sustainability assessment of medical equipment supply chain, Life Cycle Assessment (LCA) is a well-known method as it provides a standardized approach. In recent years, several studies have applied LCA to evaluate the sustainability of medical equipment. For example, Sousa et al. [11] provided a review on environmental impacts and eco-design of medical devices. The study found that although the use of biopolymers is associated with an overall improvement of the environmental impact, it is important to assess the impacts resulting from the use of agricultural products and the need of transportation across long distances resulting from the use of biopolymers in medical devices. Similarly, Eckelman et al. [12] concluded that, ordering raw materials in bulk from local suppliers can decrease impacts associated with transport. Overall, the studies indicate that, logistic of raw materials is critical for sustainability of supply chain. To handle this issue, this study provides a method for grouping suppliers based on their environmental and economic impact.

In this paper, a case study is conducted for a UK-based medical pharmaceutical systems company. To improve the company's supply chain management on a sustainable manner, inventory was classified using ABC analysis and the safety stock of raw material was calculated based on the supplier's reliability. The environmental impact of transport of raw materials from suppliers to the company was assessed using LCA. Economic impact of holding a safety stock for each raw material was calculated based on ABC classification. The key suppliers identified according to the ABC analysis classification were discussed in more detail in terms of their environmental and economic impacts.

2. Methodology

2.1. Safety Stock Calculation

The primary purpose of safety stock is to buffer the unexpected and unanticipated events that impact the supply chain. Although it would have an economic cost to hold stock 'just in case', however, keeping extra stock could ensure that the flow of materials is maintained, and customer orders are being fulfilled. Safety stock can be calculated in different ways, these include using Heizer & Render's formula [13], but that doesn't take demand changes into account, or using Greasley's formula [14] which does not consider stock which is still in production and not yet ready for sale, or by using a general formula which is the most commonly used method due to its simplicity. For this research, the general formula used to calculate the safety stock is given in Equation 1,

$$Amount\ of\ safety\ stock = number\ of\ weeks\ of\ safety\ stock \times \text{weekly}\ demand\ of\ FP \times quantity\ of\ RM \times (1 + Scrap) \quad (1)$$

where FP is the final product, RM is the raw material and Scrap is the amount of raw material that goes to scrap.

ABC analysis was performed to determine the dependability of the suppliers, based on their average delay. Category A represents suppliers with a negative average delay, category B represents suppliers which have a delay below one week and the remaining suppliers were attributed to category C. Furthermore, subcategories A1, A2, and A3 were created based on the suppliers' location as follows; '1' is UK-based, '2' is EU-based, and '3' is Rest of World (RoW). Table 1 shows an example list of suppliers' categorizations regarding to average late day and supplier location. Number of weeks of safety stock was defined regarding to sub-categories of the suppliers.

Table 1. Safety stock classification.

Supplier	Average late day	Supplier location	Category	Sub-category	N* of weeks of safety stock
S1	-9	EU	A	A2	2
S2	6	EU	B	B2	3
S3	2	EU	B	B2	3
S4	3	UK	B	B1	2
S5	-4	UK	A	A1	1.5
S6	5	EU	B	B2	3
S7	14	RoW	C	C3	5
S8	15	UK	C	C1	4
S9	-3	UK	A	A1	1.5
S10	6	UK	B	B1	2
S11	8	EU	C	C2	5
S12	2	EU	B	B2	3
S13	38	EU	C	C2	5
S14	-42	UK	A	A1	1.5

2.2. LCA Analysis

After classification of company inventory using ABC analysis, LCA analysis of material transportation operation is performed to demonstrate environmental sustainability assessment. The LCA analysis aims to evaluate the environmental impact of material transportation and contribute to identifying the items that are most important not only in terms of high demand but also in terms of environmental impact.

LCA analysis was performed only for one year of transportation operations for materials from supplier to the company. Storage area was not taken into consideration as it is only a space occupation. The electricity usage of the storage area is low, and the stored materials do not need a specific storage condition such as cooling or vacuum. The inventory list of the company has been narrowed down to the materials purchased in kg for easy modeling of transportation operations. The functional unit for the transport of the materials, expressed in "tonne-kilometre [tkm]", was calculated for each material and implemented into LCA transport model for freight transport. Materials from different continents are transported to the company by sea transportation. Inland transports from the supplier location to ports and from ports to the company location are conducted by trucks. Due to the lack of primary data from the company, the most common sea cargo shipment routes from the suppliers' country to the UK were selected for sea transport. It was assumed that the location of the supplier is in the capital of the country. The supplier countries and the distances for truck and sea transport are given in Table 2.

SimaPro 9.2 software was used in combination with Ecoinvent 3 database to carry out LCA for material transportation. The Ecoinvent 3 contains international industrial life cycle inventory data on energy supply, resource extraction, material supply, chemicals, metals, agriculture, waste management services, and transport services. As for the Life Cycle Impact Assessment (LCIA) process, the ReCiPe 2016 methodology was used [15]. ReCiPe 2016, one of the most widely used LCIA methodologies, has been chosen due to its worldwide coverage, including characterization factors for midpoint and endpoint indicators. Global Warming Potential (GWP, kg CO_2eq) is an impact category that widely recognized as an important metric for measuring the potential impact of a substance or activity on climate change. Many industries are increasingly focusing on CO_2eq emissions and trying to implement sustainability measures to address climate change. That is why, to compare the environmental impacts of suppliers, kg CO_2eq results were defined for each supplier.

Table 2. Supplier countries and distances to company.

Supplier countries	Distance in Supplier Country (km)	Distance of sea transport (km)	Distance in UK (km)
UK	-	-	*
FR	Paris – Calais Port – London Gateway Port - Company		
	344	182	212
DE	Berlin – Hamburg Port - London Gateway Port - Company		
	290	748	212
NL	Amsterdam – Rotterdom P. – Felixstowe P. – Company		
	78	208	295
IR	Dublin Port – Liverpool Port - Company		
	-	233	284
US	Mineapolis – New York Port – Liverpool P. – Company		
	1934	5746	284

* Distances of UK-based companies were defined separately.

3. Results

3.1. ABC Analysis and Safety Stock Results

The impact of keeping a safety stock has been calculated from an economic point of view, as the storage area does not need excessive amount of electricity consumption and as a result does not have a high environmental impact. A weekly unit cost per 10 ton of raw material was defined for keeping safety stock. The economic impact of each supplier according to the amount of safety stock and number of weeks was calculated using the unit cost. Comparison of suppliers regarding to ABC classification and calculated economic impact of safety stock is given in Fig. 1. The variable economic impact of suppliers in each subcategory represents the contribution of the amount of safety stock to the economic impact. Since the economic impact of safety stock is not linearly correlated with subcategories (the number of weeks of safety stock), the amount of safety stock is more impactful on the cost.

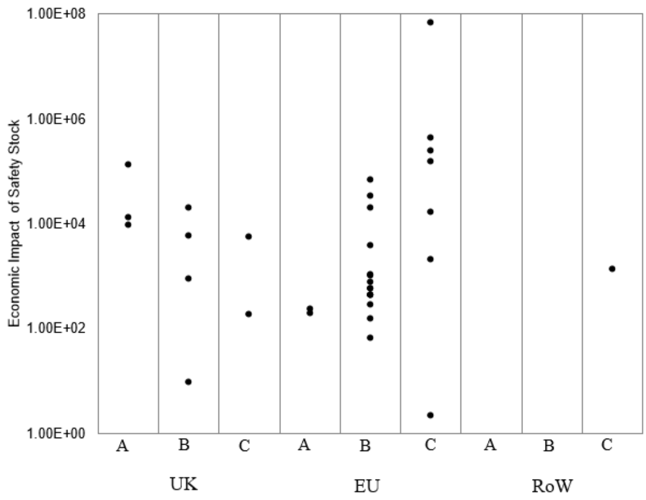

Fig. 1. Comparison of suppliers regarding to ABC classification and economic impact of safety stock.

3.2. LCA Results

Environmental impact of suppliers was defined in terms of CO_2eq emission during the transport of raw materials. Comparison of suppliers regarding to ABC classification and CO_2eq emission is given in Fig. 2. Similar to economic impact, suppliers in the subcategories showed varying environmental impacts. While the distance of suppliers has an effect of environmental impact, the amount of material is also critical.

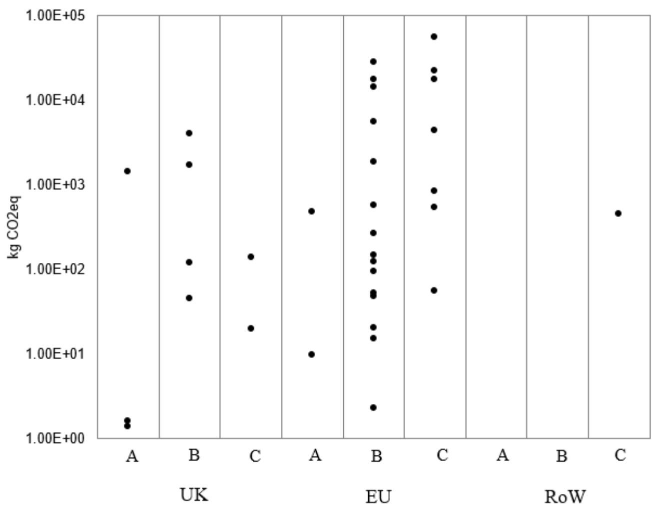

Fig. 2. Comparison of suppliers regarding to ABC classification and CO_2eq emission.

4. Discussion

To assess the environmental and economic impact of suppliers, their CO_2eq emission and economic impact of safety stock were compared as given in Fig. 3. The dotted line is used for guidance to show the correlation between environmental and economic impact, it does not indicate scientific information. This linear correlation shows that annual consumption of raw material impacts both environmental and economic sustainability. From these results, suppliers can be aggregated into four supplier groups:

1. High environmental – high economic impact: This group is highlighted in red in Fig.3. This class refers to suppliers that have a significant impact on both the environment and the economy. These suppliers are critical for the company as they provide materials with high annual consumption rate. For this reason, it is necessary to give priority to both safety stocks and procurement operations from these suppliers.
2. High environmental – low economic: This group is highlighted in blue in Fig.3. This class refers to suppliers that have a significant impact on the environment but are not so critical in terms of their economic impact. These suppliers need to be monitored for procurement operations to ensure that their operations are sustainable and environmentally responsible.
3. Low environmental – high economic: This group is highlighted in green in Fig.3. This class refers to suppliers that have a low impact on the environment, but a high impact on the economy. These suppliers need to be monitored for their safety stock.
4. Low environmental – low economic: This group includes all suppliers not highlighted in Fig. 3. This class refers to suppliers that have low impact on both the environment and economy. These suppliers need less attention than the other suppliers grouped above.

These aggregation of suppliers into groups can help the company to optimize its supply chain management processes, reduce its inventory carrying cost, and minimize its environmental impact, while still ensuring that it has appropriate levels of inventory. One way for the company to reduce its environmental impact is by collaborating with groups that have a significant impact on the environment. This could involve encouraging suppliers to improve the loading efficiency of their transport vehicles and increase fuel efficiency [16]. Alternatively, the company could switch to suppliers with a lower environmental impact. Similarly, to reduce inventory carrying costs, the company could work with groups that have a high economic impact. By optimizing safety stock levels with suppliers that have a significant economic impact, the company can potentially reduce inventory costs.

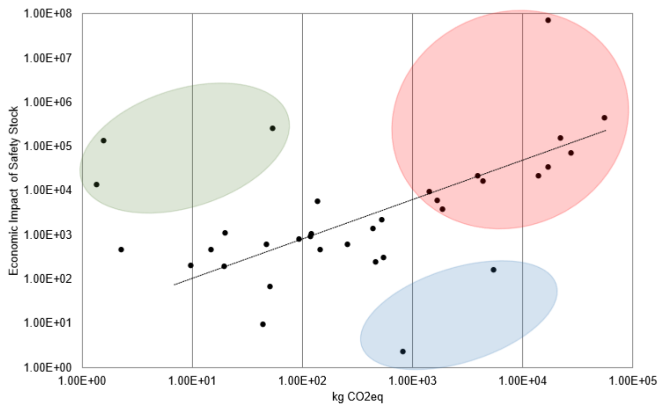

Fig. 3. Comparison of suppliers regarding to CO_2eq emission and economic impact of safety stock. The dotted line does not indicate scientific information, it is for guidance only.

5. Conclusion

Managing medical equipment supply chain sustainably poses a challenge due to its critical significance. While minimizing the environmental and economic impact of supply chain practices, a shortage of medical materials and supplies can impede the delivery of adequate healthcare services. Hence, it is crucial to implement efficient supply chain management to sustain a constant supply and mitigate the environmental and financial effects of inventory storage and logistics. The goal of the study was to evaluate the environmental and economic impact of safety stock and raw material transportation of a medical equipment manufacturer. ABC analysis was used to classify suppliers and safety stock calculations were performed for each raw material type. Economic impact of safety stock was calculated regarding to weekly unit price of holding a stock. Environmental impact of raw material transportation was defined using LCA analysis.

The results of this study provided valuable insights into the sustainability and economic efficiency of the medical equipment manufacturer's supply chain management practices. The ABC analysis helped the manufacturer prioritize inventory management efforts and reduce waste in less critical items. The safety stock analysis provided the information to ensure that sufficient stock is maintained to meet the demand for medical equipment while minimizing the economic impact of holding excess inventory.

The LCA approach used to identify the most environmentally impactful suppliers. This information can be used to improve the sustainability of the supply chain and reduce the overall environmental impact of the medical equipment manufacturer.

Furthermore, the calculation of the cost of holding safety stock provided a more comprehensive understanding of the economic impact of inventory management practices. This information can be used to optimize supply chain strategies and improve the financial efficiency of the manufacturer.

In conclusion, this study highlights the importance of considering both environmental sustainability and economic efficiency in supply chain management practices in the medical equipment industry. The findings can be used by medical equipment manufacturers to improve their supply chain management processes and reduce their environmental impact while improving their economic efficiency. This study gives baseline information from a group of suppliers, however further research is necessary to evaluate the entire supply chain and identify the suppliers that require a balanced approach of inventory management strategy so that the company's economic and environmental impacts are considered. As such, all procurement practices and value streams, starting from packaging to used transportation methods and storage areas shall be considered.

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