Closed-Loop Supply Chain

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A CLSC can be defined as “a supply chain system entailing design and implementation for enhancing the useful value throughout the product life cycle while dynamically extracting value from different returned products”[1].

Closed loop supply chain, cost optimization

1. Introduction

Supply chain management (SCM) integrates different parties involved in the business network. It considers various aspects of decisions such as acquisition of raw materials and the delivery of finished goods [2]. Traditionally, supply chains involved the analysis primarily based on cost; however, recent advents have demonstrated the integration of several other aspects such as environmental sustainability and well-being of employees, to name a few [3]. Besides, a constant pressure is being exerted by government agencies and society to limit the environmental footprints of production and supply chain networks [1]. The supply chain is thought to be the leading source of global warming, environment degradation and carbon emissions [4].

Traditionally, the forward supply chain was focused to provide the goods to end consumers using cost-effective and responsive mechanisms. Such supply chains were based on forward logistics without taking into account the end-of-life (EOL) treatment of products retrieved from the end consumer. As logistics has received more attention from law makers and customers, businesses have embedded the reverse logistics into their practices. The reverse logistics can take a cross-company dimension as well where in-house operations such as return, disassembly and remanufacturing are prioritized. This is done to reduce environmental impact and improve the carbon footprint of businesses.

Van Hoek et al. [5] argue that the inclusion of reverse logistics is not enough, and businesses need to incorporate the idea of green supply chains to become more sustainable in their practices. The leap from reverse logistics to the supply chain concept is defined by a shift from reactive approaches to value seeking approaches. For instance, the manufacturing system can react to the environmental footprint concerns by taking initiatives for mitigating the emissions, etc. On the other hand, if the environmental aspects are considered as an opportunity to seek value, the businesses can take a pro-active approach to define its long-term vision for green supply chains. Thus, a sustainable edge, cost cutting and innovation base can be formed.

The green supply chain starts at the supply source and its scope extends towards the packaging, product transportation, distribution and end customer. Furthermore, at the end of life, the products are called back to the manufacturing system where they are re-manufactured or used for value extraction. Thus, a holistic perspective of supply chain system is taken into account which provides a long lasting impact on green practices. Such perspective ensures that the manufacturing system takes full responsibility for product re-use to play a strategic role in minimizing the environmental impacts by integrating environmental activities.

Together, the forward and reverse logistics make up a closed-loop supply chain (CLSC). An effective CLSC needs to be managed, controlled and run to enhance the profit values and reduce the anticipated costs throughout the life cycle of the product [6]. The manufacturing system can consider various challenges which hinder the boost of an efficient CLSC. These challenges can be in the form of facility deployment, designing the product flow, cost reduction and environmental protection [7][8]. Though the CLSC analysis has been considered from different viewpoints, the analysis of time, number of machines, production disruption and different market niche, to name a few, are missing in the concerned literature.

2. Studies on Closed-Loop Supply Chain

CLSC has been attaining research attention and recent comprehensive reviews to this field have been offered by [7][8][9]. There are different contributions offered towards the analysis of the CLSC network. For example, Pazhani et al. [10] proposed a multi-objective model that included the objectives of cost and efficiency to analyze the performance of a CLSC. The synthesis was based on decisions of locating warehouses, production and distribution of goods.

The environmental aspects have been receiving an increasing amount of research focus to cater the emission and footprint issues. There have been different contributions to analyze the environmental aspects of a CLSC. A multi-echelon CLSC was considered in [11] by using an incentive plan and retrieval of used products based on different quality levels. A multi-objective model was presented to optimize the total cost and the environmental impact of the CLSC. Yavari and Gerali [12] studied the CLSC for perishable goods by presenting and analyzing a multi-product, multi-period and multi-echelon model. A multi-objective model was presented to minimize the total cost and the environmental pollutants.

Soleimani et al. [13] analyzed the objectives of profit maximization, reduction of lost working days and environmental aspects. Different recycling strategies i.e., product, component and material recycling were analyzed using a genetic algorithm. Zhen et al. [14] proposed a stochastic bi-objective model to optimize the operating cost and environmental aspects of a CLSC network. A multi-echelon and low-carbon based network was designed that included the decisions regarding production, recovery, distribution, disassembly and customer locations. Zhalechian et al. [15] studied a sustainable CLSC problem and considered the aspects of CO_2 emission, fuel consumption and social concerns of a new job opening. Mohammed et al. [16] analyzed the environmental impact and total cost by proposing a multi-period and multi-product based CLSC. A trade-off was proposed between CO_2 emission and the cost of a supply chain network. Although an adequate amount of research has been offered towards the establishment of an efficient CLSC, there still is a dearth of literature to address the environmental concerns of CLSC, emission, etc. [17]. A detailed procedure was adopted to extensively analyze the concerned literature and it is discussed below.

2.2. Embedded Factors and Market Levels

The CLSC operates in a way to collect the products once they have completed their useful life. If the product is of adequate quality, it is re-manufactured to make it as good as (or almost as good as) a new product. Secondly, if the product is non-repairable, maximum level of energy is extracted from it which is subsequently fed to the production processes. Thirdly, the product is disposed of after acquiring energy from it, or if it is in such a poor state of quality that it cannot offer any useful amount of energy. Thus, the embedded factors considered here relates to re-manufacturing, energy extraction and disposal. The distribution of embedded factors is provided in Figure 2a. It can be observed that re-manufacturing is the most opted strategy adopted for returned products (56% articles) (refer to [18][19][20] etc.,) compared to energy extraction (8%) [21][22] and disposal (36%) [23][24]. It might be due to the fact that legislators and customers are constantly pushing for minimizing the carbon footprint of products through re-manufacturing. Similarly, there is a dearth of literature focusing on the integration of all three factors (e.g.,[25][26][27][28]).

The market levels refer to the number of times the product is re-launched in different quality conditions. Initially, a perfect quality product is supplied to primary market and upon completion of the useful life, it is retrieved, refurbished and then supplied to the secondary market. The product launched in the secondary market is somewhat inferior in quality compared to the products launched in the primary market. We introduce the notion of tertiary market based on quality differentiation where the maximum amount of energy is attained and the remaining is disposed. The CLSC literature distribution according to market levels is provided in Figure 2d. As is obvious, most of the optimization studies in CLSC launch the products initially to the primary market (85%) [29][30] as opposed to distribution to secondary (14%) [31][32] and tertiary market (1%) [18].

Figure 2. Distribution of literature according to (**a**) Embedded Factors, (**b**) Objective functions, (**c**) Solution approaches and (**d**) Market levels.

2.3. Choice of Objective Functions and Additional Aspects

From the managerial perspective, it is important to support the design of a CLSC network by optimizing it against certain criteria. These criteria can be in the form of cost, time, responsiveness, etc. For the current analysis, we surveyed the associated literature with respect to the objectives of cost, environment and social aspects and time. Cost has been more often chosen as the choice of objective function to optimize the performance of a CLSC network (77%) [32][33][34]. The aspects of cost used in the analysis comprises, but are not limited to transportation, purchasing, re-manufacturing, capacity cost, etc. [23][35]. Until now, the concerned literature has lacked in analyzing the cost related to disruptive performance of machine.

Beside cost, the second choice of objective function is environment and social aspects (23%). The environmental aspects considered in the published literature are: energy spent, emissions, environmental impacts, trading price of carbon emission, etc. [25][36][37]. The social aspects considered for the CLSC optimization are based on the selection of a responsible supplier, societal development, job security and wages. etc. [27][28].

An important point to note is that none of the CLSC studies have optimized the network design on the basis of time. Time is an essential aspect of a production system/supply chain as it impacts the throughput and responsiveness towards the customers.

With respect to the additional aspects of vehicle speed and disruption, the aspect of vehicle speed plays a sensitive role in the performance of CLSC as beside other factors, it affects the time to deliver a product. The existing literature analyzes the vehicle speed; however, the sensitivity analysis of such parameters on the performance of the CLSC network performance is observed less often. Similarly, disruption in the supply chain can affect the performance of the latter and it has been analyzed in only a few studies. The existing literature considers disruptions such as supplier disruption and demand disruptions. Certain disruption related issues are also addressed in the open supply chain literature in the form of demand disruptions and manufacturing cost disruptions. To the best of our knowledge, none of the existing studies in the CLSC literature have addressed the issue of machine disruption.

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