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A Sustainable Online-to-Offline (O2O) Retailing Strategy for a Supply Chain Management under Controllable Lead Time and Variable Demand

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Abstract: Every industry always tries to provide the best service to its consumers. To provide better service to the consumer and optimize profit, a sustainable online-to-offline retailing strategy is proposed in this current study. Both online and offline systems are considered here, i.e., to provide the best service, the industry sells its products online and offline. Due to the consideration of online and offline systems, the selling price of the products is also different for different modes, and the demand for a particular product is the combined demand of online demand and offline demand, which depend on the selling price of the product. Moreover, the exact lead time and exact backorder are calculated to obtain the system's exact cost or profit, which directly improves the system's service. Different investments are incorporated to optimize the total system profit. A distribution-free approach is utilized to solve this model. Numerical examples are provided to prove the applicability of the model in reality. Sensitivity analysis is performed based on critical parameters. Special cases and graphical representations also prove the global optimality of the current study.

Keywords: sustainability; O2O retailing; service; supply chain management; Marketing; backorder

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1. Introduction

The central theme of any supply chain is the trade-off between manufacturer and retailer. Different strategies were developed for both the supply chain players to optimize the cost or the supply chain's profit. A smooth supply chain is always beneficial for any industry. Most industries are currently based on supply chains, where the manufacturer and the retailer control supply chains. Efficient SC is achieved when both the manufacturer and the retailer are satisfied and optimize their profits and costs. To satisfy both manufacturers and retailers, researchers have developed different models using new concepts and ideas. A supply chain is sustainable when the economic, environmental, and social benefits of all stakeholders are considered over a long period (Seok et al. [1]). Sustainability encourages businesses to frame decisions regarding environmental, social, and human impact for the long-term, rather than on short-term gains such as next quarter's earnings report. It influences them to consider more factors than merely the immediate profit or loss involved. Sustainable development means the fulfillment of the requirement of stakeholders (Chowdhury et al. [2]). Chowdhury et al. [2] proved that concomitant with the changes in the stakeholders' priorities of the sustainability requirements, the organizational sustainability practices, strategies, and capabilities also change over time. The supply chain sustainability brings a better conceptual understanding of the dynamic changes in stakeholder requirements and allows managers to choose the optimal strategies and make astute decisions while balancing the economic, social, and environmental viability simultaneously. A sustainable supply chain is essential (Chowdhury and Quaddus [3]). Moreover, a sustainable supply chain improves the performance of the market. Chowdhury and Quaddus [3] developed and validated a multidimensional scale of supply chain sustainability and investigated the importance of supply chain sustainability on market performance through a mediated-moderated modeling approach. Moreover, they proved that supply chain managers would adopt appropriate supply chain sustainability practices and governance mechanisms to reduce sustainability risks and improve market. performance. In the current study, a sustainable supply chain model is developed under the consideration of economic, environmental, and social benefits along with O2O retailing strategy, making the system more sustainable compare to the traditional one.

To make the supply chain more sustainable, the concept of a smart O2O retailing strategy (Sett et al. [4]) is adopted in this current study. Nowadays, human beings love to spend their time on smart devices like smartphones, laptops, or computers. Thus, researchers also try to develop some strategies based on human behavior or useful for humans. Owing to the massive use of smartphones, researchers try to develop their models under the consideration of online advertisement systems. The thinking and the lifestyle of people were changed unexpectedly due to the Internet's acceptance and frequent mobile internet evolution. Thus, e-commerce had a significant impact on optimizing the profit or cost for any industry. Online-to-offline (O2O) takeaway, as a specific e-commerce form, combines O2O with traditional industry. This e-commerce model provided customers a novel opportunity to choose their required product offline and paid online to get the product in his/her doorstep or workplaces. Online-to-offline business strategy is one of the most useful strategies in those days to optimize system profit or cost. In the O2O strategy, a customer can buy their product through online mode or offline mode. In this strategy, customers can choose their products online, and products will be delivered to the customer's doorstep in offline mode.

In parallel, a customer can buy his/her required product by visiting any retailer's shop, i.e., the whole process of choosing and buying the product made through offline mode. Many companies have been criticized for exploiting cost-cutting measures such as offshoring production to obtain cheaper labor. Although beneficial for the bottom line, this practice often comes at the price of compromised worker safety and security. As products are ordered online, different transport uses are reduced, which directly reduces the rapid growth of carbon emissions. That means one of the essential pillars of the sustainable supply chain, i.e., environmental benefits directly enhanced through O2O retailing strategy.

Moreover, in the online system, the retailer does not need any showroom to display the product. He/she only needs better technology to attract customers. Thus, the retailer or manufacturer can both reduce their showroom cost, simultaneously total system cost, which directly reduced the unit selling price of the product. A lower price increases the demand for a particular product, which directly enhances the profit of any system. Some consumers still believe in offline shopping due to the reliability issue. They preferred to choose the product offline. Thus, both online and offline demands are significant in those days to optimize the system profit.

With these rapid growths of e-commerce business strategy, most of the industries nowadays go for this O2O policy, which is negatively impacted for offline retailers and they provided a different type of rebate or gift to increase their profit (Pei et al. [5]). It was observed that customers could get the same product at a lower price in an e-commerce system to compare to the offline retail shop. Moreover, the O2O system provided more service proved by Sett et al. [4]. The e-commerce system's disadvantage is that some unreliable e-commerce retailers provide fewer quality items to their customers. Owing to this unreliability, some customers visit the retailer shop to purchase their required product.

Moreover, to attract customers, the offline retail shop provides different discounts, which was beneficial for the customers, and customers can physically check its quality.

Thus, in this research, a model is developed where both e-commerce and offline sell are considered under the supply chain environment. Two different prices for the same product were considered, where one is for the online price, and another is for offline price. Moreover, the demand for the product, both online and offline, depends on the selling price. The current study developed based on online and offline demand for a particular product. Due to the O2O retailing strategy, a particular product's demand increases, which directly increases the total supply chain's profit. Thus, the most vital pillar of the sustainable supply chain, i.e., economic benefit, directly increases through this smart O2O retailing strategy. Moreover, to deliver those products offline, which were ordered online, some labor is required, which means the O2O retailing strategy also takes care of the supply chain's social benefits. Thus, the use of the O2O retailing strategy makes a supply chain more sustainable. The stock situation can happen for both online and offline sales. Thus, backorder plays a significant role for any supply chain industry (Wee et al. [6], Sarkar et al. [7]). Moreover, lead time has a significant impact on any supply chain model (Sarkar and moon [8]).

Different researchers developed several supply chain models under the consideration of backordered or lead time, but an O2O system under the consideration of backordered and lead time, where demand depends on online and offline selling price, still a significant gap in research in this direction, which was fulfilled by this model. This study proves that the use of an O2O retailing strategy makes a supply chain more sustainable. Moreover, as it is challenging to find the lead time's exact distribution, two cases were developed under the consideration of normally distributed lead time and distribution-free approaches for the lead time distribution. The novelty and research gap in the literature and its uniqueness compared to existing literature are summarized in Table 1.

Table 1. Contributions of previous authors.

Author(s)	O2O Retailing	SCM	Lead Time	Backorder	Demand Rate
Dey et al. [9]	NA	Integrated	Poisson	Planned	Price dependent
Gallego and Moon [10]	NA	Newsboy	DFA	NA	Constant
Sarkar and Moon [8]	NA	Normal	Variable	Partial	Constant
Seok et al. [1]	NA	Sustainable	NA	NA	Constant
Sett et al. [4]	Yes	Normal	Normal	Planned	Price dependent
Sroufe et al. [11]	NA	Sustainable	NA	NA	Constant
Xiao and Dong [12]	Yes	Normal	NA	NA	Constant
Zimon et al. [13]	NA	Sustainable	NA	NA	Constant
This study	Yes	Sustainable	DFA & Normal	Planned	Online & offline price dependent

NA stands for Not Applicable, SCM stands for Supply chain management, and DFA stands for Distribution free approach.

The existing research related to this field is described in the next section, whereas the actual problem definition and Notations and assumptions are provided in Section 3. Section 4 contained the model along with the special cases for the normal distribution model and distribution-free model. Numerical examples for different cases along with a graphical representation are presented in the next Section 5. Section 6 contained the effect of critical parameters as a Sensitivity analysis. Finally, some concluding remarks, limitations, and future extensions are provided in Section 7.

2. Related Literature Review

2.1. Supply Chain Management

The supply chain is a means of getting the product to the customer from the production house through different means. The amount of profit and the popularity of the product depend on the number of members and their performance. An active supply chain helps the business grow by satisfying the customers' needs promptly. Its work has been seen randomly in some previous research papers. Pal et al. [14] discussed a multi-echelon supply chain model. They introduced multiple market facilities if any supply disruption. In their model, defective or scraped items, after the rework, sells to the secondary market. The previous model was developed by Rad et al. [15] through the concept of the backorder and price-sensitive demand. Giri et al. [16] discussed a supply chain management (SCM) model which is the same as the previous one, but they introduced closed-loop SCM for green items. Their model introduced revenue sharing strategy with green-sensitive customer demand. Price and service competition among the retailers is a significant impact discussed by Ali et al. [17]. The decorated effects demand disruption in supply chain management. A two-echelon supply chain model with price promotion and advertisement was developed by Malekian et al. [18]. They considered the Stackelberg game policy to optimize the decision level. Liu et al. [19] introduced a coordination mechanism in their model to modify the relational contract among the supply chain members. They considered an essential concept of penalty rate among the supply chain members on corporate social responsibility. The procedure of solving the unreliability of the supply chain through different game strategies and advanced technology was discussed by Sardar and Sarkar [20]. They considered radio frequency identification techniques. Keeping in mind the best service level and the competition for the supply chain network's equilibrium, Zhang et al. [21] considered a dual-channel SCM model. A sustainable supply chain model was developed by Sarkar et al. [22]. Carbon emission and quality improvement were included in their model to update the products' environmental issues and lifetime.

2.2. Sustainable Supply Chain Management

Sustainability aims to fulfill the present demands without compromising future generations' ability to fulfill their demands. Sustainability depends on three fundamental pillars: economic, environmental, and social, formally known as profit, planet, and people. Sustainable development is one of the trending strategies to optimize the total system profit for any supply chain system (Tayyab et al. [23]). Three essential pillars of a sustainable supply chain were economic, environmental, and social (Seok et al. [1]). An advanced optimization approach for sustainable development was introduced by Chowdhury and Quaddus [24]. In this model, they developed a multi-phased quality function deployment-based optimization technique for overcoming the barriers of lack of awareness, lack of skilled human resource, poor logistical support, and resource shortage inhibit effective delivery of m-health service and to deliver sustainable m-health service. For maintaining the relationship between financial development and social responsibilities, a sustainable supply chain was essential in any industry (Hossain [25]). Chowdhury et al. [26] prove that a sustainable supply chain was too beneficial to fulfill the stakeholders' requirements. They identified the requirements for stakeholders' sustainability and developed its procurement strategies in terms of stakeholders' requirements for a sustainable supply chain. They also discussed the relationship between the companies' brand image and the sustainability of a supply chain system. A practical implementation towards sustainable supply chain management was proposed by Zimon et al. [13]. Their model discussed the stainability of a supply chain system for reactive, cooperative, and dynamic models. Given environmental benefits, reduction in carbon emission is one of the main objectives for any sustainable supply chain system (Ahmed and Sarkar [27], Shaharudin et al. [28], and Mishra et al. [29]). A symmetric review for green product production was presented by Appolloni et al. [30]. Because of social responsibilities, different firms upgrade the relationship between social stainability and financial performance (Sroufe et al. [11]). The condition and barriers related to sustainable development were characterized by Zimon et al. [31]. Some creative approaches can make a supply chain sustainable (Schulz et al. [32]). Recently, bearing in mind social responsibility, a production model for the green and non-green product was developed by Sana [33]. Due to the O2O retailing strategy in this current study, all three pillars of the sustainable supply chain are fulfilled. The use of an online ordering policy reduced transportation, which directly reduced carbon emissions. Moreover, due to the smart strategy, system profit is also optimized. Several researchers developed their model under the consideration of stainability. However, a sustainable supply chain due to online and offline smart strategy still a significant research gap in this research direction. Moreover, it is challenging to find the exact distribution of the customers during lead time. For this reason, several researchers developed supply chain model under the consideration of the distribution-free approach (Gallego and Moon [10], Dey et al. [34], and Sarkar et al. [35]). However, a sustainable supply chain under O2O retailing strategy, where different investments were introduced to reduced system cost and optimized the profit still a significant research gap, which is trying to fulfill by this current study.

2.3. O2O Retailing

The online to offline retailing system is a significant method used in today's society. It is an easy way to provide daily necessities in an environmentally friendly manner. Currently, many companies are increasing their profits through online business. In that case, the online to offline method will make a profit, satisfy customers, and provide a timely supply. Many researchers have been already published on sustainable O2O retailing. The home delivery of necessary products by offline concept at first through the review model was introduced by Visser et al. [36]. The use of online to offline (O2O) in e-commerce markets for a hidden semi-Markov model was investigated by Xiao and Dong [12]. Different pricing strategies and location evolution for competitive O2O markets were proposed by He et al. [37]. Product returns are an essential aspect of consumers (Yan and Cao [38]). As online shopping becomes more familiar to all, the return policy is a critical part of doing business in the market today. Besides attracting more customers, companies now gave some reward points or gifts that customers can use in their next purchase (Yan et al. [39]), which also increases the brand image of the company as well as maximize the total system profit. In the present situation, different online shopping apps are available in the market. Among them, food delivery apps also actively satisfy customer demand by delivering the desired food (Ray et al. [40]). The concept of rating and recommendation was another critical issue in any O2O supply chain management introduced by Yuchen et al. [41]. Son et al. [42] developed a model based on the effects of out-of-stock, return, and cancellation amounts of retailer order. They investigated in their model that how the customers' impact of different cases such as return amount, cashback offers, cancellation amount, and out of stock situation reflect the business system. Recently, a service related to O2O retailing was discussed by Sett et al. [4], where they proved that service played a vital role in the optimization of supply chain profit. They also considered an unreliable retailer in their model. Another manufacturer rebate model was discussed by Pei et al. [5]. Recently, by considering innovation inputs, Yang et al. [43] developed a dual channel supply chain. Advertising is an essential platform to gain popularity in the customer area. Through investment in this section, one can easily reach their satisfactory profit level, and the interaction of outdoor advertising (Wei et al. [44]) recently spread even to remote areas. Some customers were afraid of the quality of the online product. They buy their products offline through present physically at the retail shop. Thus, due to different circumstances, the same product's demand and price were different for online and offline mode. Therefore, the research related to price-dependent demand was elaborated in the next subsection.

2.4. Price Dependent Demand

To optimize the profit of any industry, the demand for any product plays an important role. The demand for any product cannot always be fixed. It depends on some fundamental components like advertisements, the product's quality, and the company's service. Out of all those components, the most effective component is the price. Generally, any product's demand is inversely proportional to product price Sett et al. [4]. Different models were developed under the consideration of price-dependent demand (Dey et al. [9], Feng et al. [45], and Pal et al. [46]). A production model for the deteriorating item was established by Thangam and Uthayakumar [47], where demand depends on product selling price. Moreover, they proved that tread credit policy helps the industry to optimize their profit. A deterministic model under the consideration of delay in payments and price discount policy was developed by Sana and Chaudhuri [48]. An inventory model for deteriorating items was developed by Sana [49] under the consideration of partial backlogging. He also optimized the selling price of the product and lot size. In the next year, Sana [50] extended his own model by considering the initiatives of the salesman. He used "Pontryagin's Maximal Principal" to solve this model. The effect of fixed selling price and contingent-price offers in a supply chain with two types of customers was analyzed by Ku and Chang [51]. They also optimized optimum production lot size and discussed different policies for selling the products. Sarkar et al. [52] developed an inventory model where demand depends on the product's selling price. They developed the model for deteriorating items. The service level of the industry is always a significant issue for any industry (Abad [53]). Abad [53] also optimized the product's selling price along with the size of the order of a news vendor problem. To keep the selling price reasonable for the customer, a quantity discount policy was successfully implemented by Alfares and Ghaithan [54], where demand depends on selling price and holding cost depends on time. Every deteriorating product had an expiration date, and the selling price of that product depends on the life cycle of the product (Wu et al. [55]). A model was analyzed in a similar direction by Li and Teng [56], where they considered a deterioration product, and demand depends on selling price, display stocks, and freshness of the product. An inventory model with the consideration of advanced payment policy was developed by Khan et al. [57], where demand depends on selling price and advertisement. Due to perishable items, they considered that holding costs depend on time. A tourism supply chain was developed by He et al. [58], where they utilized the concept of O2O strategy. Most previous researchers considered a selling price that depended on the demand for inventory model, production model, or supply chain model. However, price depended on demand for a smart O2O supply chain model in the industrial sector still a gap in research. Moreover, two different selling prices for the same product due to offline and online sales are still negligible assumptions for any O2O supply chain model. In this study, a pioneer attempt is taken to fill this research gap.

2.5. Backorder

Nowadays, backorder due to online selling is an essential aspect of the business. The profit and loss of the business depend on the needs and patience of the customer. The massive supply of alternate products in the market can meet the customer's demand and patience. Therefore, depending on the supply and demand of goods in the market, backorder becomes an indicator of a business. There are two types of the backorder: partial and fully type of backorder. Previously, many research papers on this topic have been found. An EPQ model with rework and planned backorders for a single-stage manufacturing system were taken by Wee et al. [6]. They considered an alternative inventory policy for reworking the defective products to reduce the total cost. Sarkar and Moon [8] introduced an imperfect production system with quality improvement and setup cost reduction technique. For reducing the total system costs, variable backorder was included in their model. The random defective rate and rework of the defective products with planned backorder were taken by Sarkar et al. [7]. An integrated production inventory model was developed by Liu et al. [59] through the multi-product concept. Their model introduced a preventive maintenance policy to reduce system failure and continue the smooth production process. Through optimum energy consumption and a reduced failure rate, a multi-product smart production system was developed by Bhuniya et al. [60]. Kim et al. [61] considered an improved way to calculate the defective products in a long-run production system with backorders. A distribution-free approach with known mean and standard deviation helps their model to find the optimal solutions. Delay in payment in a multi-product EPQ model with partial backordering was discussed by Taleizadeh et al. [62]. They considered the new concept of failure in repair policy and improved algorithm. Guchhait et al. [63] discussed defective products based production model with a backorder and warranty policy. Their model introduced quality improvement and setup cost reduction policy to optimize the expected joint cost. Inventory management of deteriorating products with a backorder and controllable carbon emission was developed by Mishra et al. [29]. They considered the preservation of technology investment for the reduction of deterioration. A stochastic inventory control model with partial backordering was discussed by Taleizadeh et al. [64]. They introduced supply disruption to the base stock periodic review model. Different supply chain or production models were developed under the consideration of full or partial backordered, but an O2O-based supply chain model, where demand and price of the same product were different for two different channels (online and offline), has not been considered yet. This study fulfilled this gap. Lead time also had a significant impact on any supply chain system. The effect of lead time in the supply chain was described in the next subsection.

2.6. Variable Lead Time

In this impatient age of busyness, every customer wants to get the necessary items immediately. The time gap between an order received by the vendor and the vendor's order is the lead time. A supply chain can be made more trustable and robust based on minimum lead time. Short lead time makes a good relationship between customer and retailer. Furthermore, lead time controls the market demand. Many studies have been published based on variable lead time. Snyder et al. [65] considered a model based on means and variance of the variable lead time-dependent demand. They calculated finding mean and variance through smoothing methods. A single vendor–buyer model of stochastic demand was developed by Hsiao et al. [66]. He considered a delay in transportation and variable lead time to achieve his goal. Moon et al. [67] developed a paper-based on inventory, in which service level constraints improve the customer's satisfaction. Their distribution-free review model introduced a negative exponential lead time crashing cost function. An integrated inventory model was developed by Sarkar et al. [7] through defective production concepts and delay-in-payments. They considered a stochastic lead time and inspection policy to reach the accuracy level. Sarkar et al. [68] extended the previous model by incorporating the quality improvement and price discount policy. They considered different distribution of lead time demand to achieve the minimum cost. Wang et al. [69] studied a paper based on the application of stochastic lead time duration and mitigating variance. Dominguez et al. [70] presented a model based on variable lead time and remanufacturing. They also considered the dynamic property of the closed-loop supply chain system and the multi-echelon supply chain. An unreliable supply chain model was introduced by Hota et al. [71]. They considered variable transformation, carbon footprint, and unequal lot size for optimizing the joint total cost. Haeussler et al. [72] introduced a model based on optimization techniques. They compared two models of the constant and variable type of lead time duration. A flexible manufacturing idea in supply chain management was introduced by Malik and Sarkar [73]. They considered game strategy and stochastic lead time demand to reduce the total expected cost. They considered game strategy and stochastic lead time demand to reduce the total expected cost. Several models were developed to reduce the lead time by different researchers. However, an O2O-based supply chain model that considers backordered and lead time reduction is still a significant research gap in this direction. The current study was performed to fill this research gap, where the demand and price of the different channels are different for the same product.

3. Problem Definition, Notation, and Assumptions

In this section, the problem is discussed, along with notation and assumptions for this model.

3.1. Problem Definition

A sustainable O2O supply chain model was developed in this current study, where a single product was sold through online and offline modes with two different prices.

Variable safety stock reduces the lead time duration of the supply chain system. The expected backorder for the buyer is a function of the probability distribution of the safety stock. Instead of the expected value, one can get the supply chain's exact cost due to marginal value and the exact amount of lead time. Every improved supply chain always reduces the lead time to fulfill customer demand. Due to the O2O channeling system, the advertisement cost was reduced, and the supply chain transfer to a sustainable supply chain. Moreover, a constant ordering cost was instated, and a variable ordering cost was calculated under some continuous investments, which reduced the system cost and made the model sustainable. Some continuous investment also implied increasing the system reliability, which directly improves the service of the O2O channeling and make the model more sustainable. The manufacturer uses a SSMD transportation policy along with fixed and variable transportation and carbon emission cost. Moreover, it is almost impossible to find the exact distribution of backordered. Thus, a normally distributed model and a distribution-free approach model were developed for the backorders. It is considered that the defective rate follows a particular distribution. Finally, the total system profit is maximized along with the optimum value of the decision variables, and it is found that supply chain profit is maximized when the defective rate follows a Triangular distribution.

3.2. Notation

To formulate this model, the following notation and assumptions are used:

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p	minimum duration lead time component $(p = 1, 2, ..., n)$
q	normal duration lead time component $(q = 1, 2, ..., n)$
Decision	**variables**
V_s	volume of each shipment (unit)
r	reorder point (unit)
L_e	lead time (weeks)
s_1	product's online selling-price ($/unit)
s_2	product's offline selling-price ($/unit)
P_ϕ	probability of going to the *out-of-control* state
C_b	ordering cost for retailer ($/unit)
x	number of product shipment per lot, (a positive integer)
Parameters	
Q_l	lot size (units)
D_b	demand rate of retailer, $D_b = F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2}$ (units)
P_r	production rate of manufacturer, $P_r > D_b$ (units/time)
O_{C_0}	initial ordering cost ($/order)
T_C	cycle time, $T_C = Q_l/D_b = xV_s/D_b$ (time)
h_B	inventory holding cost for retailer ($/unit/unit time)
P_{ϕ_0}	initial probability to transfer "out-of-control" state
H_c	inventory holding cost for manufacturer ($/unit/unit time)
P_{uv}	manufacturer's unit production cost per unit ($/unit)
T_D	technology development cost for O2O channeling ($/unit)
P_{ub}	retailer's unit purchase cost per unit ($/unit purchased)
I	fixed investment to develop the technology ($/cycle)
S_c	unit shortage cost per unit ($/unit shortage)
C_{wd}	web page designing cost for O2O installation ($/unit)
A_S	setup cost ($/unit)
C_{ph}	internet host purchasing cost for O2O installation ($/unit)
γ	standard normal probability density function
C_{vw}	web page visualization cost for O2O installation ($/unit)

F_a	annual fractional cost for the capital investment for online sell (\$/investment)
F_b	annual fractional cost for the capital investment for offline sell (\$/investment)
α_1	price elasticity parameter for online sell
α_2	price elasticity parameter for offline sell
β	defective rate, which follows certain distribution
Θ	standard normal cumulative distribution function
C_{lw}	labor charge for O2O installation (\$/unit)
$C(L_e)$	consumer's total number during lead time L_e
ζ	backorder rate
$P(L_e)$	total amount purchased by time L_e
$R(L_e)$	total crashing cost is related to the lead time (\$/week)
a_p	component p of lead time with a_p as minimum duration(days)
b_p	component p of lead time with b_p as normal duration(days)
I_{ccb}	fixed carbon emission cost of consumer (\$/shipment)
B_{ccb}	variable carbon emission cost of consumer (\$/unit)
I_{ccv}	fixed carbon emission cost of manufacturer (\$/shipment)
B_{ccv}	variable carbon emission cost of manufacturer (\$/unit)
F_T	fixed transportation cost (\$/shipment)
V_T	variable transportation cost (\$/unit)

3.3. Assumptions

To develop this model the one can consider the following assumptions:

1. This paper deals with a single-retailer, single-manufacturer sustainable O2O retail channeling supply chain for a single product type.
2. The retailer sold the items online and offline, whereas the manufacturer only sold in the offline mode to the retailer. Thus, the demand for both online and offline modes depends on selling price, thus the demand of the supply chain is given by $D_b = F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2}$, which makes the model more sustainable.
3. Two investments are introduced to reduce ordering costs and upgrade the production process's reliability.
4. Reduction of lead time is another component for service improvement. There are different crashing costs to reduce the lead time for different, mutually independent components are contemplated in this model. Let b_p be the normal duration of the $a-$th component and a_p be the minimum duration where the crashing costs per unit time u_p satisfy $u_1 \leq u_2 \leq ... \leq u_n$. Suppose L_{t_a} is the length of the lead time for which components $1, 2, 3, ..., p$ crash to their minimum duration, and let $L_{t_0} = \sum_{y=1}^{n} b_p$. Then $L_{t_p} = L_{t_0} - \sum_{y=1}^{p}(b_p - a_p)$ and the crashing cost $R(L_e)$ can be written as $R(L_e) = u_p(L_{t_p} - L_e) + \sum_{y=1}^{p}(b_q - a_q)$ for $p = 1, 2, ..., n$.
5. A single-setup multi-delivery (SSMD) policy is adopted for transportation in this model. The manufacturer produced the products in a single lot and transported them in the multi-delivery process. The main reason for adopting the SSMD policy is that this policy makes the supply chain model more sustainable in the O2O environment. As multiple deliveries were used, the number of deliveries and the transportation cost also increased. Thus, there is a trade-off between the retailer's holding cost and the increased transportation cost. For this transportation, variable and fixed transportation costs and carbon emission costs were considered to make the model more sustainable.
6. The safety stock and the sum of the expected demand during the lead time measured the reorder point, i.e., $Pp = D_b L_e + s_f \sigma \sqrt{L_e}$.
7. Fully backordered shortages are permitted at the normally distributed backorder rate, and distribution-free approaches are considered to formulate two models.

4. Mathematical Model

Sustainable development is needed to recover human beings' dynamic way of life in the current social crisis. Moreover, the online business makes this supply chain even stronger. The mentioned model refers to a sustainable green supply chain with a single vendor and a single buyer. Demand depends on the price, quality, and service facility based on the current market. Another facility of online-to-offline makes the model more realistic. The different cost of vendor and buyer is discussed separately in the following section.

4.1. Retailer's Profit

The buyer is an essential member of this model through which products can be reached before the customer's hand through online or offline mode. Here, the buyer has tried to increase profits by adopting various ways such as service facility, reducing ordering cost, technology development. The cost described below has been considered in favor of the buyer.

4.1.1. Holding Cost (HC)

It is an essential factor in the cost incurred by the buyer. It is not to say that the products from the vendor to the buyer will be sold immediately, thus it is necessary to stock them. This type of investment is essential in reducing lead time and for customer attraction and satisfaction. The following formula describes the holding cost.

$$h_B\left[\frac{V_s}{2}+r-D_bL_e+(1-\zeta)E(X-r)^+\right]$$

4.1.2. Ordering Cost (OC)

The ordering cost means when the buyer gives the information to the vendor regarding the required quantity of products, product quality, and market demand, then it has been utilized. Nevertheless, in this supply chain online-to-offline business strategy, vendors always try to utilize a smart policy as their order policy, i.e., through a smart system. Therefore, ordering process is done so quickly with lower investment. Thus, the ordering cost be such follows.

$$\frac{C_b(F_as_1^{-\alpha_1}+F_bs_2^{-\alpha_2})}{V_s}$$

4.1.3. Investment for Improve the Service by Reducing Ordering Cost

In this new strategy, the service facility is improved, but the cost is less. For example, do everything online without sending any member to the ordering policy, without looking at the samples. In this case, the ordering cost can be reduced using a single, convenient network without increasing the cost on different networks. Besides, through this technique, ordering policy becomes so quicker and smarter. Thus, the required cost formula for such investment is as follows.

$$O_i = g\ln\frac{O_{c_0}}{C_b}$$

4.1.4. Backorder Cost (BC)

Backorder cost is a sensitive issue in today's competitive market. Nowadays, everyone's time is of the essence, so customers always want to immediately get what they need. In that case, there should be little gossip between the order and delivery of the products. Depending on the lead time between order receive and given delivery, the backorder can be divided into two parts: partial backorder and full backorder. If the delay-in-delivery customer cannot wait for another buyer, it must be fully backorder. If the customer waits for the delivery, although there is delay-in-delivery, it is entirely back. Fully backorder mainly depends on the behavior of the buyer and the crisis of shortages of the products. Altogether backorder has negative impacts on the business process through less popularity.

Therefore, planned backorder considers the following cost expression.

$$\frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s}\left(\pi_x + \pi_0\left(1-\zeta\right)\right)E(X-r)^+$$

4.1.5. Technology Development Cost (TDC)

It is an important platform to survive in the current competitive market. It is beneficial in online-to-offline business. Through such a cost, buyers order the products, advertise them, display stock, retrieve the customer's order, deliver timely feedback, receive feedback, and know the improvement level. Customers and supply chain members greatly benefit from this technology investment. However, moving toward a sustainable supply chain, the O2O supply chain takes a significant role, and it is too important to develop the technology for a better service, which makes the system more sustainable. The following expression indicates such investment.

$$TDC = I + T_D\frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s} \tag{1}$$

4.1.6. Lead Time Crashing Cost (LTCC)

It is a turning point of online-to-offline green sustainable supply chain management. It depends on the lead time, buyers' popularity, business level, and length of stay in the competitive market. If a long-term delay-in-delivery occurs, the buyer has to incur additional costs such as a gift policy to retain the customer. Besides full backorder, the business's loss is also enclosed within the lead time crashing cost. Thus, the mathematical expression of this cost be such that

$$\frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s}R(L_e)$$

Therefore, the retailer's total cost is given by

$$\begin{aligned}
& TC_R(V_s, s_1, s_2, k, L_e, C_b) = HC + OC + TDC + BC + LTCC \\
= & \left[h_B\left(\frac{V_s}{2} + r - DL + (1-\zeta)E(X-r)^+\right)\right] + I \\
+ & \frac{C_b(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s} + g\ln\frac{O_{c_0}}{C_b} + T_D\frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s} \\
+ & \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s}\left(\pi_x + \pi_0\left(1-\zeta\right)\right)E(X-r)^+ \\
+ & \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s}R(L_e)
\end{aligned}$$

The revenue for the retailer is $= (s_1 - P_{ub})F_a s_1^{-\alpha_1} + (s_2 - P_{ub})F_b s_2^{-\alpha_2}$, where P_{ub} purchasing cost of the retailer. Thus, the profit function for the retailer's in O2O channeling along with batter service is given by

$$
\begin{aligned}
& \text{Profit}_R(x, V_s, k, L_e, s_1, s_2, C_b) \\
= & \left((s_1 - P_{ub})F_a s_1^{-\alpha_1} + (s_2 - P_{ub})F_b s_2^{-\alpha_2}\right) - TC_B(V_s, s_1, p_2, \sigma, L_e, C_b) \\
= & \left((s_1 - P_{ub})F_a s_1^{-\alpha_1} + (s_2 - P_{ub})F_b s_2^{-\alpha_2}\right) - \Bigg[\Bigg[h_B\Bigg(\frac{V_s}{2} + r - DL_e \\
+ & (1-\zeta)E(X-r)^+\Bigg)\Bigg] + I + \frac{C_b(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s} \\
+ & g \ln \frac{O_{c_0}}{C_b} + T_D \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s} + \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{mV_s}\Bigg(\pi_x \\
+ & \pi_0\left(1-\zeta\right)\Bigg)E(X-r)^+ + \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{xV_s}R(L_e)\Bigg] \qquad (2)
\end{aligned}
$$

4.2. Manufacturer's Profit

The vendor produces and sells products according to retail's orders. The main issue for the vendor is the products, which reduces the environmental pollution as well as sustainable development of the society through supply chain. Besides, vendor's effectiveness also importance for the strong supply chain management. The considerable shortages are completely backlogged. The different costs related to the vendor are described in details in the following section.

4.2.1. Setup Cost for Supply Chain Model

By investing in a production setup, the equipment can be prepared to process different batches of goods. By investing one's time, the output over the entire cycle time and the next time can be obtained. It is the essential cost of starting a business and running it efficiently. Depending on the developed setup, the production process improves at a rapid pace. Besides the production of green products, the vendor should focus on it through an important issue. Here, the setup cost is considered as

$$\frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})A_S}{xV_s}$$

4.2.2. O2O Installation Cost

For running a smooth O2O supply chain, O2O installation is necessary. A fixed cost is added to install the O2O configuration. The cost is the summation of the cost for design the web page (C_{wd}), cost for purchase a host from the internet (C_{ph}), visualization of web page C_{vw}, and labor charges (C_{lw}). Thus, making the system more sustainable, O2O installation cost takes a significant role. The cost is given by

$$O2O_{IC} = C_{wd} + C_{ph} + C_{vw} + C_{lw}$$

Thus, O2O installation charges throughout the cycle are given by

$$\frac{(C_{wd} + C_{ph} + C_{vw} + C_{lw})(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{xV_s}$$

4.2.3. Carbon Emission Cost for O2O Supply Chain Model

It needs environmental improvement. Nevertheless, in this proposed model, due to the single-setup-multi-delivery policy, the shipment number increases, and environmental pollution increases with the proportional relation with the number of shipments. Companies can achieve their sustainable needs by cutting emissions, lowering their energy usage, sourcing products from fair trade organizations, and ensuring their bodily waste is disposed of correctly and with as small a carbon footprint as possible.

Therefore, the effects of carbon on the environment are considered, fixed, and variable carbon emission costs for the vendor are contemplate in this model. Thus, the fixed carbon emission cost for the vendor is $V_{ccv}x$ and the variable cost concerning the number of received shipments is $(F_{ccv}x)$. Thus, the total carbon emission cost is

$$CE_v = F_{ccv}x + V_{ccv}xV_s$$

4.2.4. Transportation Cost for O2O Supply Chain Model

O2O supply chain management can only progress through strong transportation. The produced green products can reach before customers hand only through quick transportation within the said time. Besides, another application of the single-setup-multi-delivery policy makes transportation easier and reduces the setup cost. Due to this SSMD policy, the transport's number increased, and both fixed and variable carbon emissions are contemplated for quality improvement.

Thus, the cost of transportation is $xF_T + xV_TV_s$.

4.2.5. Investment to Improve Process Quality

Defective production is an essential factor for a production system, which gives uncertainty to a supply chain. A production system is reliable when the top products produced are perfect. Here, the vendor invests capital for improving the quality of the products to reduce the production of defective products, i.e., to make the system in-control from out-of-control. However, moving toward sustainable production is often a complex process for companies. By basing decisions on longer timelines, some of the higher upfront investments in efficiency and renewable sources are easier to justify. Companies can implement the zero-waste production process to make the system more sustainable. Thus, process quality improvement directly helps to make a production system more sustainable. The number of defective items is $\frac{S_c(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})V_s P_\phi}{2}$, and the quality improvement is given by

$$b \ln\left(\frac{P_{\phi_0}}{P_\phi}\right)$$

4.2.6. Holding Cost of the Manufacturer

The holding cost yields a substantial inventory as well as active supply chain management. All unsold products are stored through this type of investment. It is an essential constituent of the total supply chain cost. Therefore, the holding cost can be calculated (see Figure 1).

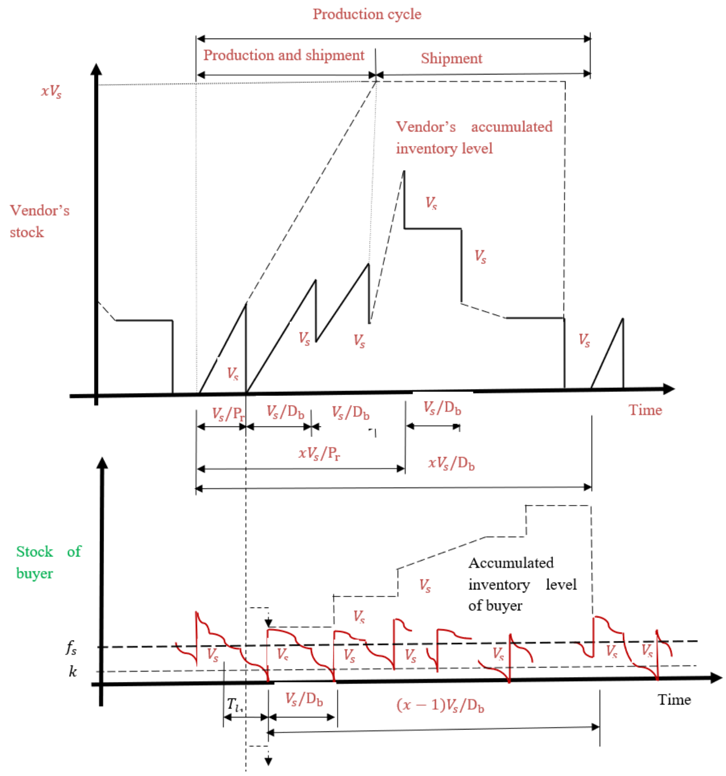

Figure 1. Inventory level for both retailer and manufacturer.

$$\frac{[\text{shaded-area}]}{V_s/\left(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2}\right)}$$

$$=\left[\frac{V_s}{2}+\frac{(x-2)V_s}{2}\left(1-\frac{\left(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2}\right)}{(1-\beta)P_r}\right)\right]$$

Therefore, the manufacturer's total holding cost is given by

$$=\left[\frac{V_s}{2}+\frac{(x-2)V_s}{2}\left(1-\frac{\left(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2}\right)}{(1-\beta)P_r}\right)\right]H_c$$

Thus, the manufacturer's annual total cost is given by

$$\begin{aligned}
&TC_M(x,V_s,s_1,s_2,P_\phi)\\
=\;&\frac{\left(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2}\right)}{xV_s}\left(A_S+C_{wd}+C_{ph}+C_{vw}+C_{lw}\right)\\
+\;&\frac{V_s}{2}\left[1+(x-2)\left(1-\frac{\left(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2}\right)}{(1-\beta)P_r}\right)\right]H_c\\
+\;&\frac{xS_c\left(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2}\right)V_sP_\phi}{2}+b\ln\frac{P_{\phi 0}}{P_\phi}\\
+\;&\frac{F_T\left(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2}\right)}{V_s}+V_T\left(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2}\right)\\
+\;&\frac{\left(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2}\right)F_{ccv}}{V_s}+V_{ccv}\left(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2}\right)
\end{aligned}$$

The manufacturer's revenue is given by $(P_{ub}-P_{uv})F_a s_1^{-\alpha_1}+(P_{ub}-P_{uv})F_b s_2^{-\alpha_2}$

Then, the profit function of the manufacturer is given by

$$\begin{aligned}
&\text{Profit}_M(x, V_s, s_f, s_1, p_2, P_\phi)\\
=\ & \Big((P_{ub} - P_{uv})F_a s_1^{-\alpha_1} + (P_{ub} - P_{uv})F_b s_2^{-\alpha_2}\Big) - TC_V(x, V_s, s_f, s_1, p_2, P_\phi)\\
=\ & \Big((P_{ub} - P_{uv})F_a s_1^{-\alpha_1} + (P_{ub} - P_{uv})F_b s_2^{-\alpha_2}\Big)\\
-\ & \Bigg[\frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{xV_s}(A_S + C_{wd} + C_{ph} + C_{vw} + C_{lw})\\
+\ & \frac{V_s}{2}\left[1 + (x-2)\left(1 - \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{(1-\beta)P_r}\right)\right]H_c\\
+\ & \frac{xS_c(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})V_s P_\phi}{2} + b\ln\frac{P_{\phi 0}}{P_\phi} + \frac{F_T(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s}\\
+\ & V_T(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2}) + \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})F_{ccv}}{V_s}\\
+\ & V_{ccv}(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})\Bigg]
\end{aligned} \tag{3}$$

Thus, the retailers' and manufacturers' total profit is presented in Equations (2) and (3). Thus, the joint total expected annual profit of the green supply chain is given by

$$\begin{aligned}
&\text{Total profit}(x, k, V_s, L_e, s_1, s_2, P_\phi, C_b)\\
=\ & \Big((s_1 - P_{uv})F_a s_1^{-\alpha_1} + (s_2 - P_{uv})F_b s_2^{-\alpha_2}\Big) - TC(x, k, V_s, L_e, s_1, s_2, P_\phi, C_b)\\
=\ & \Big((s_1 - P_{uv})F_a s_1^{-\alpha_1} + (s_2 - P_{uv})F_b s_2^{-\alpha_2}\Big) - \Bigg[\Bigg[h_B\left(\frac{V_s}{2} + r - D_b L_e\right.\\
+\ & \left.(1-\zeta)E(X-r)^+\right)\Bigg] + I + \frac{C_b(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s}\\
+\ & g\ln\frac{O_{c0}}{C_b} + T_D\frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s} + \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s}\Bigg(\pi_x\\
+\ & \pi_0\Big(1-\beta\Big)\Bigg)E(X-r)^+ + \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s}R(L_e)\Bigg]\\
+\ & \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{xV_s}(A_S + C_{wd} + C_{ph} + C_{vw} + C_{lw})\\
+\ & \frac{V_s}{2}\left[1 + (x-2)\left(1 - \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{(1-\beta)P_r}\right)\right]H_c + b\ln\frac{P_{\phi 0}}{P_\phi}\\
+\ & \frac{xS_c(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})V_s P_\theta}{2} + \frac{F_T(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s} + V_T(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})\\
+\ & \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})F_{ccv}}{V_s} + V_{ccv}(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})\Bigg]
\end{aligned} \tag{4}$$

4.3. Normal Distributed Model

Assuming that the lead-time demand is normally distributed, the retailer's expected shortage quantity can be calculated as

$$E(X-r)^+ = \int_r^\infty (m-r)f(m)dm$$

where $f(m) = \frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{(m-\mu)^2}{2\sigma^2}}$, μ and σ being the mean and standard deviation, respectively.

Therefore, for demand with mean $D_b L_e$ and standard deviation $\sigma\sqrt{L}$ during the lead-time, the expected shortage quantity is given by

$$E(X-r)^+ = \int_r^\infty (m-r)\frac{1}{\sqrt{2\pi}\sigma\sqrt{L_e}}e^{-\frac{1}{2}\left(\frac{m-D_bL_e}{\sigma\sqrt{L_e}}\right)^2}dm,$$

One can have $k = \frac{r-D_bL_e}{\sigma\sqrt{L_e}}$, and further assuming $z = \frac{m-D_bL_e}{\sigma\sqrt{L}}$, the above equation takes the following form:

$$E(X-r)^+ = \sigma\sqrt{L_e}\int_k^\infty (z-k)\theta(z)dz,$$

where $\theta(z)$ is the standard normal probability density function.

Assuming $\Psi(k) = \int_k^\infty (z-k)\theta(z)dz$, one can have

$$E(X-r)^+ = \sigma\sqrt{L_e}\Psi(k) \tag{5}$$

Then, the above equation can be rewritten as

$$\begin{aligned}
& \text{Total profit}(x,k,V_s,L_e,s_1,s_2,P_\phi,C_b) \\
= & \left((s_1-P_{uv})F_a s_1^{-\alpha_1} + (s_2-P_{uv})F_b s_2^{-\alpha_2}\right) - TC(x,k,V_s,L_e,s_1,s_2,P_\phi,C_b) \\
= & \left((s_1-P_{uv})F_a s_1^{-\alpha_1} + (s_2-P_{uv})F_b s_2^{-\alpha_2}\right) - \left[\left[h_B\left(\frac{V_s}{2} + k\sigma\sqrt{L_e}\right.\right.\right. \\
+ & \left.\left.(1-\zeta)\sigma\sqrt{L_e}\alpha(k)\right)\right] + I + \frac{C_b(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s} \\
+ & g\ln\frac{O_{c_0}}{C_b} + T_D\frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s} + \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s}\Bigg(\pi_x \\
+ & \pi_0\left(1-\beta\right)\Bigg)\sigma\sqrt{L_e}\alpha(k) + \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s}R(L_e)\Bigg] \\
+ & \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{xV_s}(A_S + C_{wd} + C_{ph} + C_{vw} + C_{lw}) \\
+ & \frac{V_s}{2}\left[1 + (x-2)\left(1 - \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{(1-\beta)P_r}\right)\right]H_c + b\ln\frac{P_{\phi_0}}{P_\phi} \\
+ & \frac{xS_c(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})V_s P_\phi}{2} + \frac{F_T(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})}{V_s} + V_T(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2}) \\
+ & \frac{(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})F_{ccv}}{V_s} + V_{ccv}(F_a s_1^{-\alpha_1} + F_b s_2^{-\alpha_2})\Bigg]
\end{aligned} \tag{6}$$

4.4. Distribution-Free Approach

In many practical situations, the lead time distribution is unknown. As a result, one cannot calculate the expected shortages per replenishment cycle $E(X-r)^+$ and instead apply the min-max distribution-free approach, which has been made easier by Gallego and Moon [10]. In this manner, one can find the least favorable distribution function in F for each decision variable and then minimize the decision variables' total cost. Therefore, the problem is reduced to

$$Min_{F\in\Omega} MaxTP \;\text{ subject to }\; 0 < P_\theta \le P_{\theta_0}, \;\; 0 < O_c \le O_{c_0}$$

the concept of Gallego and Moon's [10] approach is applied here with the reorder point as $r = D_b L_e + k\sigma\sqrt{L_e}$. One can obtain an upper bound of the expected shortages per replenishment cycle as

$$E(X-r)^+ \quad \geq \quad \frac{1}{2}\sigma\sqrt{L_e}\left(\sqrt{1+k^2}-k\right) \qquad \text{for any} \quad F \in \Omega$$

Moreover, this upper bound is tight by Gallego and Moon [10]. The value of the backorder rate ζ is expressed by using the above inequality as

$$\zeta \quad \geq \quad \frac{2\zeta}{1+\zeta}$$

Therefore, the problem reduces to as follows in which represents the worst distribution.

$$\begin{aligned}
& \text{Total profit}(x,k,V_s,L_e,s_1,s_2,P_\phi,C_b) \\
= & \left((s_1-P_{uv})F_a s_1^{-\alpha_1} + (s_2-P_{uv})F_b s_2^{-\alpha_2}\right) - TC(V_s,L,s_1,s_2,P_\phi,C_b) \\
= & \left((s_1-P_{uv})F_a s_1^{-\alpha_1} + (s_2-P_{uv})F_b s_2^{-\alpha_2}\right) - \left[\left[h_B\left(\frac{V_s}{2}+k\sigma\sqrt{L_e}\right)\right]\right. \\
+ & I + \frac{C_b(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2})}{V_s} + g\ln\frac{O_{c_0}}{C_b} + T_D\frac{(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2})}{V_s} \\
+ & \frac{(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2})\pi_x}{2V_s}\sigma\sqrt{L_e}(\sqrt{1+k^2}-k) + \frac{(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2})}{V_s}R(L_e) \\
+ & \left.\frac{1}{2}\left(h_B + \frac{(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2})\pi_0}{V_s}\right)\left(\frac{1-\zeta}{1+\zeta}\right)\sigma\sqrt{L_e}\left(\sqrt{1+k^2}-k\right)\right] \\
+ & \frac{(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2})}{xV_s}(A_S+C_{wd}+C_{ph}+C_{vw}+C_{lw}) \\
+ & \frac{V_s}{2}\left[1+(x-2)\left(1-\frac{(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2})}{(1-\beta)P_r}\right)\right]H_c + b\ln\frac{P_{\phi_0}}{P_\phi} \\
+ & \frac{xS_c(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2})V_s P_\phi}{2} + \frac{F_T(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2})}{V_s} + V_T(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2}) \\
+ & \left.\frac{(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2})F_{ccv}}{V_s} + V_{ccv}(F_a s_1^{-\alpha_1}+F_b s_2^{-\alpha_2})\right]
\end{aligned} \tag{7}$$

In this model, the defective rate $\beta = E[f(x)]$, where $f(x)$ follows (1) Uniform distribution, (2) Triangular distribution, and (3) Double triangular distribution.

The total profit function is nonlinear. Due to the high complexity of these highly nonlinear equations, it is too challenging to find analytic solutions. Thus, optimum profit and the decision variables' optimal values are obtained numerically, which were provided in the next section.

5. Numerical Experiment

5.1. Example for Normal Distribution

For numerical experiments, data of the parameters are taken from Sarkar et al. [8] and Dey et al. [74]: F_a = 34,000, F_b = 10,500, $\alpha_1 = 2.2$, $\alpha_2 = 1.5$, P_{ub} = \$0.2/unit, h_B = \$1.2/unit, $\mu = 2$, O_{c_0} = \$90, $g = 25$, I = \$10/unit, T_D = \$2/unit, α = \$5/unit, A_S = \$2/unit,C_{wd} = \$0.5/unit, C_{ph} = \$2/unit, C_{vw} = \$10/unit, C_{lw} = \$2/unit, P_r = 200 unit, P_{uv} = \$2.6/unit, H_c = \$1.7/unit, $b = 40$, $P_{\theta_0} = 0.001$, F_{ccv} = \$2/unit, V_{ccv} = \$1.2/unit, F_T = \$1.4/unit, V_T = \$2.2/unit. The value of scaling parameters for Uniform distribution are given by $(0.03, 0.07)$, Triangular distribution are given by $(0.04, 0.07, 0.05)$, and Beta distribution are given by $(0.03, 0.07)$. Then, profit was maximized for the optimum value of the decision variables, shown in Table 2. The profit is maximum when defective items follows a Triangular distribution. From Table 2, it is clear that the profit is \$427.10. The optimum online and offline selling price were \$24.46 per unit and \$40.03 per unit, respectively, where the optimum shifted quantity per shipment is 36.07 units with optimum number of shipment 3. Ordering cost reduces to \$37.87 per order, from the initial ordering cost \$90 per order. The convexity of the profit function graphically shown in the Figures 2 and 3 . Figure 2 represents the total profit function's concavity concerning the online and offline selling prices when the defective rate follows Triangular distribution for normally distributed lead time. By Figure 2, it is cleared that the total profit is globally optimum when the optimum value of the online selling price is \$24.46 per unit and the offline selling price is \$40.03, whereas total optimum profit is \$427.10. Similarly, Figure 3 represents the total profit's concavity concerning the online selling price and quantity of each shipment. From Figure 3, one can easily find out that the total system profit is globally optimum when the online selling price of the product is \$24.46 per unit and optimum value of the quantity in each shipment is \$36 per unit.

Table 2. Optimum values.

	Uniform Distribution	Triangular Distribution	Double Triangular
x^*	3	3	3
V_s^* (units)	36.22	36.07	36.56
s_1^* (\$)	24.36	24.46	24.14
s_2^* (\$)	39.87	40.03	39.50
P_ϕ^*	0.00041	0.00041	0.00040
L_e^* (weeks)	4	4	4
r^*	12.47	11.25	11.23
C_b^*(\$)	37.76	37.87	37.49
TP (\$)	426.55	427.10	425.25

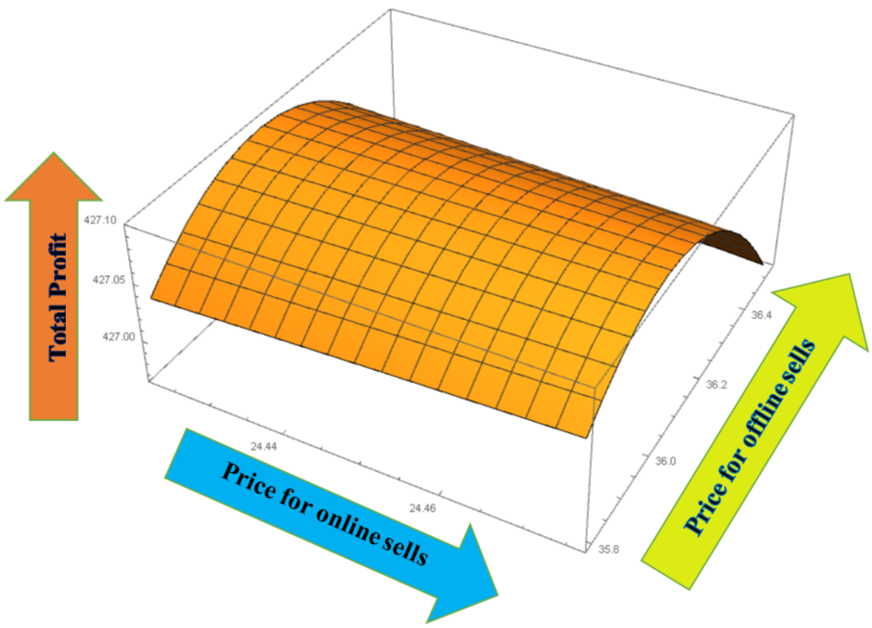

Figure 2. Concavity of the profit function with respect to two selling prices.

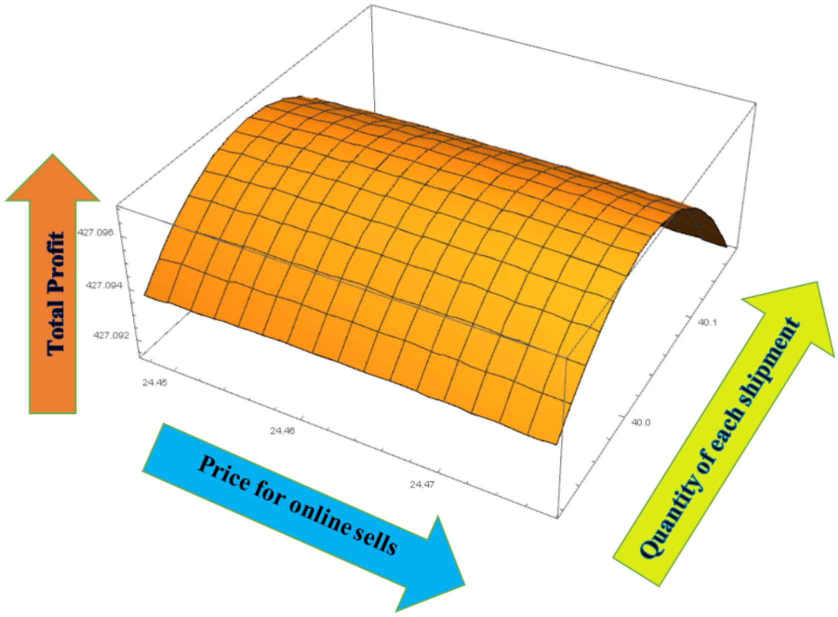

Figure 3. Concavity of the profit function with respect to online selling price and quantity.

5.2. Example for Distribution-Free Approach

To provide the optimal result and the optimum value of the decision variables for the distribution-free case, one can use the data to find the optimal value for the normally distributed case. Then, the optimum results for the distribution-free case are provided in Table 3. It is quite natural that profit was less in the distribution-free model compared to the normal distribution model. From Table 3, it is clear that an optimal result is obtained when defective rate follows a Triangular distribution, and in this case the total system profit is \$359.79 per cycle. Simultaneously, the online and offline optimum selling prices are \$13.71 per unit and \$17.45 per unit, respectively. Moreover, optimum shipment size is 21 units, and shipment number is 3. The variable ordering cost is \$16.23 per order, where the initial ordering cost is \$90 per order and safety stock is 11.25 unit. Figures 4 and 5 represent the total profit function's concavity for the distribution-free approach when the defective rate follows a triangular distribution. Like normally distributed lead time, Figure 4 represents the concavity of the total profit function's concavity concerning two selling prices. It is clear from Figure 4 that the total system profit is globally optimum when online selling price is \$13.71 per unit and offline selling price is \$17.45 per unit, and in this case the total system profit is \$359.79. Figure 5 represents the concavity of the total system profit concerning the online selling price and quantity of quantity in each shipment.

Table 3. Optimum values for distribution-free case.

	Uniform Distribution	Triangular Distribution	Double Triangular
x^*	3	3	3
V_s^* (units)	21.19	21.11	7.13
s_1^* (\$)	13.67	13.71	35.25
s_2^* (\$)	17.40	17.45	52.47
P_ϕ^*	0.0006	0.0006	0.0037
L_e^* (weeks)	4	3	4
r^*	5.24	11.25	4.12
C_b^* (\$)	16.19	16.23	13.41
TP (\$)	336.42	359.79	305.61

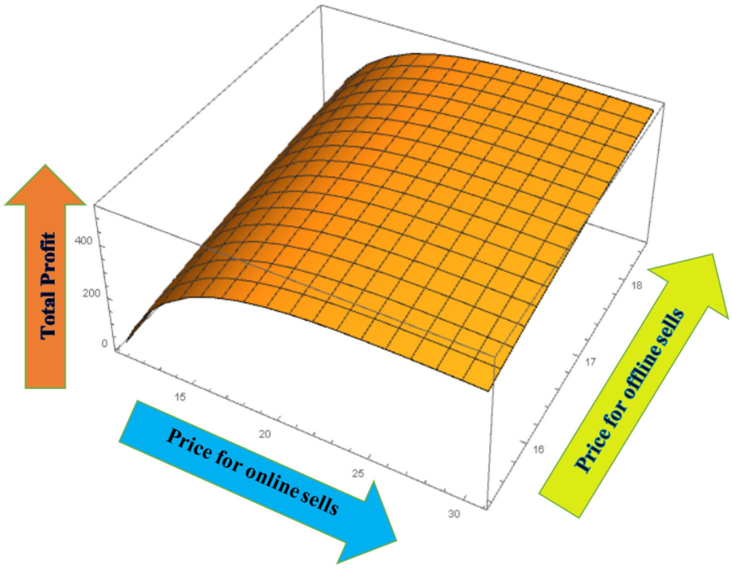

Figure 4. Concavity of the profit function with respect to two selling prices.

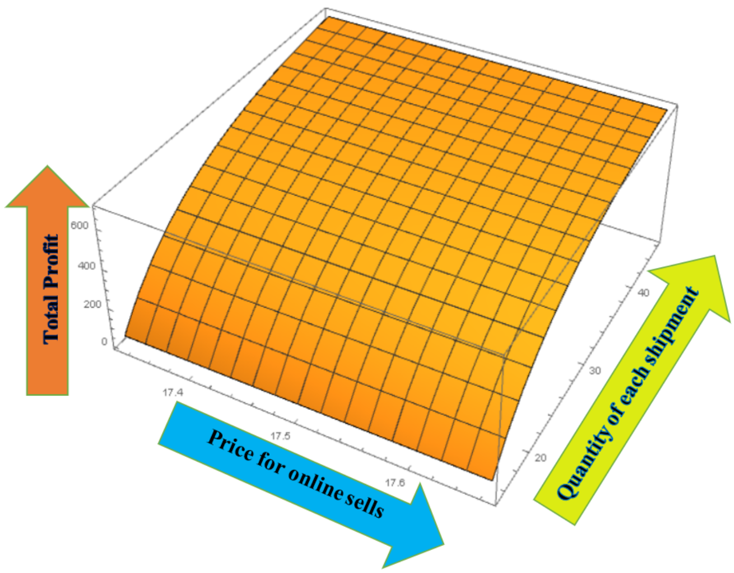

Figure 5. Concavity of the profit function with respect to online selling price and quantity.

5.3. Discussion

Some comparison with the existing literature based on numerical results is discussed in this section.

A model was formulated in this similar direction by Sana and Chaudhuri [48], where demand depends on product selling price. However, they developed their model without considering sustainability or O2O retailing strategy. Moreover, they ignored the condition of defectiveness and lead time. The total system profit of Sana and Chaudhuri's [48] model was $91.54, when the optimal selling price was $49.57 and optimum ordered quantity was 14 units. Recently, Sana [33] developed a model under the consideration of a socially responsible firm, and the system profit for non-green products was $168.05, whereas the product selling price was $63.71 per unit. However, in this current study the optimal system profit is $427.10 (Normal distributed lead time) and $359.79 (Distribution free approaches). From the optimum result in Tables 2 and 3, it is clear that the use of the concept of sustainability and O2O retailing strategy in any supply chain system is much more beneficial. The comparison with existing literature is provided in Table 4 and the graphical representation in Figure 6.

Table 4. Comparison with existing literature.

Sana and Chaudhuri's [48]	Sana [33]	This Study
$91.54	$168.05	$427.10

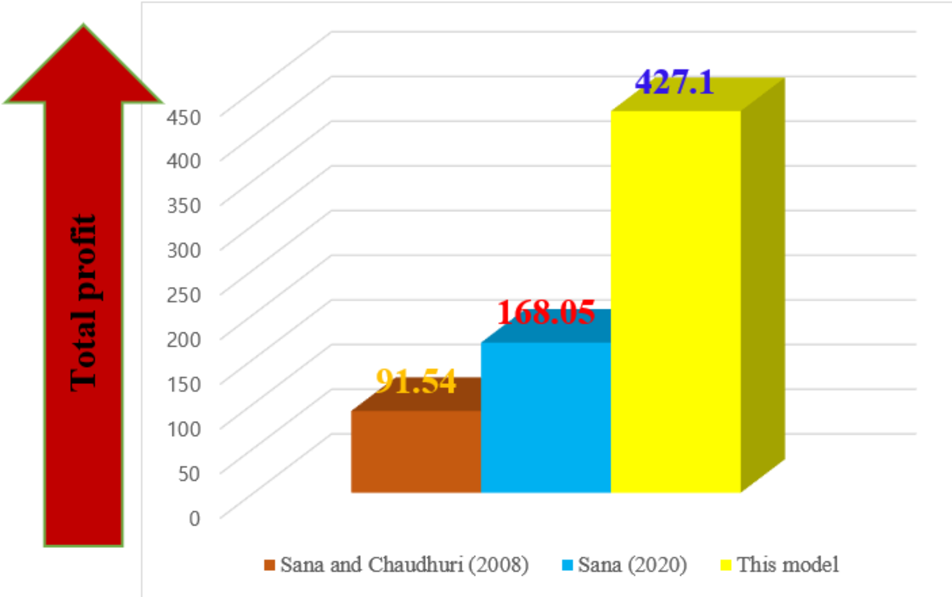

Figure 6. Comparison with existing literature.

6. Sensitivity Analysis

The effect of critical parameters with the change in (−50%, −25%, +25%, +50%) the total profit is calculated in this section. One can conclude the following from the sensitivity results in Table 5.

(i) The price elasticity parameter for online sales is highly sensitive. A small change in the online sale elasticity parameter significantly impacts the total system profit and is proportional to system profit.
(ii) Production rate had a significant impact on any sustainable supply chain. In this sustainable O2O supply chain model, production rate plays a vital role. Production rate and system profit are inversely proportional, i.e., reducing production increases the system's profit.
(iii) Holding cost for the retailer, the retailer's initial ordering cost, and the manufacturer's defective rate are quite sensitive. All those components are inversely proportional to the system profit. Thus, the reduction of those costs always beneficial for any industry.
(iv) The scaling parameter, related to process quality, is slightly sensitive. Reduction in this parameter is beneficial for the industry.
(v) Production cost for the manufacturer is slightly sensitive as usual. Reduction in production always costs beneficial for any production industry.
(vi) Technology development cost and all other cost parameters related to supply chain are very little sense. Change from −50% to +50% in those costs, the total system profit changes below 0.5%.

Table 5. Sensitivity analysis table.

Parameters	Changes (in%)	*TP* (in%)	Parameters	Changes (in%)	*TP* (in%)
F_a	−50	−39.02	P_{uv}	−50	+1.67
	−25	−19.51		−25	+0.84
	+25	+19.51		+25	−0.84
	+50	+39.02		+50	−1.67
h_B	−50	+3.02	O_{C_0}	-50	+4.06
	−25	+1.51		−25	+1.68
	+25	−1.51		+25	−1.31
	+50	−3.02		+50	−2.37
T_D	−50	+0.28	P_r	−50	+40.62
	−25	+0.14		−25	+13.54
	+25	−0.14		+25	−8.12
	+50	−0.28		+50	−13.54
S	−50	+4.68	b	−50	+4.13
	−25	+2.34		−25	+2.06
	+25	−2.34		+25	−2.06
	+50	−4.68		+50	−4.13
F_T	−50	+0.28	B_{ccb}	−50	+0.32
	−25	+0.14		−25	+0.16
	+25	−0.14		+25	−0.16
	+50	−0.28		+50	−0.32

The graphical representation of the sensitivity analysis was provided in Figure 7.

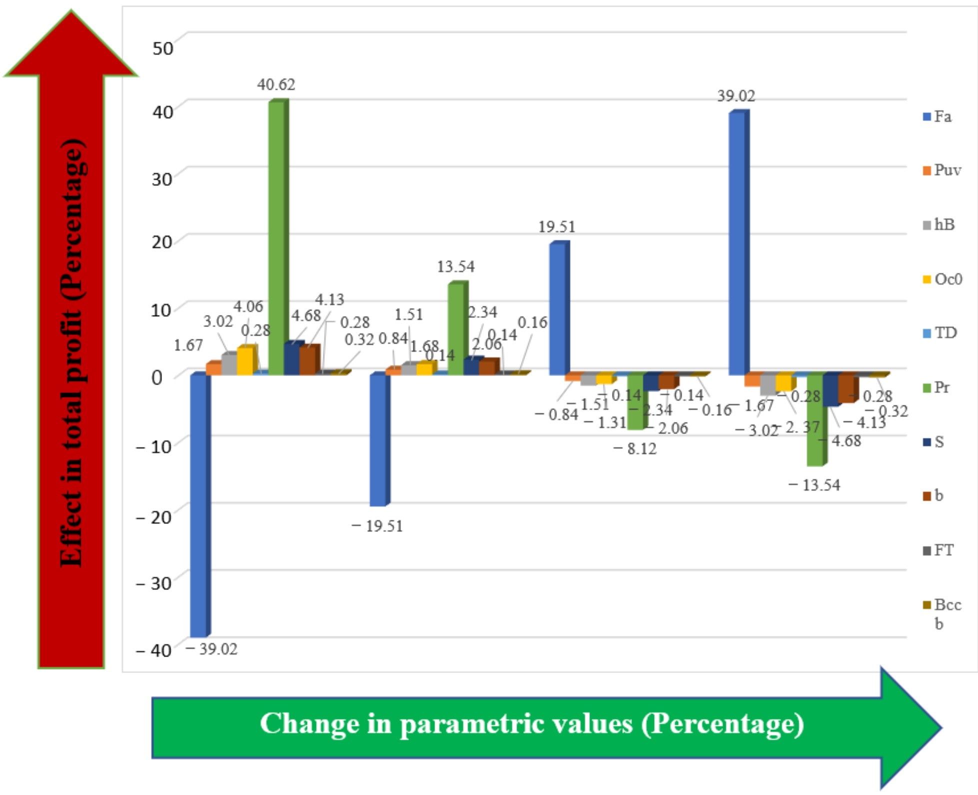

Figure 7. Effect of key parameters in total system profit.

7. Managerial Insights

(i) It is a sustainable supply chain management in the presence of a smart O2O environment, where the total joint profit of the supply chain is optimized along with the optimized values of selling prices for both online and offline sales, safety factor, shipment size, shipment numbers, ordering cost for retailer, lead period, and probability to transfer the production process from the "in-control" to the "out-of-control" state.

(ii) It is a sustainable supply chain due to the presence of the concept of online and offline sales. The retailer can purchase the product from the manufacturer online or offline. Due to the O2O strategy, holding costs for the manufacturer reduced, making the supply chain sustainable.

(iii) To control carbon emissions and keep the environment clean, variable and fixed carbon emission costs were employed along with fixed and variable transportation costs, making the supply chain more sustainable.

(iv) The supply chain system's ordering cost can be reduced by some continuous investment, which improves the total supply chain management service, making this model more sustainable. Some investment also improved the process quality. It also has a significant impact on the total joint expected profit of the O2O supply.

(v) Lead time and shortages always create a terrible image of any company, affecting its customers' service. This current model lead period and safety factor were also optimized along with different decision variables that provided better service and made the model more sustainable.

8. Conclusions

A sustainable O2O supply chain model under the consideration of price-dependent demand was developed in this current study. Due to rapid growth in the e-commerce business strategy, in this model, two different costs and two different demands for the same product are considered, where one product sells through two different channels online and offline. Naturally, the product's price offline is slightly higher than online channels due to increased costs in advertisements, retail shop to display the product, and labor charges. Though the product's price in the offline channel is slightly higher, some customers prefer to visit the store to purchase particular products due to service quality. The effect of the backorder and lead time is also considered in this research. Some exceptional cases were described by considering normally distributed lead time demand and distribution-free approaches for lead time. The numerical result shows that the supply chain's profit was optimized for the normal distributed lead time. The total system profit was optimized along with the optimized value of the selling price of two different channels, per batch shipment size, safety stock, lead time, ordering cost, and the probability for shifting in-control to out-of-control state.

Integer optimization for batch size and lead time is a limitation of this model. Another limitation of the current study is the fixed production rate. Moreover, the fixed setup cost for the manufacturer is another limitation of this model. In the online channel, the product was ordered online but delivered to the customers offline. Like robots or drones, some electronic devices can also be done this transportation, representing an interesting future research direction. This model can also be extended by considering some offers or gifts paid by the offline seller to attract customers and increase the system profit. One can explore this model by considering the product's quality or considering variable production rate Bhuniya et al. [60].

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