A Comparative Analysis of Linear and Circular Supply chains Performance in Resource Management and Risk Mitigation: A Simulation Approach

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Abstract. The concept of circular economy has emerged as a driver to sustainability. Recent studies suggest that circularity can also promote supply chain resilience. In literature, few works are investigating how the transition towards circular supply chain can enhance the ecosystem viability. The purpose of this paper is to compare the performance of linear and circular supply chain in term of resource management and risk mitigation. A simulation-based approach is adopted to assess the performance of each configuration through a case study of two supply chains operating autonomously and collaboratively. The findings indicate that the circular practices promote resource and waste management. However, the outcomes underline the vulnerability of the circular network to risks. The results provide valuable insights for scholars and professionals in promoting knowledge regarding the transition toward the circular ecosystem.

Keywords: Linear supply chain, circular economy, Simulation, Disruptions, AnyLogistix

1 Introduction

In face of mounting interest to environmental concerns and resources scarcity, the traditional business model is increasingly being challenged [1]. The classical manufacturing process consisting of “take- make-dispose” is no more acceptable. Because these practices increase virgin raw materials consumption and generate waste leading to a non-sustainable future[2]. Circular economy (CE) has emerged as a condition to achieve sustainability[3]. The concept aims to achieve the zero waste through 10Rs, refuse, reduce; rethink, reuse, remanufacture, repair, refurbish, repurpose, recycle and recover [4]. It emphasizes resources efficiency and product life management. CE practices promote the economic and social sustainability [5]. On other hand, literature supports the contribution of CE to promote resource availability during crisis [6], [7], [8].

The circular SC refers to the integration of CE strategies into SC [9]. It integrates a closed-and-open loops to enhance resource efficiency and take advantage of the generated waste[10]. Collaboration among sectors is seen as key factor to achieve circularity and effective resource and waste management [11]. In fact, there are several intersections between SCs as they can use common raw materials and infrastructures and manage them collectively [7]. Moreover, SCs aligns their processes such as inventories and distribution strategies to enhance efficiency and responsiveness. Also, the integration of advanced technologies facilitates communication among SCs and eases information sharing[12]. The adoption of circular practices requires connecting various SC for an efficient use of material toward zero waste [2].

The transition toward the circular business model has gained a great interest in the last decade [13]. Several studies have shown that integrating circular practices into SC may increase efficiency, reduce costs, promote competitiveness and foster healthier communities [2], [13]. However, few studies are focusing on the opportunities brought by the collaboration in the context of CE. Further, little is known about the behavior of the circular network during disruptions. To address this gap, this study performs a comparative analysis of the linear and circular SC performance in term of resource efficiency and risk mitigation. To that end, a simulation approach is adopted to first, assess the ability of linear and circular SC to effectively manage resources and waste. Second, analyse the impacts of disruption on both configurations. In this sitting two questions arise:

RQ1: What are the opportunities brought by circular economy to SC in term of resource efficiency?
RQ2: How a circular network mitigates risks?
The remainder of this paper is as follow: a literature review is conducted in section 2. Section 3 explains the problem and presents the methodology. The simulation approach and the experiments are presented in section 4. Section 5 discusses the results and section 6 summarizes this paper.

2 Literature review

Research on circular SC performance is gaining more interest with the increasing pressures for sustainability and viability. Table 1 presents the related works that assess and compare the performance of linear and circular configurations.

Table 1. Previous related works

Reference	Focus	Approach
Nattassha et al., 2020 [15]	Examine the differences between linear and circular supply chain models	Case study, The process modeling and the performance measurement pillars of the SCOR model.
Eberhardt et al., 2019 [16]	Highlight the deviations in life cycle environmental impacts and material flows in linear and circular designing building	Case-study, Life Cycle Assessment approach

Manavalan and Jaya-krishna, 2019 [18]	Transform a linear SC into circular and investigate the opportunities of Industry 4.0 for CE	Case study Process analysis
Sariatli, 2017 [17]	Identify opportunities, threats, weakness and strength of linear and circular SC.	SWOT analysis
Nasir et al., 2017 [14]	Compare the environmental benefits in terms of carbon emissions gained through the adoption of circular practices to the performance of the linear SC	Case-study, Life Cycle Assessment approach

Although, CE is positively influencing SC performance, many studies have explored the risks that may occur in this type of network. [19] investigate the risk propagation in the circular SC. [20] identify and analyze the risks to promote effective circular practices implementation. [21] link supply chain integration and SC risk management in the context of CE. In parallel, diverse studies have shed the light on the ability of material circularity to mitigate disruptions through securing material availability [6], [7] and [20].

The present study is different from the literature in two ways:

- First, the comparative analysis of linear and circular SC is performed with a focus on resource efficiency and risk analysis.
- Second, a method based on the simulation of a case study with multiple scenarios is adopted.

3 Problem statement and methodology

3.1 Case study

The companies 'ABC' and 'XYZ' located in Asia, produce sugar and paper respectively. The customers are dispersed in the same continent and in Africa. The networks encompass one supplier for each SC, sugar cane farmers and pulp provider respectively. Both suppliers are located in Asia. There are two distribution centers (DCs) owned by each enterprise. Figure 1 shows the design of the two SCs.

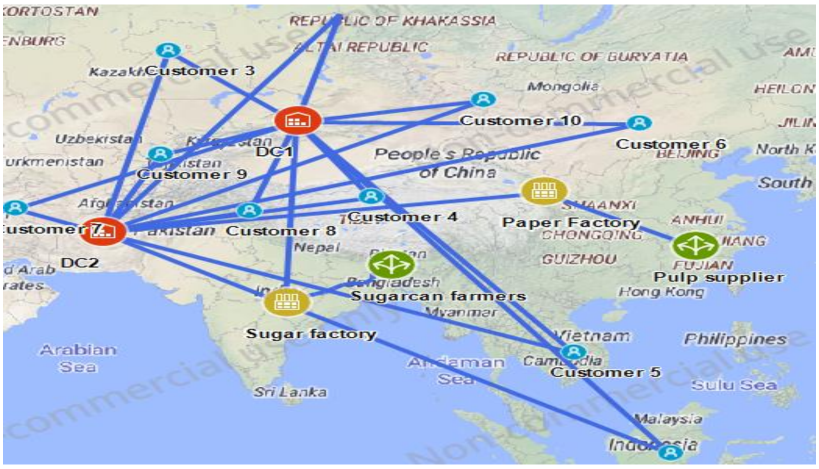

Fig 1. SCs network

3.2 Problem statement

Two SCs of four echelons are considered in this study. As there are several intersections between them, the decisions-makers want to create a circular network. The purpose is to enhance resource efficiency and promote collaboration. In the current situation, the inputs are virgin raw materials and no end-of-life strategy is defined (The obsolete products are disposed). Further, the managers want to evaluate the ability of the circular network to withstand supply and demand disruptions.

The scope of this study is to explore the opportunities and the weakness of the circular structure in term of resource efficiency and risk mitigation.

3.3 Methodology

Figure 2 shows the methodology followed in this paper. The process is adopted by several studies in literature [7], [24], [25]. They simulate and evaluate SC configurations in multiple scenarios to assess the financial and operational performance. In the first step, we simulate and analyze the performance of each linear supply chain operating autonomously in normal conditions using AnyLogistix software (personal learning edition). Then, the performance of the circular network is assessed. Lastly, disruption events are introduced to evaluate the ability of each configuration to mitigate risks.

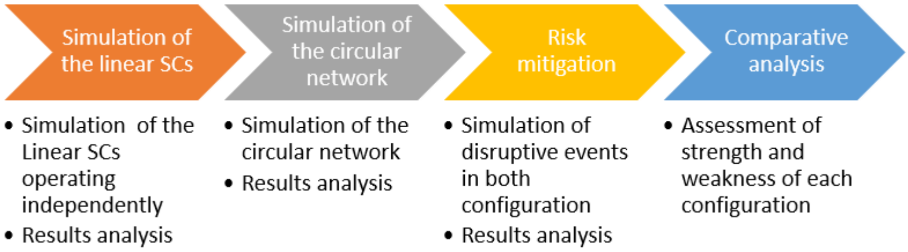

Fig 2. Research methodology

4 Simulation and experiment

4.1 Simulation logic and input data

Figure 3 and Figure 4 show the simulation logic of each configuration and Table 2 summarizes the input data. When the SCs operate autonomously, the flow of materials is forward. Customers order sugar and paper from the DC owned by sugar and paper enterprises respectively. These DCs operate with a Min-Max inventory control policy, and accordingly, orders are sent to the manufacturing factories. The pulp supplier and sugar cane farmers provide the raw materials to the manufacturers.

When the SCs collaborate in a circular network, a reverse flow of materials is created and interactions between facilities are established. The paper factory uses the bagasse (a by-product of the sugar production) and the recycled papers as raw materials. The packaging of sugar is outsourced in the paper factory. At the end of life, all types of papers are collected and recycled.

Data were collected following discussions with professionals from both industries. These are introduced into AnyLogistix according to the requirements of each configuration. For instance, the BOM (Bill of Material) of paper in the linear flow contains pulp, while it contains bagasse in the circular flow. A fixed periodic demand is generated by Anylogistix each 7 days for sugar and paper with a fixed quantity for citizens.

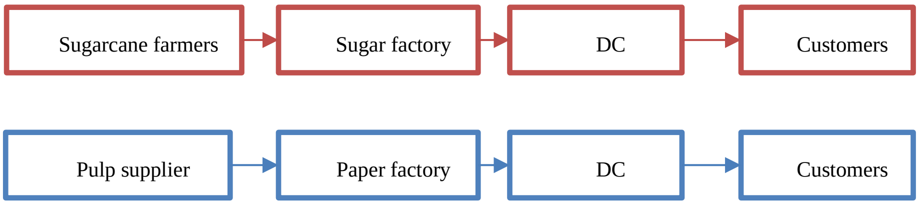

Fig 3. Linear supply chains

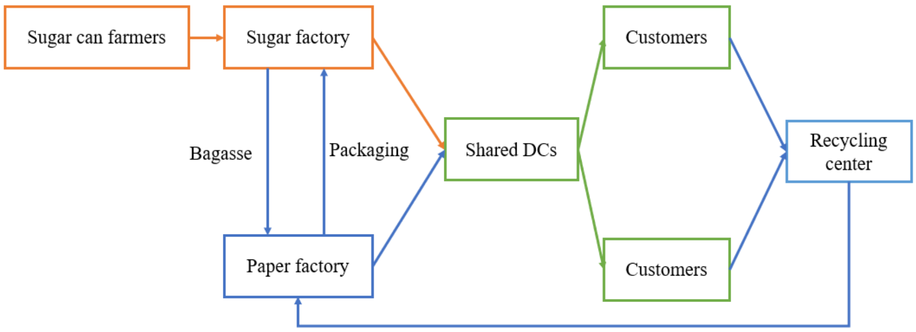

Fig 4. The circular supply network.

Table 2. Main input data

Elements	*Description*
Price	- 1kg of sugar = 1$ - 1kg of paper= 3$ - 1kg of sugarcane = 0.40$ - 1kg of pulp = 1.5$
Production	- 10 kg of sugarecane is needed for 1 kg of sugar - For 1kg of sugar, 3kg of bagasse are generated - 1.5 kg of pulp is needed to produce 1kg of paper - 2.5 kg of bagasse is needed to produce 1kg of paper
Inventories	- MIN-MAX policy with safety stock (SS) s=d*(LT)+SS S=2*s Where s is the re-order point, S is the target level, d is the demand, and LT is the lead time
Demand	- Periodic demand each 7 days - Generated by AnyLogistix for each citizen.

4.2 Experiments results

Figure 5 shows the inventory dynamics in the linear SCs. It is observed that in the normal conditions (Disruptions free/ Baseline scenario), the available inventory of sugar and paper can satisfy customers' demand without any shortage or backlog. This is because the production aligns with demand. The quantity of the bagasse increases over the time.
Figure 6 presents the experiments results when a disruption hit the paper SC. The pulp supplier closure has affected the available inventory leading to shortages at the paper factory as it relies on the pulp as the principle raw material.

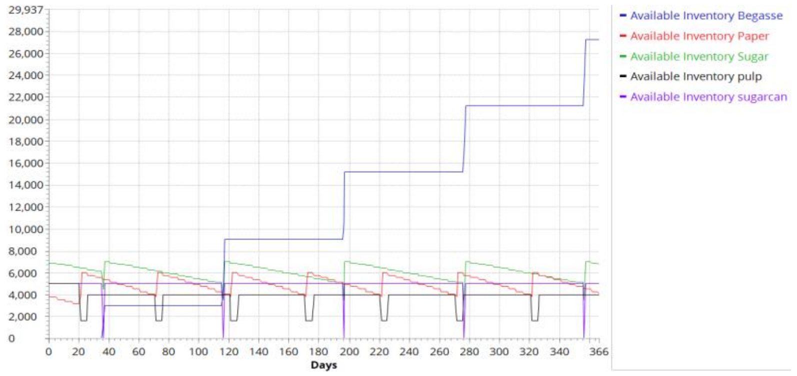

Fig 5. Available inventory of products, raw materials and byproduct in the linear SCs

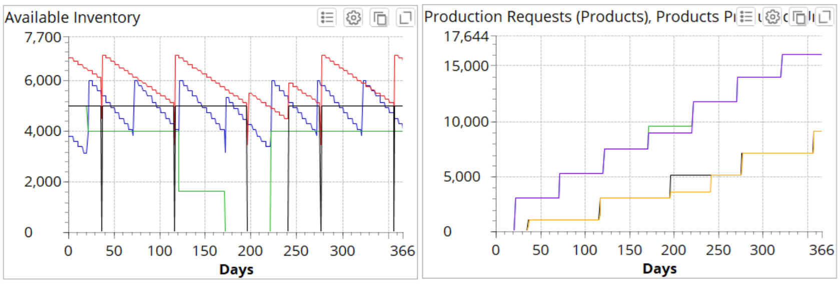

Fig 6. Experiments results of Supply disruption in the Linear SCs.

Figure 7 shows the available inventory of bagasse at the sugar and paper factories in the circular network. For the first, bagasse is a byproduct and for the second it is a raw material. It can be seen that use of bagasse as input for the paper SC has decreased its quantity at the sugar factory destinated to disposal. Because the quantity of bagasse generated as waste is higher that the need of the paper company, variations are observed.

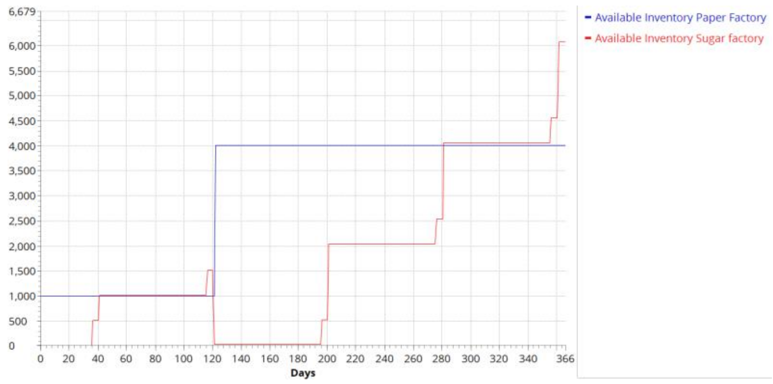

Fig 7. Available inventory of bagasse in the circular network.

Figure 8 presents the experiment results of demand decrease for sugar in the circular network. A difference between the produced production and the production quested for paper is observed during this disruption. This has decreased the service level as a percentage of demand are not met. The important quantity of bagasse generated and the use of recycled waste paper have helped the paper enterprise to satisfy a part of demand.

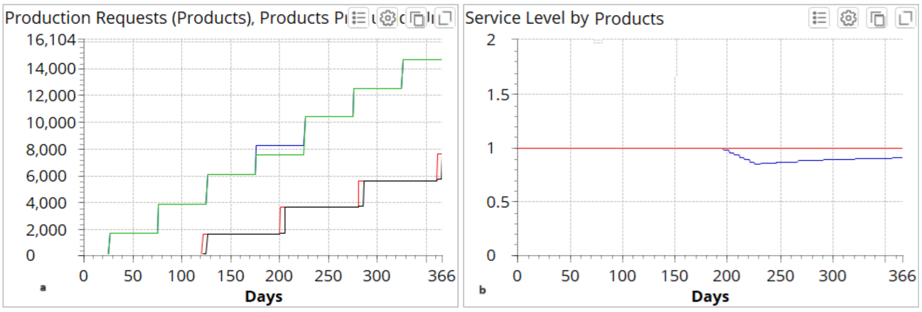

Fig 8. Experiments results: demand decrease for sugar, (a) requested and products produced, (b) service level by order

5 Discussion

The findings of this study suggest that the circular network promotes collaboration (1), enhances resource efficiency (3) and helps to avoid shortage of critical material during crisis (3). The results are in line with many studies that have shown the importance of CE strategies in reducing resource consumption[17], [26], [27], minimizing waste disposal[10], [28], [29] and ensuring resource availability during disruptions[7], [22].

(1) Collaboration is one of the important enablers to CE implementation [11]. Using the fibrous residue from sugarcane manufacturing was economically beneficial for both companies. Further, outsourcing packaging of sugar allows this company to acquire a custom and sustainable packaging at lower price.

(2) The focus of CE is resource efficiency. In this context, the sugar factory has avoided the disposal process of the bagasse and the paper has avoided the use virgin raw material. Further, the packaging of sugar is produced by the paper factory using bagasse and recycled waste paper which guarantee its sustainability.

(3) In the linear flow, during the disruption of supply and demand, the paper company suffered from shortage as its only source of input was the pulp supplier. However, collecting and recycling the cartons, packaging and waste paper has helped the company to reduce the impact of disruptions.

However, the paper sheds the light on the vulnerabilities of this connected network due to intersections and dependencies. In this case study, the paper factory relies on the bagasse purchased from the sugar factory and the collected waste paper. Although this strategy seems to be built upon the diversification principle, the paper production has experienced raw material shortage. This is because the part of inputs covered by the collected waste paper remains low. In this context, organizations should establish contingency plans such as exploring other type of waste to use or having a contract with a backup supplier of pulp.

6 Conclusion

The objective of this paper is to assess the performance of linear and circular SCs in term of resource efficiency and risk mitigation. To that purpose, a simulation based approach is adopted though a case study of two SCs operating autonomously and collaboratively. Findings indicates that resources and waste are effectively managed in the circular network. Further, circularity ensure resource availability in the beginning of the disruption. However, the network may be subject to severe consequences if suitable contingency strategies are not adopted.

The findings can guide managers in the transition toward the circular collaborative network. Moreover, evidence is given about the vulnerabilities and the dependencies in the context of CE. In doing so, scholars are investigating and validating these findings through other case studies.

As limitations, the number of disruptive scenarios is limited and the simulation logic suggests that bagasse and waste paper are totally used by the paper factory. Further, the collected data may vary if we consult other professionals. Future research can simulate multiple scenarios such as factory or DC closure and assess the ability of each configuration to mitigate this disturbance. Moreover, scholars can consider the uncertainty of return rate and waste generation.

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