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Value of Information Management in Closed Loop Supply Chain with Blockchain Applications

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ABSTRACT

Purpose: Rapidly developing information technology increases expectations for obtaining much more efficient structures by providing accurate, sufficient and secure information sharing in supply chains as well as in many other fields. Traceability is a critical element in supply chain management, especially in security-sensitive sectors such as food, medicine, etc. Blockchain is a decentralized record platform that provides traceability, transparency and security, and it shows promise in alleviating traditional supply chain management problems and making a positive contribution. This article aims to improve the relevant literature by revealing the level of impact of blockchain technology on supply chain management.

***Methodology*:** First of all, a traditional closed-loop supply chain (CLSC) network was designed and modeled. Then, the main model was developed by creating four more scenarios for different applications of the blockchain technology to the existing model and the application results were analyzed.

Findings: This paper demonstrated the implementation of blockchain technology in forward and reverse flows activities coordination for effective and efficient supply chain management, and the resulting gains by developing appropriate models through explanatory scenarios. The implications showed that blockchain technology could significantly reduce supply chain costs.

Originality: While blockchain technology is gaining attention, there are very few studies focused on its integration into the supply chain. Apart from the applications in the field of finance, the most important contribution and originality of the study is the application of the blockchain to CLSC from different aspects as partial, full, only forward flow and only reverse flow.

Keywords: Blockchain, CLSC Optimization, Information Management, Returned Product Management.
JEL Codes: C02, C61, L23, M11.

Blok Zincir Uygulamaları ile Kapalı Döngü Tedarik Zincirinde Bilgi Yönetiminin Değeri

ÖZET

Amaç: İzlenebilirlik, tedarik zinciri yönetiminde özellikle gıda, ilaç vb. gibi güvenliğe duyarlı sektörlerde kritik bir unsurdur. Blok zincir teknolojisi, izlenebilirlik, şeffaflık ve güvenlik sağlayan merkezi olmayan bir kayıt platformudur ve geleneksel tedarik zinciri yönetimi sorunlarını hafifletme konusunda umut vaat etmektedir. Bu makale, blok zincir teknolojisinin tedarik zinciri yönetimi üzerindeki etki düzeyini ortaya koyarak ilgili literatürü geliştirmeyi amaçlamaktadır.

***Yöntem*:** Öncelikle geleneksel bir kapalı döngü tedarik zinciri ağı tasarlanmış ve modellenmiştir. Daha sonra mevcut durumun yanında blok zincir teknolojisinin mevcut modele farklı uygulamaları için dört senaryo oluşturularak ana model geliştirilmiş ve uygulama sonuçları analiz edilmiştir.

Bulgular: Bu çalışma, etkili ve verimli tedarik zinciri yönetimi için ileri ve geri akış faaliyetleri koordinasyonunda blok zinciri teknolojisinin uygulama olanaklarını ve açıklayıcı senaryolar aracılığıyla uygun modeller geliştirerek elde edilen kazanımları göstermiştir. Sonuçlar, blok zincir teknolojisinin tedarik zinciri maliyetlerini önemli ölçüde azaltabileceğini göstermiştir.

Özgünlük: Blok zincir teknolojisi dikkat çekerken, tedarik zincirine entegrasyonuna odaklanan çok az uygulama çalışması bulunmaktadır. Blok zincirin kapalı döngü tedarik zincirine entegrasyonunun incelenerek etkinliğinin değerlendirilmesinin yanında tedarik zincirine kısmi, tam, yalnızca ileriye ve yalnızca tersine dönük olarak farklı yönlerden uygulanması çalışmanın literatüre en önemli katkısı ve özgünlüğüdür.

Anahtar Kelimeler: Blok zincir, Kapalı Döngü Tedarik Zinciri, Bilgi Yönetimi, Geri Dönen Ürün Yönetimi.
JEL Kodları: C02, C61, L23, M11.

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1. INTRODUCTION

Modern supply chains have emerged into extremely complex value networks because of the enhanced number of intermediaries between the manufacturer and the final customer. Globalisation and market growth have forced companies to extend their product variety and lifecycles to meet the requirements of modern age markets. Accordingly, there is not enough information on the processing or transportation journey of the product. Since it has become progressively difficult to confirm the source of raw materials and keep visibility of products as they pass through the value chain network (Azzi et al., 2019; Rejeb et al., 2019). From the very beginning, supply chain financing has been a very important issue. Uncompleted information, weak communication and insecurity among members of supply chains are among the basic problems of modern supply chains. In this dynamic environment, companies are turning to implement new technologies such as machine learning (ML), the Internet of Things (IoT), business analytics, artificial intelligence (AI), cloud computing and blockchain technology to cope with the need to overcome these challenges and increase competitiveness (Rejeb et al., 2019).

Blockchain technology varies from most current information system designs in that it incorporates four fundamental features: Security, decentralization, auditability, and smart execution (Saberi et al., 2019). One of the biggest concerns with the blockchain is the high energy consumption due to the need to copy and accumulate a lot of data. This technology, which also has a complex structure, is in competition with central databases and ledgers in these regards.

Blockchain technology is identified as *a distributed, shared, encrypted database that serves as an irreversible and incorruptible repository of information* (Kamble et al., 2021). This technology promises high efficiency with its possibilities and diversified applications. The blockchain technology that was first acquainted with assuring the Bitcoin electronic currency system's security has recently started to take place in various areas besides financial areas such as supply chain management processes (Kumar and Iyengar, 2017) that have inadequate information and are not clear enough.

Information system management is centralized in many sectors such as health, food, finance and education. That is, all transactions are inspected by third-party agents. This system can be risky in terms of data integrity, resilience and availability and may expose the system to fraud and tampering. A reliable ecosystem should also be established between suppliers and their consumers. This is reached by a polity like blockchain technology, which focuses on chain transparency to provide product traceability where correct and secure data collection and storage are needed (Azzi et al., 2019). There is no requirement for a third party for transactions with this technology. All transactions are processed into the encrypted block by the supply chain members. Each block is linked to previous and next blocks and can't be deleted or changed by a single member of the supply chain. With the blockchain that is an autonomous technology, all transactions could be made automatically by connecting to conditions. Accordingly, the problems related to the blockchain technology application in the supply chains are tried to be solved and the effective supply chain objectives such as safety, transparency, cost, recycling, demand flexibility, quality and speed are tried to be realized (Wang et al., 2019). Improved visibility with blockchain technology, procures auditable tracking of every step a product goes through. That is especially important in industries where proving the details of a product is vital.

Despite significant progress in recent years, the integration of blockchain and supply chain management is still in its infancy (Queiroz et al., 2019; Wamba and Queiroz, 2020). In view of the great investments by industry, academic research that investigates potential implications and directs companies is needed (Treiblmaier, 2018). Therefore, to evaluate the efficiency and adequacy of blockchain-based supply chains, multi-case analyses have been conducted by developing descriptive models of a CLSC that includes blockchain technology as partial, full, only forward flow and only reverse flow in this study.

The rest of the study is structured as follows. Section 2 presents the related literature. Afterwards, the research methodology is described and the problem with different five supply chain senarious is defined in Section 3. Section 4 explains and compare the traditional supply chain model and improved models by integrating blockchain and gives the dataset’s details. Section 5 presents the research results and managerial implications. Finally, Section 6 concludes the paper with further research directions.

2. LITERATURE REVIEW

With the prominence of the traceability feature of the blockchain- known for its applications in the field of finance- it has been seen that it will also benefit the applications in the supply chain for the tracking of products, and various studies have been started on this subject.

Numerous studies have analyzed the existing literature as well as reporting the practical application, key benefits and challenges of blockchain technology in logistics and supply chains. Treiblmaier (2018) explored the potential applications of blockchain technology for supply chain management, presenting a framework built on four established economic theories. Cole et al. (2019) sought to promote the research of blockchain technology from the perspective of operations and supply chain management, identify potential application fields and present an agend for future research. Azzi et al. (2019) examined the benefits of integrating the blockchain into the supply chain architecture and the challenge faced in the blockchain-enabled supply chain management ecological system. Schmidt and Wagner (2019) developed a set of six propositions utilizing the transaction cost theory; they argued that blockchain limits the influence of environmental and behavioral uncertainty, opportunistic behavior, and decreases transaction costs allowing transparent and valid transactions. Saberi et al. (2019) studied blockchain technology and smart contracts with their potential implementation to supply chain management.

Batwa and Norrman (2020) identified and explored various blockchain implications in supply chain management. They suggested a systematic literature review framework of blockchain-related articles for analysis and founded that supply chain finance and traceability are the most applicable blockchain application in supply chain management. Dutta et al. (2020) examined all the relevant research using blockchain integration in supply chain operations and highlighted its opportunities, societal impacts. Esmaeilian et al. (2020) provided an overview of blockchain technology and Industry 4.0 for sustainable supply chains. They expanded blockchain capabilities extending sustainability, under four main areas, and discussed adversary effects of blockchain, research gaps, and future research directions. Queiroz et al. (2019) followed the systematic review approach to analyze and synthesize 27 articles published in peer-reviewed journals between 2008 and 2018 on integrating blockchain and supply chain management. They aimed to highlight the present blockchain implications/the main challenges of blockchain adoption/ blockchain's future in supply chain management. Wamba and Queiroz (2020) reviewed blockchain evolution and provided a discussed the role of blockchain in value creation in operations and supply chain management. Wang et al. (2020) demonstrated blockchain technology application possibilities with the coordination of activities for effective and efficient supply chain management. Dietrich et al. (2021) researched recent publications combining supply chain management and blockchain technology and classified them according to the complexity to be mapped on the blockchain. Moosavi et al. (2021) conducted a systematic review of bibliometric and network analysis to define how blockchain could conduce to supply chain management.

Apart from these studies, there are some inferential case studies related to the implication of blockchain technology to the supply chain, although there are few in the literature. Kumar and Iyengar (2017) built a rice supply chain system using blockchain technology, assuring rice safety during the processes of supply chain management. Casado-Vara et al. (2018) proposed a new blockchain-supply chain model that enables the circular economy concept and eliminates several existing supply chain disadvantages. Casino et al. (2019) developed a functional model based on blockchain technology and smart contracts to provide traceability of decentralized and automated food supply chains. Rejeb et al. (2019) demonstrated how blockchain technology deployment combined with the Internet of Things infrastructure could benefit and streamline modern supply chains, and then they derived six research propositions outlining how this technology could affect the core features of the Internet of Things, thereby laying the basis for future projects. Choi (2020) studied financing problems of a fashionable products supply chain. He developed analytical models for both the traditional and blockchain-supported supply chains and then compared the performances of optimal systems between the two supply chains. Sund et al. (2020) contributed to the blockchains feasibility study for the world's largest furniture retailer, IKEA. Li et al. (2020) proposed a production capability evaluation system by incorporating the Internet of Things, blockchain technology, and machine learning for supply chain networks and evaluated this system through a simulation experiment. Tönnissen and Teuteberg (2020) used multi-case analysis to develop an illustrative model on the interaction of actors in an operational supply chain with blockchain technology. Di Vaio and Varriale (2020) explored the important implications of blockchain technology for operations management, focusing on decision-making processes in supply chain management from a sustainable performance perspective, and in this direction, they successfully explored an Italian airport infrastructure as the main blockchain technology application in the airport industry. Wong et al. (2020) studied behavioral intent to adopt blockchain technology for supply chain management and offered valuable insights into its applicability by analyzing the data collected from 157 companies. Kamble et al. (2021) examined the direct influence of blockchain on supply chain integration and sustainable supply chain performance and the interactive effect of blockchain and supply chain integration on sustainable supply chain performance. Accordingly, they analyzed the responses of 138 Indian automotive firms following structural equation modeling and confirmatory factor analysis.

While blockchain technology attracts attention, there are few application studies on its integration into the supply chain. In our study, we will develop appropriate models over different scenarios and analyze the results to display what kind of gains will be reached by blockchain technology applications in the traditional supply chains and how this will affect the costs. Apart from being an application study to address the lack of literature in this field, this article provides originality in terms of performing the gradual application of blockchain to closed-loop supply chains.

3. RESEARCH METHODOLOGY

In this study, the application of blockchain technology in supply chain management was investigated. A case studies-based research strategy was adopted to evaluate the efficiency and adequacy of the blockchain-based supply chain**.**

Four main entities play a role in blockchain-based supply chains; Registrars, Standards Organizations, Certifiers, and Actors. Every product in the supply chain has a digital blockchain asset so that all relevant actors can have direct product profile access. It is possible to collect a range of data such as the type, condition, and standards of the product. An information tag attached to a product represents an identifier that ties physical products to their virtual identities on the blockchain. Actors must obtain permission to enter new information on this product's profile. Before a product is transferred (or sold) to another actor, both parties sign a digital contract to validate the exchange. The records of data transactions are automatically updated by the system when the change is initiated. In this way, the blockchain eliminates the need for a trusted central organization operating and maintaining this system and allows for seamless surveillance of customers. Apart from this, blockchain also affects financial transactions in the supply chain process. It provides a significant potential advantage and saves millions of dollars by eliminating the intermediation of financial intermediaries, including payment networks, money transfers, and exchanges between partners (Saberi et al., 2019).

Working on scenarios involving different blockchain implementations on a traditional supply chain network will highlight features that need to be considered for building an efficient blockchain-based supply chain. To validate the theoretical work, scenarios were modeled and appropriate datasets were created. In line with these data, the developed models were solved using the GAMS package program. A general algebraic modeling system (GAMS) is a high-level modeling system used for mathematical programming and optimization. It is designed to model and solve different types of problems such as linear, nonlinear, and mixed integer optimization problems (Andrei, 2013).

3.1. Research Design

The developed CLSC network design attempts on maximizing the profit of a firm consisting of two different manufacturers and a collection and recycling center with multiple facilities. CLSC network-based design and its actors are given in Figure 1.

The flow starts with the purchase of steel plates in tones from suppliers, and the purchased plates are transformed into steel auto parts in factories and sent to the markets. There are suppliers in three different segments according to the quality of the steel plates and markets in three different segments according to the quality of the auto parts. Therefore, factories manufacture three different quality products according to the steel plates and offer each quality on sale by pricing separately.

Case 1 (Current situation): The collection & recycling center collects auto parts that have expired or returned from customers as a result of various technical problems and accidents, and as a result of the melting process, they are transformed into 3rd quality steel plates and sent to factories to be remanufactured.

However, the company wants to gain more advantages by using the recycling system more efficiently. At this stage, blockchain technology is used to provide product information. With blockchain technology, challenges such as incomplete information, low communication, and insecurity are struggled, and supply chain goals such as safety, transparency, recycling, cost, speed, quality, and efficiency are efforted to be achieved (Wang et al., 2019). Improved visibility obtained with blockchain technology monitors every step of a product by controlling it. That is principally significant for industries where proof of details, condition, and quality of a product is required. This study aims to reveal what gains will be achieved by applying blockchain technology in the existing supply chain and how this will affect the costs. In this direction, four new scenarios have been developed in addition to the current situation.

3.2. Developed Model Scenarios

Case 2: In the new model, all members of the supply chain record all their transactions of both forward and reverse flows on the blockchain. This data is decentralized, and each member can read relevant data for their transactions on the blockchain. This system provides higher security in transactions. Accordingly, the communication between the company and the suppliers is carried out through the blockchain application, and thus, all processes from product order to delivery gain an autonomous structure, providing the forward flow with the opportunity to supply reliable, flexible, and most importantly, less costly (Although there is no exact figure, it is included in the literature (Dutta et al., 2020; Júnior et al., 2022; Wang et al., 2020) and was assumed to be 10% in this study-The 10% is taken as hypothetical. As a result of the fact that the blockchain is a new technology, there is not enough data from the sector based on the application in the literature yet, so a hypothetical number has been used-). In reverse flow, the collection & recycling center collects auto parts that have expired or returned from customers, and offers them on sale for reuse by applying different processes according to their quality. According to the markets, there are customers in three different segments (Class A, B, C) each in a different region (Region 1, 2, 3) as seen in Figure 1. The collection & recycling center provides a number of incentives to customers according to their region and the quality of their products in order to increase the amount of returned auto parts. Product lifecycle information of returned products is obtained and shared through blockchain technology. The recovery processes applied by the collection & recycling center according to the region and quality are given in Table 1. These decisions are made based on returned product lifecycle information.

Case 3: In the third model, in the supply chain, only the forward flow members record all their transactions on the blockchain; that is, the blockchain technology is used only in the forward flow of the supply chain, and traditional applications are made in the reverse flow as in the first case.

Case 4: Another model is the opposite of the third case, that is, only the reverse flow members record all their transactions on the blockchain, the product life cycle information of the returned products is obtained and shared through blockchain technology, and the forward flow is carried out with traditional methods as in the first case.

Case 5: In this model, there is a mixed structure that reflects the transition from the first model to the second model. Namely, it is the case where only certain members of the chain record their transactions on the blockchain. It is assumed that only suppliers 2, 5, and 7 use blockchain technology in the forward flow and, thus the procurement costs for these suppliers are 10% less than their current situation; for reverse flow when the evaluation process of returned products is redesigned, it is assumed that only Region 2 uses blockchain technology and data on the quality of products returned from this region are obtained, other regions are not included in this technology network, so they do not record and share data on the blockchain of the supply chain. In this case, only the recovery processes of the second (Class B) region given in Table 1 will be applied.

In addition, the collection & recycling center, which has three facilities in different locations, aims to put maximum two of them into service with minimum cost and determine the customers who will receive service from these facilities. Other assumptions about the problem are given below.

- Customer demands are certain for each period and are fully met.
- The capacities of the suppliers are fixed and certain; the production capacity for other facilities is sufficient for all product requirements.
- There isn’t stock out.
- The product and parts are processed in tones.
- The number of Collection & Recycling center facilities to be opened is known.
- All Collection & Recycling Center facilities are of equal quality.
- The locations where the Collection & Recycling Center facilities are to be opened are known.
- It has been assumed that no waste is generated from returned products.

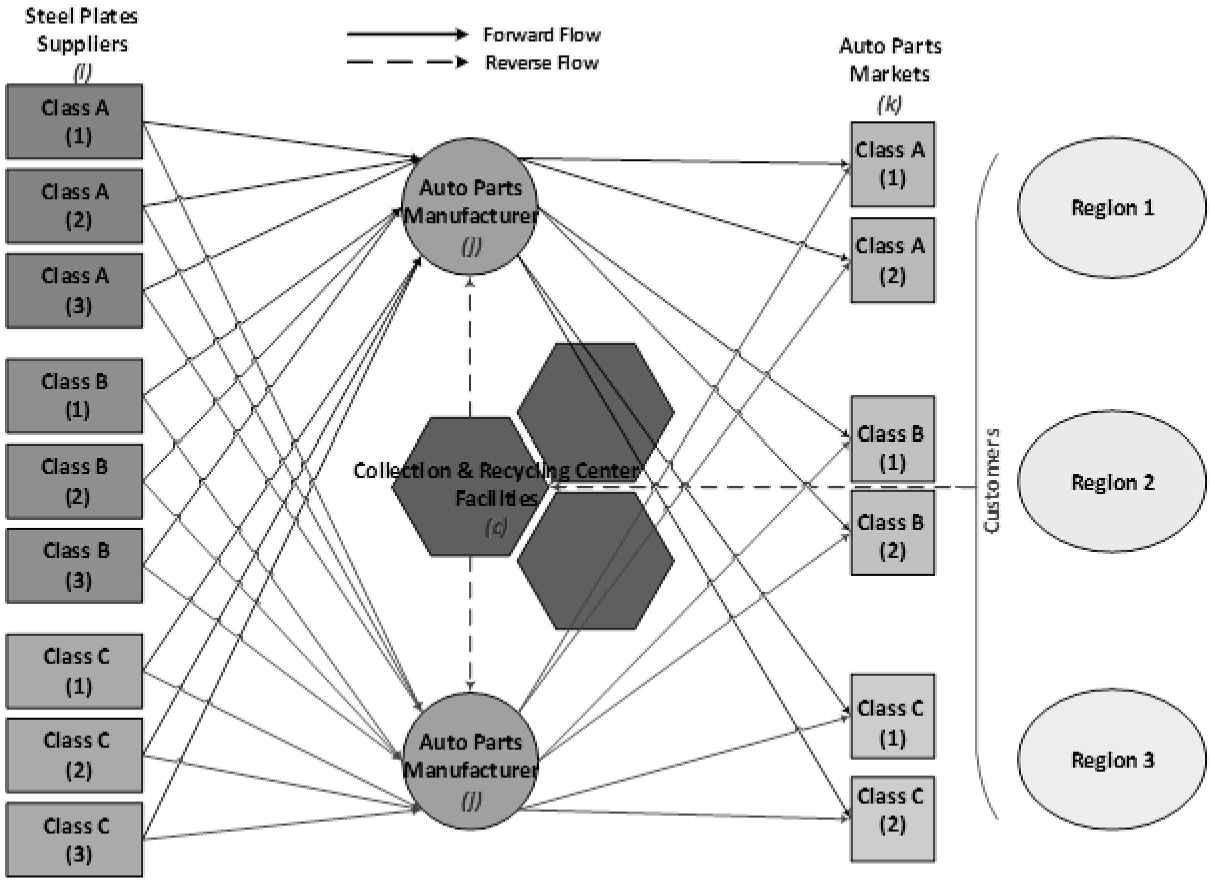

Figure 1. Representative CLSC network

Table 1. Recovery processes applied according to region and quality obtained by blockchain technology

Region	*Quality 1*	*Quality 2*
Region 1 (Class A)	After being sent to factories, these are renewed and sold as Class B auto parts to markets.	These are melted by the collection & recycling center and sent to the factories as Class B steel plates, and then remanufactured by the factory and sold as Class B auto parts to markets.
Region 2 (Class B)	After being sent to factories, these are renewed and sold as Class C auto parts to markets.	These are melted by the collection & recycling center and sent to the factories as Class C steel plates, and then remanufactured by the factory and sold as Class C auto parts to markets.
Region 3 (Class C)	These are melted by the collection & recycling center and sent to the factories as Class C steel plates, and then remanufactured by the factory and sold as Class C auto parts to markets.	These are thrown away by the customers.

4. MATHEMATICAL MODELS

In this section, firstly, a basic model is developed for the first case of the main problem under consideration. Then, with the implication of Blockchain technology to the existing supply chain model, changes on the model are included in line with four new scenarios (Cases 2, 3, 4, and 5). Based on the above assumptions, the model tries to maximize profit while meeting demand.

Model of Case 1

Indices

i: Suppliers $(i = 1, 2, \dots, I)$

j: Factories $(j = 1, 2, \dots, J)$

k: Markets $(k = 1, 2, \dots, K)$

c: Collection & recycling facilities $(c = 1, 2, \dots, C)$

m: Customer regions $(m = 1, 2, \dots, M)$

l: Steel plate classes $(l = 1, 2, \dots, L)$

n: Auto part classes $(n = 1, 2, \dots, N)$

t: Period $(t = 1, 2, \dots, T)$

Parameters

p_{ij} : Supply cost per unit of steel parts from supplier i

mr_j : Manufacturing cost per unit of auto parts in factory j

r_j : Remanufacturing cost per unit of auto parts in factory j

s_{jk} : Unit sales price of auto parts from factory j to market k

a : Unit steel plate transportation cost

b : Unit auto part transportation cost

e_{ij} : Distance between supplier i and factory j

f_{jk} : Distance between factory j and market k

g_{jc} : Distance between factory j and collection & recycling facility c

h_{cm} : Distance between collection & recycling facility c and customer region m

f_c: Fixed cost of opening and operating collection & recycling facility c

c_i: Capacity of supplier i

d_{kt} : Demand of market k in period t

h_{mt}: The number of product holders in m in period t

R : The amount of incentive to be paid for the returned product

p : Number of collection & recycling facilities to be opened

M: A big number

Three classes are defined for suppliers and markets. The class l steel plate and class n auto part are determined as follows. Here, nl_1 and nl_2 denote the boundaries of classes for steel plate l and nn_1 and nn_2 for auto part n.

$$l = \begin{cases} 1 \quad (Class\ A) & 1 \le i < nl_1 \\ 2 \quad (Class\ B) & nl_1 \le i < nl_2 \\ 3 \quad (Class\ C) & nl_2 \le i \le I \end{cases} \qquad \forall i \quad \text{and} \quad 0 < nl_1 < nl_2$$

$$n = \begin{cases} 1 \quad (Class\ A) & 1 \le k < nn_1 \\ 2 \quad (Class\ B) & nn_1 \le k < nn_2 \\ 3 \quad (Class\ C) & nn_2 \le k \le K \end{cases} \qquad \forall k \quad \text{and} \quad 0 < nn_1 < nn_2$$

Decision Variables

X_{ijt} **:** The amount of steel plate transported from supplier i to factory j in period t

Y_{jkt} **:** The amount of auto parts transported from factory j to market k in period t

Z_{cjt} **:** The amount of steel plate transported from collection and recycling facility c to factory j in the period t

V_{jnt} **:** The stock amount of class n auto part of factory j in period t

W_{ct} **:** The stock amount of steel plate of collection and recycling facility c in period t

y_c**:** $\begin{cases} 1 & if\ the\ collection\ \ recycling\ facility\ c\ is\ opened, \\ 0 & otherwise \end{cases}$

x_{mc}**:** $\begin{cases} 1 & if\ customer\ region\ m\ assigned\ to\ collection\ and\ recycling\ facility\ c, \\ 0 & otherwise \end{cases}$

Objective Functions

In the model under consideration, the objective function is to maximize the total profit. That is, the model minimizes the total cost while maximizing the total revenue. Therefore, objective functions are calculated as the difference of total revenue (TR) and total cost (TC). The two-part objective function is given in Equation 1.

$$Z = TR - TC \tag{1}$$

1. Total Revenue (TR): The first part consists of income from the auto parts sold and is formulated as in Equation 2.

$$TR = \sum_j \sum_k \sum_t Y_{jkt} . s_{jk} \tag{2}$$

2. Total Cost (TC): The company incurs four different costs: total purchasing cost (TPC), total manufacturing cost (TMC), total transportation cost (TTC), and fixed facility cost (TFC). Therefore, TC is formulated as in Equation 3.

$$TC = TPC + TMC + TTC + TFC \tag{3}$$

2.1. Total purchasing cost (TPC): The first part of the TPC shows the supply cost to meet the steel plate demand of the mills, and the second part shows the incentive cost paid to customers for used products. The supply cost here consists of many expenses such as order preparation, ordering, purchasing, commission, insurance, loading. The formulation of this item is given in Equation 4.

$$TPC = \sum_i \sum_j \sum_t X_{ijt}\, p_{ij} + \sum_m \sum_t h_{mt}\, R \tag{4}$$

2.2. Total manufacturing cost (TMC): It consists of the factory's unit steel plate processing cost and is formulated as in Equation 5.

$$TMC = \sum_i \sum_j \sum_t X_{ijt} mr_j + \sum_c \sum_j \sum_t Z_{cjt} r_j \tag{5}$$

2.3. Total transportation cost (TTC): Transportation is handled based on the steel plate and auto parts in the model. Steel plate transportation costs from suppliers to factories and again from the collection & recycling facility to the factories are considered equal. It is also assumed that auto part transportation costs from factories to markets and from customers to the collection and recycling facility are equal. Accordingly, the total transportation cost is calculated as in Equation 6.

$$TTC = a\left(\sum_i \sum_j \sum_t X_{ijt}\, e_{ij} + \sum_c \sum_j \sum_t Z_{cjt}\, g_{jc}\right) + b\left(\sum_j \sum_k \sum_t Y_{jkt}\, f_{jk} + \sum_m \sum_c \sum_t h_{mt}\, h_{cm} x_{mc}\right) \tag{6}$$

2.4. Total fixed facility cost (TFC): It is the cost incurred for the collection & recycling center facilities to be opened and is calculated as follows in Equation 7.

$$TFC = \sum_c f_c . y_c \tag{7}$$

Constraints

$$\left[\sum_{i=1}^{nl_1-1} X_{ijt} + V_{jn(t-1)}\right] - \left[\sum_{k=1}^{nn_1-1} Y_{jkt} + V_{jnt}\right] = 0 \qquad \forall\, j, t, n = 1 \tag{8}$$

$$\left[\sum_{i=nl_1}^{nl_2-1} X_{ijt} + V_{jn(t-1)}\right] - \left[\sum_{k=nn_1}^{nn_2-1} Y_{jkt} + V_{jnt}\right] = 0 \qquad \forall\, j, t, n = 2 \tag{9}$$

$$\left[\sum_{i=nl_2}^{I} X_{ijt} + \sum_c Z_{cjt} + V_{jn(t-1)}\right] - \left[\sum_{k=nn_2}^{K} Y_{jkt} + V_{jnt}\right] = 0 \qquad \forall\, j, t, n = 3 \tag{10}$$

$$\left[\sum_m h_{mt} + \sum_c W_{ct-1}\right] - \left[\sum_c \sum_j Z_{cjt} + \sum_c W_{ct}\right] = 0 \qquad \forall\, t \tag{11}$$

$$\sum_j Y_{jkt} = d_{kt} \qquad \forall k, t \tag{12}$$

$$\sum_j X_{ijt} \le c_i \qquad \forall i, t \tag{13}$$

$\sum_c x_{mc} = 1$ $\quad \forall m$ (14)

$x_{mc} \leq y_c$ $\quad \forall m, c$ (15)

$\sum_c \mathrm{y}_c \leq p$ (16)

$\mathrm{Z}_{cjt} \leq \mathrm{M.x}_{mc}$ $\quad \forall m, c, j, t$ (17)

$W_{ct} \leq \mathrm{M.x}_{mc}$ $\quad \forall m, c, t$ (18)

$\mathrm{X}_{ijt}, \mathrm{Y}_{jkt}, \mathrm{Z}_{cjt}, V_{jnt}, W_{ct} \geq 0$, $\quad \forall i, j, k, c, n, m, q, t$ (19)

$\mathrm{y}_c, \mathrm{x}_{mc} = \{0, 1\}$, $\quad \forall c, m$ (20)

Equations 8 - 11 (Balance Constraints*)* ensure that the amount of input for the factories and the collection & recycling center is equal to the amount of output. Equation 12 (Demand Constraint) indicates that auto parts sent to markets must meet the demand. Equation 13 (Capacity Constraint) ensures that the amount of steel plate transported from suppliers to factories cannot exceed the capacity of the relevant supplier. Equations 14 and 15 (Allocation Constraints) ensure that a customer region sends all returns to only one collection and recycling facility; in other words, each customer region is assigned only one collection and recycling facility and prevent that any customer regions from being assigned to a closed collection and recycling facility. Equation 16 (Number of Facilities Constraint) ensures that the number of open collection and recycling facilities is equal to p. Equations 17 and 18 (Utilization Constraints) if the collection and recycling facility is not open, prevent the flow of products from there to the factories and the keeping stocks in there. Equations 19 and 20 define the non-negativity and binary constraints on decision variables, respectively.

Model of Case 2

In the new situation, the improvement of the existing model, due to the use of blockchain technology by all members of the supply chain network, can be achieved by adding the following new index, parameters to the model and revising some existing notations, constraints and objective functions. The steel part supply costs *(*p_{ij}*)* from all suppliers in this model will be 10% less than the first model.

Additional indices

q***:*** Returned product quality *(*$q = 1, 2, \ldots, Q$*)*

Additional parameters

rf_j ***:*** Refurbishing cost per unit of auto parts in factory j

P_{mqt}***:*** Proportion of customers with quality q product in region m who drop off their used products to the collection & recycling center in the period t.

Revised parameters

h_{mq} ***: Number of customers with the quality q product in region*** m ***(***h_{mt}***)***

R_{mq} ***: The amount of incentive offered per unit of quality*** q ***return from region*** m ***(***R***)***

Revised decision variables

Z_{mqcjt}***:*** The amount of quality q product in region m transported from collection and recycling facility c to factory j in the period t.

W_{mqct}***:*** The stock amount of steel plate of collection and recycling facility c in period t.

Revised objective functions

Total purchasing cost (TPC): The first part of the TPC shows the supply cost to meet the steel plate demand of the mills, and the second part shows the incentive cost paid to customers for used products. Its formulation is given in Equation 21.

$$\mathrm{TPC} = \sum_i \sum_j \sum_t \mathrm{X}_{ijt}\, \mathrm{p}_{ij} + \sum_m \sum_q \sum_t h_{mq} . \mathrm{P}_{mqt} . R_{mq} \quad (21)$$

Total manufacturing cost (TMC): It consists of unit steel plate processing cost (production, remanufacturing and refurbishment costs) within the factory and is formulated as in Equation 22.

$$TMC = \sum_i \sum_j \sum_t X_{ijt} mr_j + \left(\sum_{m=1}^{2} \sum_c \sum_j \sum_t Z_{m2cjt} + \sum_c \sum_j \sum_t Z_{31cjt}\right) r_j + \sum_{m=1}^{2} \sum_c \sum_j \sum_t Z_{m1cjt}\, rf_j \quad (22)$$

Total transportation cost (TTC): In the model, transportation is handled based on the steel plate and auto parts. Steel plate transportation costs from suppliers to factories and again from the collection and recycling facilities to the factories are considered equal. It is also assumed that auto part transportation costs from factories to markets and from customers to the collection and recycling facility are equal. Accordingly, the total transportation cost is calculated as in Equation 23.

$$TTC = a\left(\sum_i \sum_j \sum_t X_{ijt}\, e_{ij} + \sum_m \sum_q \sum_c \sum_j \sum_t Z_{mqcjt}\, g_{jc}\right) + b\left(\sum_j \sum_k \sum_t Y_{jkt}\, f_{jk} + \sum_m \sum_q \sum_c \sum_t h_{mq} P_{mqt}\, h_{cm} x_{mc}\right) \quad (23)$$

Total Revenue (TR) and Total Fixed Facility Cost (TFC) objective functions are the same as in the first model.

Revised constraints

$$\left[\sum_{i=nl_1}^{nl_2-1} X_{ijt} + \sum_q \sum_c Z_{mqcjt} + V_{jn(t-1)}\right] - \left[\sum_{k=nn_1}^{nn_2-1} Y_{jkt} + V_{jnt}\right] = 0 \;, \quad \forall\, j,t,n = 2, m = 1 \quad (24)$$

$$\left[\sum_{i=nl_2}^{I} X_{ijt} + \sum_q \sum_c Z_{2qcjt} + \sum_c Z_{31cjt} + V_{jn(t-1)}\right] - \left[\sum_{k=nn_2}^{K} Y_{jkt} + V_{jnt}\right] = 0, \;\forall\, j,\, t,\, n = 3 \quad (25)$$

$$\left[h_{mq}.P_{mqt} + \sum_c W_{mqct-1}\right] - \left[\sum_c \sum_j Z_{mqcjt} + \sum_c W_{mqct}\right] = 0 \quad \forall t, m = 1,2 \mid q = 1,2 \; or \; m = 3 \mid q = 1 \quad (26)$$

$$Z_{mqcjt} \le M.x_{mc} \qquad \forall m,q,c,j,t \quad (27)$$

$$W_{mqct} \le M.x_{mc} \qquad \forall m,q,c,t \quad (28)$$

$$X_{ijt}, Y_{jkt}, Z_{mqcjt}, V_{jnt}, W_{mqct} \ge 0 \;, \qquad \forall i,j,k,c,n,m,q,t \quad (29)$$

Equations 24-26 (Balance Constraints) are revised version of constraints 10 and 11 in the first model- It ensures that the amount of incoming product is equal to the amount of output for the factories and the collection & recycling center. Equations 27 and 28 (Utilization Constraints) are revised version of Equations 17 and 18 in the first model- if the collection and recycling facility is not open, prevent the flow of products from there to the factories and the keeping stocks in there. Equation 29 (Sign Constraint) is a revised version of Equation 19 in the first model- shows that the decision variables should not be negative. Except for the above constraint; the first balance, demand, capacity, assignment, number of facilities, and binary variable constraints are the same as in the first model.

Model of Case 3

In this case, the current main model is implemented as it is without any revisions, as only forward flow blockchain technology is used in the supply chain network. Only the values of the p_{ij} parameter should be updated to be 10% less than the first model.

Model of Case 4

In the new case, the improvement of the existing model as a result of using blockchain technology only in reverse flow in the supply chain network can be achieved by revising it as in Case 2. Also, care should be taken to treat the p_{ij} parameter values as in the main model.

Model of Case 5

In the new case, the improvement of the existing model as a result of the fact that only suppliers 2, 5, and 7 use blockchain technology in the forward flow, and only Region 2 uses the blockchain technology in the reverse flow, can be achieved by adding the following new indices, parameters and continuous variables to the model, and revising some existing notation, constraints and objective functions, and adding additional constraints. In addition, care should be taken to update only the p_{ij} parameter values of suppliers 2, 5, and 7.

Additional indices

q**:** Returned product quality $(q = 1, 2, \dots, Q)$

Additional parameters

rf_j **:** Refurbishing cost per unit of auto parts in factory j

h_{2q} **:** Number of customers with the quality q product in region 2

P_{qt}**:** Proportion of customers with quality q product in region 2 who drop off their used products to the collection & recycling center in the period t.

Revised parameters

R_q **:** The amount of incentive to be paid for per unit of quality q product (R)

Revised decision variables

Z_{2qcjt}**:** The amount of quality q product in region 2 transported from collection and recycling facility c to factory j in the period t

W_{2qct}**:** The stock amount of steel plate of collection & recycling facility c from region 2 in period t

Revised objective functions

Total purchasing cost (TPC): The first part of the TPC shows the supply cost to meet the steel plate demand of the mills, and the second and third part shows the incentive cost paid to customers for used products. Its formulation is given in Equation 30.

$$TPC = \sum_i \sum_j \sum_t X_{ijt}\, p_{ij} + \sum_{\{m\epsilon M|m=1 or\ m=3\}} \sum_t h_{mt}\, R_2 + \sum_q \sum_t h_{2q}.P_{qt}.R_q \tag{30}$$

Total manufacturing cost (TMC): It consists of unit steel plate processing cost (production, remanufacturing and refurbishment costs) within the factory and is formulated as in Equation 31.

$$TMC = \sum_i \sum_j \sum_t X_{ijt} mr_j + \sum_c \sum_j \sum_t (Z_{cjt} + Z_{22cjt})\, r_j + Z_{21cjt} rf_j \tag{31}$$

Total transportation cost (TTC): In the model, transportation is handled based on the steel plate and auto parts. Steel plate transportation costs from suppliers to factories and again from the collection and recycling facilities to the factories are considered equal. It is also assumed that auto part transportation costs from factories to markets and from customers to the collection and recycling facility are equal. Accordingly, the total transportation cost is calculated as in Equation 32.

$$\mathrm{TTC} = a\big(\sum_i \sum_j \sum_t \mathrm{X}_{ijt}\, \mathrm{e}_{ij} + (\sum_c \sum_j \sum_t \mathrm{Z}_{cjt} + \sum_q \sum_c \sum_j \sum_t \mathrm{Z}_{2qcjt})\mathrm{g}_{jc}\big) + b\big(\sum_j \sum_k \sum_t \mathrm{Y}_{jkt}\, \mathrm{f}_{jk} + \sum_{\{m\epsilon M|m=1 or\ m=3\}} \sum_c \sum_t h_{mt}\, h_{cm} \mathrm{x}_{mc} + \sum_q \sum_c \sum_t h_{2q} P_{qt}\, h_{c2} x_{2c}\big) \tag{32}$$

Total revenue (TR) and total fixed facility cost (TFC) objective functions are the same as in the first model.

Revised constraints

$$\left[\sum_{i=nl_2}^{I} X_{ijt} + \sum_c \mathrm{Z}_{cjt} + \sum_q \sum_c Z_{2qcjt} + V_{jn(t-1)}\right] - \left[\sum_{k=nn_2}^{K} Y_{jkt} + V_{jnt}\right] = 0 \quad \forall j,t,\ n = 3 \tag{33}$$

$$\left[\sum_{\{m\epsilon M|m=1 or\ m=3\}} h_{mt} + \sum_c W_{ct-1}\right] - \left[\sum_c \sum_j \mathrm{Z}_{cjt} + \sum_c W_{ct}\right] = 0 \quad \forall t \tag{34}$$

$$\mathrm{Z}_{cjt} \le \mathrm{M.x}_{mc} \quad \forall m\epsilon M|m = 1 or\ m = 3, c, j, t \tag{35}$$

$$W_{ct} \le \mathrm{M.x}_{mc} \quad \forall m\epsilon M|m = 1 or\ m = 3, c, t \tag{36}$$

$$\mathrm{X}_{ijt}, \mathrm{Y}_{jkt}, \mathrm{Z}_{cjt}, V_{jnt}, W_{ct}, \mathrm{Z}_{2qcjt}, W_{2qct} \ \ge \ 0, \quad \forall i,j,k,c,n,q,t \tag{37}$$

Additional Constraints

$$\left[h_{2q}.P_{qt} + \sum_c W_{2qct-1}\right] - \left[\sum_c \sum_j Z_{2qcjt} + \sum_c W_{2qct}\right] = 0, \quad \forall q,t \tag{38}$$

$$Z_{2qcjt} \le M.x_{2c} \quad \forall q,c,j,t \tag{39}$$

$$W_{2qct} \le M.x_{2c} \quad \forall q,c,t \tag{40}$$

Equations 33 and 34, which are the revised version of Equations 10 and 11 in the first model, and Equation 38 which is newly added to the model (Balance Constraints) ensures that the amount of incoming product is equal to the amount of output for the factories and the collection & recycling center. Equations 35 and 36, which are the revised version of Equations 17 and 18 in the first model and Equations 39 and 40 which are newly added to the model (Utilization Constraints), if the collection and recycling facility is not open, prevent the flow of products from there to the factories and the keeping stocks in there. Equation 37, which is a revised version of Equation 19 in the first model (Sign Constraint) shows that the decision variables should not be negative. Except for the above constraint; the first and second balance, demand, capacity, assignment, number of facilities and binary variable constraints are same as in the first model.

Data Set for Application

The planning of the main model was made over three periods. Unit steel plate transportation cost *(a),* unit auto part transportation cost *(b),* incentive amount to be paid to the returned product ***(R)***, and the number of collection and recycling facilities to be opened (p) were determined as $0.04, $0.08, $7 and $2 respectively. For steel plate and auto part, the limits of classes are considered as $nl_{\mathbf{1}} = 4$, $nl_{\mathbf{2}} = 7$, $nn_{\mathbf{1}} = 3$, and $nn = 5_{\mathbf{2}}$. Other parameters are given in the following tables (2-4). For the models of Case 2 and Case 3, the refurbishment costs (rf_j) of the factories were determined as $3 and $3.2 respectively, and the additional required parameters are given in Table 5 and Table 6, respectively. The p_{ij} values given in Table 2 should be updated to be 10% less than specified in the Models of Case 2, 3 and 5.

Table 2. Steel plate supply costs (p_{ij}), processing costs (m_{rj}, r_j) and supplier capacities (c_i)

Factories (j) / Suppliers (i)	p_{ij} 1	2	c_i
1	30	28.5	600
2	30	30	700
3	30	30.3	750
4	21	22	950
5	20	20	900
6	20.5	20.5	850
7	10	10	450
8	10	10.2	480
9	10	10	496
m_{rj}	7	7.2	
r_j	8	8.2	

Table 3. Auto parts sales prices (s_{jk}) and customer (market) demands (d_{kt})

Markets (k) / Factories (j)	s_{jk} 1	2	3	4	5	6
1	350	350	120	120	95	95
2	360	360	130	130	98	98
Markets (k) / Period (t)	**d_{kt} 1**	**2**	**3**	**4**	**5**	**6**
1	200	200	300	250	400	440
2	360	300	200	420	490	405
3	300	150	230	250	400	440

Table 4. Distances (e_{ij}, f_{ik}, g_{jc}, h_{cm}), number of product holders (h_{mt}), fixed costs (f_c)

Factories (j) / Suppliers (i)	e_{ij} 1	2	3	4	5	6	7	8	9
1	300	350	330	450	400	440	500	450	490
2	360	300	200	420	490	405	630	502	500
Markets (k) / Factories (j)	**f_{jk} 1**	**2**	**3**	**4**	**5**	**6**			
1	200	250	120	128	90	85			
2	220	208	128	125	80	87			
C&R facilities (c) / Factories (j)	**g_{jc} 1**	**2**	**3**						
1	95	180	150						
2	120	220	120						
C&R facilities (c) / Cust. regions (m)	**h_{cm} 1**	**2**	**3**	**Period (t) / Cust. regions (m)**			**h_{mt} 1**	**2**	**3**
1	50	52	15				250	350	325
2	35	20	30				250	350	325
3	35	75	20				250	350	325
f_c	500	700	650						

Table 5. For models of Case 2 and 4: Number of product holders by region (h_{mq}), incentive amounts (R_{mq}) and customer rates (P_{mqt})

					Period (t)					
					1		2		3	
Returned product quality (q)	h_{mq}		R_{mq}		P_{mqt}					
Customer regions (m)	1	2	1	2	1	2	1	2	1	2
1	500	600	13	10	0,3	0,2	0,6	0,6	0,1	0,2
2	400	750	10	7	0,4	0,3	0,5	0,5	0,1	0,2
3	750	0	7	0	0,3	0,4	0,3	0,4	0,4	0,2

Table 6. Customer rates (P_{qt}), number of product holders in the region 2 (h_{2q}), and incentive amounts (R_q) for the model of Case 5

Period (t) / Returned product quality (q)	P_{qt} 1	2	3	h_{2q}	R_q
1	0,4	0,5	0,1	400	10
2	0,3	0,5	0,2	750	7

5. FINDINGS

The developed mixed-integer linear programming models were solved separately for different cases with the GAMS package program: in line with the data, the following results were obtained (Table 7).

Table 7. Optimal objective function values

Objective Functions	Z	TR	TC	TPC	TMC	TTC	TFC
Case 1	746980.20	1010450	263469.80	101478.0	43777	117564.80	650
Case 2	771611.00	1010450	238839.00	84400.20	39792	113996.80	650
Case 3	755028.00	1010450	255422.00	93430.20	43777	117564.80	650
Case 4	765233.20	1010450	245216.80	90778.00	39792	113996.80	650
Case 5	749808.20	1010450	260641.80	101778.0	41867	116346.80	650

Since the demands are equal in all five cases, the revenues (TR) are also the same. Again, in all scenarios, only the 3rd collection & recycling facility was opened, and all regions were assigned to this facility, and thus equal fixed operating costs were incurred. Apart from this, other costs incurred differ for all scenarios, and accordingly, different results on profits are revealed for all scenarios.

In order to more clearly observe the contribution of blockchain technology to the supply chain through different scenarios, the scenarios are presented in Figure 2 by ranking according to the objective function (total profit) values. Above the curve - the right-pointing arrows represent the forward flow, and below the curve -the left-pointing arrows represent the reverse flow of the supply chain network in Figure 2. Blank arrows indicate that blockchain technology was not applied on the respective flow; half-full arrows indicate that it was partially applied; full arrows indicate that it was fully applied.

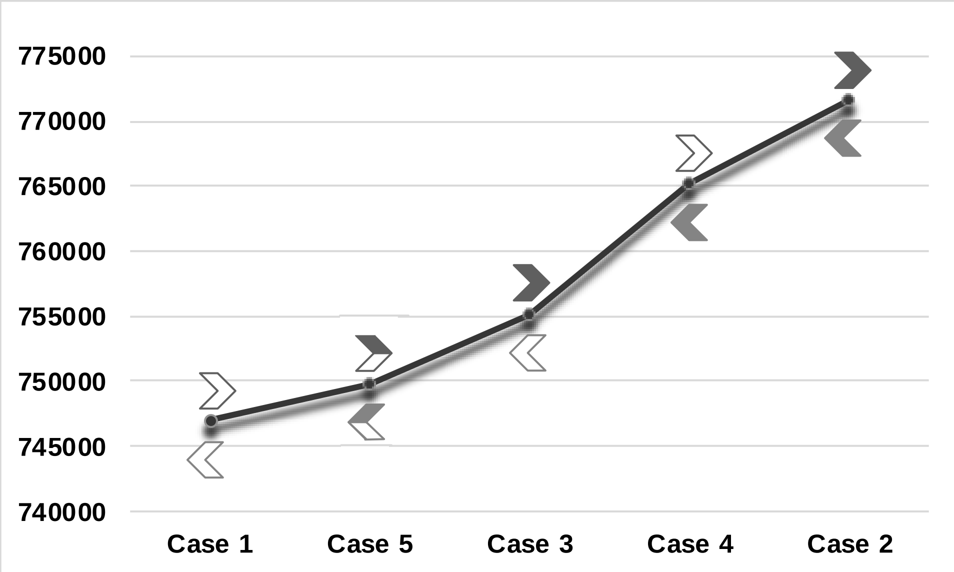

Figure 2. The impact on profits of scenarios based on different blockchain technologies applied to the supply chain

Accordingly, the total profit (Z) is the least in the main model (Case 1), where the blockchain technology is not used on both flows, and the maximum in Case 2, where the blockchain technology is used by all members in the supply chain network. When we compare Case 5, where the blockchain technology is partially applied, and other scenarios, we can say that the full application of this technology gives more efficient results. On the other hand, the values obtained in Cases 3 and 4, applied separately in forward and reverse flow, clearly show that applying blockchain technology to the supply chain network on reverse flow rather than forward flow is more effective. This is due to the application rates of different product recovery options are constantly changing because of the uncertainties involved in the reverse flow, and expensive inspections and time are required to determine returned product status; In summary, it is due to the fact that it is a more difficult type of flow to make forecasts, plans and controls. Therefore, applying blockchain technology to the supply chain on reverse flow will solve more problems and provide greater gains than applying it to forward flow.

The inferences as a result of the scenario analysis demonstrate that blockchain technology has the ability to reduce supply chain costs significantly. In this direction, it is expected that companies that will apply such an important technology will gain a great advantage in increasing their profits.

6. CONCLUSION

With the improvements in technology, important innovations appear in every area and the requirements differ. Although the application of blockchain technology in the supply chain is still a new subject, the estimations on this subject are excessively important.

In this article, the problem of maximizing the profit of a CLSC consisting of two different manufacturers and a collection & recycling center with more than one facility is discussed. First, a basic model is developed for the first case of the main problem under consideration. Afterward, a blockchain technology approach is presented in line with four new scenarios to improve the existing supply chain model. This paper demonstrates the integrability of blockchain into the supply chain and aims to discover what kind of gains will be reached by blockchain technology applications in the existing supply chain and how this will affect the costs.

All developed models were solved using the GAMS 24.0.1/CPLEX package program and according to the results, the total profit was the lowest in the main model without blockchain technology and the highest in the scenario where blockchain technology was fully used. The other three scenarios in which the blockchain technology was partially applied did not yield as efficient results as fully implementing it. The values obtained as a result of integrating only forward and only reverse flow from partially applied scenarios showed that it is more effective to apply blockchain technology to the supply chain network on reverse flow rather than forward flow.

The findings obtained from the study are seen as providing and accelerating the real-time, accurate data flow between the parties as a result of the implementation of the blockchain in all supply chain processes, especially in reverse flow. In this way, the uncertainties of reverse flow can be eliminated and expensive inspections and time loss can be prevented. Apart from this, it can reduce the money and time spent in the supply process by providing communication and reliability between members. Thus, efficiency increases, waste is prevented and costs are reduced.

Given that blockchain technology is in its infancy, few articles have been published in top academic journals so far. It is still vague how different blockchain technologies will work together and integrate with other technological systems. The effect of these technologies on supply chains creates a research gap that applies to both practitioners and academics. For instance, a blockchain provides the advantage of immutability, which is seen as an essential feature. However, immutability can now be seen as a negative feature due to the renewed interest in creating 'mutable' blockchains. Therefore, additional academic research is needed to rigorously explore, explain and predict different application scenarios (Rejeb et al., 2019). This study can inspire practitioners and researchers to use of blockchain technology for different areas in future studies.

As a result of the fact that the blockchain is a new technology, sufficient and appropriate data from the application-based sector has not yet been reached, and the data used for the model proposed in the study were hypothetically produced by the researchers. The limitation of the study is that the data were not measured from a real business. Future studies may focus on the actual rate determination of the assumed 10% cost savings in the forward chain. For a better understanding of blockchain technology importance on supply chain management, reducing investment costs and eliminating its deficiencies, many advanced methods and empirical studies can be carried out in this field. Thus, it can be prevented that practitioners' approach this fairly new technology cautiously.

Yazar Katkıları / *Author Contributions*

Belkız Torğul: Literatür taraması, Kavramsallaştırma, Metodoloji, Modelleme, Veri Derleme, Analiz, Makale Yazımı-orijinal taslak Turan Paksoy: Kavramsallaştırma, Modelleme, Makale Yazımı-inceleme ve düzenleme

Belkız Torğul: Literature review, Conceptualization, Methodology, Modelling, Data Curation, Analysis, Writing-original draft Turan Paksoy: Conceptualization, Modelling, Writing-review and editing

Çatışma Beyanı / *Conflict of Interest*

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Etik Standartlara Uygunluk / *Compliance with Ethical Standards*

Yazarlar tarafından, çalışmada kullanılan araç ve yöntemlerin Etik Kurul izni gerektirmediği beyan edilmiştir.

It was declared by the authors that the tools and methods used in the study do not require the permission of the Ethics Committee.

Etik Beyanı / *Ethical Statement*

Yazarlar tarafından bu çalışmada bilimsel ve etik ilkelere uyulduğu ve yararlanılan tüm çalışmaların kaynakçada belirtildiği beyan edilmiştir.

It was declared by the authors that scientific and ethical principles have been followed in this study and all the sources used have been properly cited.

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