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An optimal two-level supply chain model for Small- and Medium-sized Enterprises (SMEs) considering rework for new products and price-dependent demands

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Abstract. With the advent of new technologies, several factors such as globalization of markets, customers' different needs, and increasingly fierce economic competition have encouraged Small- and Medium-sized Enterprises (SMEs) to improve their engagement with suppliers and to involve themselves with cost management practices in order to survive. SMEs clearly need to focus on the interests of the entire supply chain by enacting win-win policies. In this regard, the present study investigated a two-level inventory model featuring a manufacturer and a buyer in the competitive market with the policy of producing new products. The proposed model took into account imperfect and low-quality products and their capacities for rework. In other words, due to the competitive nature of the market, any increase in prices would lead to a decrease in demand. The mathematical model was proposed in two scenarios: one with the possibility of shortage and one without it. The objective function of the mathematical model revolves around maximizing the total profit of the supply chain considering both independent and joint optimization by the supply chain members. A new algorithm was then proposed to solve the mathematical model whose applicability was evaluated by using a numerical example in the analysis software MATLAB as the input. The results were then analyzed and discussed based on a sensitivity analysis approach.

1. Introduction

Cutting global competition forces of manufacturing organizations that help develop their internal manners and improve collaborative networks with their suppliers and clients would bring about mutual advantageous outcomes. Such organizations are also aware of the fact that the sole optimization of the present manufacturing foundation would fail to manage and conserve a competitive advantage. As a result, the need for promoting human capital to convert the shop floor into an adaptable system capable of promptly reacting to customers' demands is felt more than ever. Flourishing manufacturing corporations have succeeded in establishing versatile principles to integrate supply chain collaborators based on their manufacturing approaches. For these reasons, organizations place a high value on enhancing long-term connections with internal and external supply chain partners [1]. In

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this regard, researchers also believe that the formulation and implementation of supply chain policies need substantial administrative practices and utmost administrative support [2]. Directors of such thriving entrepreneurial-oriented firms who exhibit professional administrative behavior and put great emphasis on maximizing the integration with suppliers and clients succeeded in enhancing business responsiveness [3,4]. Of note, according to the findings of the referenced study, both strategic management and supply chain integration are critical components for companies to speed up the human operations [5].

In real world, each business industry seeks more profit with lower production costs. Client satisfaction is another significant issue to be considered by any business and for this reason, the quality of commodity should be improved. Increasing demands for any commodity will bring more profit for the corporations; however, it is more likely to witness more shortage and defective items due to high demand. As a result, shortage and faulty items should be taken into consideration in the case of achieving consumer satisfaction, to which the protection of stocks may provide an answer. Integration of the supply chain of Small- and Medium-sized Enterprises (SMEs) such as rework process can enhance the quality of a product and it would be beneficial to any industry. Of note, such procedures can also enhance the total profit [6].

Some commodities produced in the company may turn out to be faulty for many reasons such as the failure of equipment, operators' error, and low quality of primary substances. Therefore, deciding on the faulty items is one of the significant concerns of any corporations and production units. There are two kinds of defective items: scrap and repairable. While scraped items can be sent to the manufacturer through a single shipment, repairable items are sold after rework at a lower price. Repairable items need reworking which are usually kept in a warehouse until the rework process is called for. In this respect, a general method is required considering the cost of an intended system to do the rework process at a minimum cost. This method should cover all types of states that are likely to happen in the supply chain of SMEs. It should also provide proper schedules to managers based on the best result. This study helps administrators employ the best strategy for the rework process based on the supply chain conditions of SMEs. In addition, it attempts to provide programmers and managers with guidelines to choose the optimal production quantity with the objective of maximizing total profit. The production costs for the rework and normal production process, holding costs for imperfect and perfect items, and manufacturing rework costs were taken into consideration in this study.

The current study emphasizes the necessity of the reworking of defective items. In this supply chain inventory system, the buyer inspects items after production and shipment. Items of good quality are immediately stocked and sold to customers. On the contrary, defective items are scheduled for rework. It is assumed that the buyer and supplier in this study make a decision integrally and provide some types of equipment and facilities to rework imperfect items in the buyer place. Therefore, the buyer will pay a lower price for the imperfect goods which were reworked by itself. After inception, the vendor sends all defective commodities to the manufacturer as shipment.

This study developed an optimal inventory model in a two-level supply chain for SMEs with reworking for new products and price-dependent demand. The first novelty of this study lies in its classification of defective items into two groups of scraped or reworkable items so that the defective items can be reworked in the buyer location and an inception carried out by the distributor. Reworking is defined as the conversion of production rejects, failed, or non-conforming objects into reusable commodities of equal or lower quality during/after review. Rework is assumed to be significant and useful mainly if materials are restricted in availability and are pricey. Furthermore, rework significantly contributes to ensuring a green environment. Sometimes, the produced faulty items can be improved and reworked. In the last decade, rework investment in optimal replenishment decisions has extensively grown. Another novelty of this study lies in its utilization of two strategies based on the real-world supply chain for SMEs. In the first strategy, manufacturers and distributors make decisions independently and in the second one, the manufacturer and distributor share many of their useful information and facilities to make decisions integrally. The third novelty of this research is its consideration of new products and price-dependent demands for supply chain in SMEs. Finally, this study attempts to determine an optimal supply chain for SMEs considering reworking for new products and price-dependent demand to maximize the total inventory profit.

The next section clarifies the objective of this investigation in detail and discusses the research gaps this study aims to fill. The rest of this paper is organized as follows. Section 2 presents a thorough literature review for the models with integration considering a two-level supply chain, price-dependent demand, imperfect quality items, new product, rework, rework in the supply chain, SMEs, and two-level supply chain in SMEs. Section 3 discusses the research gap as well as the objectives of this study. Section 4 develops hypotheses and symbols of this model. Section 5 discusses the material and methods. Section 6 provides some information on the numerical studies and sensitivity. Finally, Section 7 concludes the study.

2. Literature review

2.1. Integration in two-level supply chain

Supply chain integration as a means of alignment and coordination of production within a supply chain has become a well-recognized industrial practice in recent years. The combinations of different levels of the supply chain from raw substance generation to sub-assembly/part production, commodity assembly, delivery, and selling together with the corresponding warehousing and shipping have received a great deal of manufacturing and academic attention. To meet customers' requirements, commodity quality reliability and distribution punctuality should be ensured. Meanwhile, the cost of the total supply chain should be optimized [7].

In [8], a production-inventory integration model was introduced for the supplier, producer, and retailer in a supply chain with imperfect and low-quality products. In [9], integration and generalization of the supply chain model was considered under a trade policy. The trade credit can be expressed at two levels where the supplier sells products to the retailer with a permissible delay of M and the retailer sells products to the customer with a permissible delay of n. This model was proposed to find the optimal retail price, Economic Order Quantity (EOQ), and number of shipments from the supplier to the single-time retailer and integrate an inventory system based on both the payment and price policies related to the demand rate.

In [10], the focus was the coordination of the supplier network in an integrated inventory model presented for a heterogeneous buyer and supplier as well as a single product considering the overall cost reduction of the system. Rezaei and Salimi [11] modified the size of traditional economical orders considering perfect products. Their model and analysis can be elaborated under two conditions: in the first condition, there is no relationship between the buyer's purchase and sale prices and customer's demands, while in the second one, there is a relationship between the buyer's purchase and sale prices and customer's demands. In [12], a new model was proposed by revising the lot size model that could affect the inventory level and decisions between the buyer and seller as well as the performance of the supply chain. The proposed model in this paper (JELS) could determine the system cost, order quantities, optimum size of the products, and optimal number of shipments. In [13], a vendor-buyer integrated inventory model was presented including quality enhancement investment in a supply chain. In [14], an integrated just-in-time inventory model was established where the demand rate linearly diminished with time, the generation rate was limited, and transfer time was constant and deterministic. In [15], the integration of inventory and sales decision model was presented for a two-level supply chain, taking into account imperfect quality products and backorders. In [16], a two-level supply chain comprised of a wholesaler and a retailer was investigated where the retailer works as a vendor and sells commodities to final clients. This chain only creates single deteriorating goods at a continuously deteriorating rate. The demand in this chain is deterministic and the lead time for replenishment and replacement of the vendor's product is assumed zero. This study aims to maximize the profit of the total chain by defining the optimal values of the vendor's selling price (p) and order cycle length (T). In [17], an optimal integrated vendor-buyer inventory model was proposed with imperfect items. Most research studies on faulty items considered an inspection process carried out by the buyer. They also assumed that the vendor would convey the inspection process and dispose of faulty items in multiple shipments.

In [18], a buyer and multiple suppliers were assumed where the production process in the supplier domain was affected by training which, in turn, reduced the production costs and increased the supplier's production capacity. Of note, the suppliers could reduce their sales price, thus reducing the purchaser's acquisition costs. Kim and Glock [19] examined a multi-level supply chain where equal and unequal batches were transmitted to different levels. In case of delayed delivery time in their supply chain, a fine was imposed on the system. Contrary to previous studies, this research did not limit the number of steps and only analyzed a general case. In this study, an analytical model of the supply chain was first developed and then, the model specifications were expressed. Next, a simulation study of the model analysis was conducted. In [20], a model with a single buyer, a single product, and multiple vendors was investigated. The seller was selected with the main focus of reducing the shipping and handling costs. They found that fixed shipments would result in a reduction in the total cost. In [21], a supply chain model was provided with a vendor and several retailers that used reversible transportation such as containers and boxes. In [22], a supply chain construction consisting of a single producer with a multi-buyer was introduced where the producer requested a specific number of raw substances from outdoor suppliers, processed the documents, and delivered finished commodities in unequal purchases to each client. Taleizadeh et al. [23] established a model to overcome the challenges of joint measurement of the selling price, lot size of replenishment, and determination of the number of purchases for an Economic Production Quantity (EPQ) model with the reworking of faulty items using multi-shipment method. In [24], a new multi-objective model was proposed for dynamics and it was incorporated into the network plans of a sustainable closed-loop supply chain, considering the optimized financial, environmental, and social anxieties, concurrently. In order to obtain a dynamic perspective, multiple police periods were considered throughout the outlining horizon. Moreover, different short-term decisions were integrated with long-term ones related to the network layout problem. Among the main short-term decisions are discovering the selling price of commodities in transmitting logistics and purchasing the price of used stocks from client zones in reverse logistics.

2.2. Price-dependent demand

Since market demand is intensively price sensitive, pricing is of high priority for any corporation. In this regard, it is suggested that businesses employ the pricing strategy as one of their decision policies to optimize their costs, absorb clients, and gain greater profit. When the demand in the supply chain is price sensitive and varying, it is possible to affect the costs, especially their holding costs, on the part of the producer and buyers. In this situation, the unit procurement cost for the buyers changes as well if the producer fixes its sales price based on its cost incurred in producing the items [25].

Glock and Jaber [26] suggested a model assuming that a product was used in a market where the demand was sensitive to both price and quality. In [17], a two-layer game method comprised of a supplier and two retailers was suggested for pricing, ordering, and allocation policies in a supply chain. In [27], a two-level supply chain model was considered with a producer and a retailer where the manufacturer would sell the final product in both direct and retail channels. They also assumed that the customer demand was sensitive to the selling price of each member, delivery time for direct channel, and retail service for the business. In their model, the demand for the direct business had a negative impact on higher selling price, lengthy delivery time for the direct market, and more retail servicing from the retail market.

2.3. Imperfect quality items

Producing defective items is an unavoidable problem facing companies. However, imperfect products have still a significant value to the company. In [28], a summarized review of the studies on the EOQ model was done with regard to imperfect quality products. It was assumed that all products in widely used classical EOQ models were perfect, which differed from the actual production systems where imperfect products are commonly observed in the production process [29]. In [30], an integrated lot-sizing and production model was extended for a faulty and unpredictable production method. In [31], an EPQ model was proposed for imperfect objects under screening and shortage constraints. Later, in [32], an EPQ model was proposed for an imperfect production process allowing for back-ordered shortages.

2.4. New product

The nature of competitive businesses continuously encourages the manufacturers to develop new products and meet the frequently diversified client demands. One of the advantages of globalization is the expanding opportunities for products the market can afford. On the demand side, consumers enjoy the developing options they have when choosing commodities to satisfy their needs. On the supply side, this globalization trend pushes manufacturers to enhance new products that can fulfill the upcoming demands for customized commodities at competitive prices. To meet the client demands and sustain their competitiveness, producers are required to keep improving new products.

McCann and Bahl [33] analyzed the relationship between the competitiveness of informal (unregistered) companies as well as the New Product Development (NPD) and official (registered) companies. They analyzed 9,000 official companies in Eastern Europe and Central Asia and concluded that NDP was an effective factor used for differentiating formal companies from informal ones. The current research took into account the direct effect of NDP which was moderated based on the characteristics of competition and organizational institutions. Given the significance of product design and its profound impact on the performance of the total supply chain, an increasing number of people are now aware of the necessity of integrating the commodity improvement and supply chain decisions, thus trying to bring the integration of suppliers one step closer to the design phase [34]. Joint product and supply chain configuration/design is a cross-domain, cross-space, cross-level, and cross-echelon difficulty that can optimize many decisions all at once [35]. Yao and Askin [7] explored the interests of the decision-makers whose dilemma may demand incorporation of other components such as consumer favorite, demand prediction, product and production process design, supplier preference, stock locating, logistic planning, pricing, production planning, etc. When considering such commodity variants, this joint optimization obstacle can become significantly involved. The supply chain and goods domains are at the intermediate and lower levels. Clients' needs will affect the product design and supplier choice. Once the product and supply chain designs are fixed, creation will be arranged and regulated into the supply chain and the corresponding substances will flow from suppliers to the end clients. Ilhami and Masruroh [36] put its main focus on the mathematical modeling of commodity, process, and supply chain design, i.e., 3D Concurrent Engineering (3D-CE), a classified extant research based on the dimensions considered.

2.5. Rework

Rework process is likewise a crucial backward coordination issue where utilized items are modified to reduce the total inventory cost as well as waste and environmental pollutions. Researchers in [26] examined the production line for imperfect quality products at each level. The imperfect quality products enter a reworking process that has been done incompletely, and the products that are still imperfect for the second time are considered scrap; hence, no rework can be done on them. This model was optimized for a multi-level production-inventory system and the system performance was optimized based on production time, production process performance, and shipment frequency. Chen [37] studied the integration model of production problems. They performed preventive maintenance and inventory screening of the production process and returned imperfect quality products to the inventory after rework and repairs. Preventive maintenance done at the control phase has led to a reduction in the number of imperfect quality products. Of note, performing a faulty preventive maintenance in the system would make the production process out of control with a specific probability. Under such conditions, the system would produce imperfect quality products with a specific probability. Rework is typically considered in paper, semiconductor, chemical, food, textile, pharmaceutical, glass, metal processing, and plastic industries [38–40]. The rework process has attracted significant attention due to a decline in natural source consumption and cost of raw materials. Rework processes play a significant role in eradicating waste and efficiently controlling the manufacturing cost in a production system. Therefore, determining the optimal lot size in a system that allows for reworking is a valuable objective to maximize the total inventory profit. Reworking process decreases energy usage and preserves more natural resources for future generations. In this regard, corporations suggest sustainable improvement. In [41], an integrated inventory product model with a single-stage production process and reworking of faulty objects was elaborated. Moreover, the research in [42] suggested rework with multi-production fixings. In [43], an economic generation quantity model was investigated for three kinds of faulty goods considering the rework of EPQ model problem for a single object under the hypotheses of the defective commodity. In this respect, the referenced Khanna et al. [44] performed complete rework. In [27,45], some models were developed under multiple conditions based on the planned method, one of which examined an imperfect generation system capable of producing remarkable low-quality commodities in lot-sizing restrictions. In [17], stochastic lot-sizing difficulty for a single faulty stage generation system with paramount rework, faulty preventive preservation, and minimal repair was optimized. The research in [46] studied replenishment and pricing strategies for a defective process with paramount rework and different deliveries. Chung [47] solved a multi-delivery lot-sizing dilemma with a partial rework. a lot-sizing model for a production system with back-ordering and outsourcing rework was proposed in [6]. It was concluded that repairable products could not be reworked in the firm; hence, they should be sent to a repair store. Taleizadeh et al. [6] and Tai et al. [48] examined defective models with back-ordered demand and reworked process, respectively.

2.6. Rework in supply chain

Khanna et al. [44] investigated the combined results from defective quality goods, faulty inspection process, rework process, and sales return under two-level trade credit. A single-vendor single-buyer inventory model for an imperfect production system with different production setup and rework was suggested in [49].

2.7. Small- and Medium-sized Enterprises (SMEs)

SMEs play an essential role in economy in both prosperous developed and developing countries. The roles they take mainly cover the fields of employment [50] and wealth creation, which significantly contributed to enhancing the economy capacity. In addition, SMEs efficiently utilize their restricted sources and promote their entrepreneurial abilities. According to several investigations by multiple authors, SMEs contribute significantly to the social, economic, and political foundations of both developing and developed countries. An empirical study was carried out on inventory management of retailers in SMEs in India [51]. The aforementioned study also evaluated the benefits, barriers, and impacts of inventory management implementation of SMEs. A supplier inventory integration model was provided as a multi-stage dynamic program in [52]. In addition, an inventory optimization policy was implemented for the supplier under two conditions: in the first case, there is no access to external finance while in the second case, there is possible access to external finance through inverse or traditional factors. The importance of developing a strategy in a competitive supply chain should not be underestimated; otherwise, the implementation of Supply Chain Management (SCM) would be difficult for SMEs. Regardless of these challenges, there is clear evidence that confirms the need for further investigation of the problems faced by this section including expansion of automotive SMEs resulting from globalization and outsourced constructing activities by developed countries considering their own uncompetitive high prices, etc. Of note, a variety of perspectives have been reported on explaining SME organizations.

SCM has gained notable reputation around the globe due to its importance in relation to enhancing marketing performance. Although large enterprises are capable of performing SCM successfully, SMEs are facing different restrictions that prevent the practical implementation of SCM. Serval variables affect the SCM implementation in SMEs such as technological barriers, poor coordination with the supplier's absence of government support, sources, funds, access to markets and top management support, problems in information sharing, inventory administration, insufficient SCM knowledge, and uneducated workforce [53].

2.8. Two level supply chain in SMEs

The supply chain is vital to business activities for either small or medium enterprises. The importance of all parties ranging from suppliers, producers, distributors, retailers, and clients working together in commodity production to the distribution of goods to end customers clarifies the concept of SCM [54]. An attempt was made in [55] to find an appropriate supply chain for SMEs. This research investigated the implementation of SCM by SMEs and considered the factors affecting the success of these enterprises in making a balance between supply chain capacities and customer needs. In this regard, a case study conducted on five SMEs was taken into account. Tatoglu et al. [56] did a comparative analysis of the effect of SCM and Information Systems (IS) on operating functionality in small and medium enterprises in two markets in Turkey and Bulgari. They also evaluated the moderating and inhibiting effects of SCM-IS related to the inhibitors of the SCM, IS, and OPER SME approaches. SMEs tend to project their aim in a short term, merely acting to increase positions and focus on their survival. Moreover, they share less formalized constructions and classify methods while they are mostly owner-managed, thus resulting in management and administration management culture. SMEs make their sales by reaching out to clients immediately and promptly through e-business when starting new products and penetrating into markets that might be impassable due to distribution or infrastructural limitations [57]. The inventory model for the SMEs in a two-level supply chain of several buyers and several vendors for seasonal products was studied in [58]. It was assumed in this model that every buyer had a warehouse. In addition, the location of the buyers was determined and the capacities of the warehouses were limited; consequently, the buyers would order different products from the seller considering a discount policy. The optimal location of the potential vendors is determined based on minimizing the maintenance and ordering costs and order size. The effects of SCM on the performance of enterprises were analyzed in [53]. The SCM strategy was performed considering four independent variables namely sharing information, trust, long-term connection, and collaboration. This study also analyzed the impacts of SCM on corporate performance. The sampling technique comprises a random sampling technique with a total example of 75 people consisting of small- and medium-sized leather shoes in Medan. SCM restrictions in Tanzanian SMEs was measured in [54]. In doing so, they employed mixed methods. Definitive statistics were then used to maintain the connection between SCM impediments and effective SCM implementation in Tanzanian SMEs. Finally, frequency and percentages were computed to obtain the study results. According to Cscmp.org (2019), SCM comprises planning and administration of all activities ranging from sourcing, manufacturing, and delivering raw substances to consumers. It also involves coordination among the supply chain coworkers such as suppliers, clients, intermediaries, and third-party consumers. In addition, SCM integrates supply and demand across companies. In [59], it was discovered that SCM could significantly promote SMEs to achieve liquidity, increase working capital, and improve member connections. Regardless of the advantages of SCM utilization in institutions, several challenges were documented in some researches regarding the successful implementation of SCM. Recently, in [60], it was discovered that some problems might arise for firms in terms of information sharing in their supply chain while using blockchains. In [61], the mining area in Zimbabwe was studied and the absence of a fundamental and organizational change necessary to promote sustainable SCM implementation was confirmed. The referenced study [62] demonstrated that firms in Zimbabwe were susceptible to several SCM restrictions such as unfriendly market conditions, restrictive tax management, poor regulatory method, lack of stable government policy, financial limitations, poor procurement, inventory policies, and poor logistics and communication. It was illustrated in [63] that the limited number of purposes, short-term objectives, lack of collaboration, poor willingness among the supply chain partners, and economic, managerial, and technological limitations to be issued would prevent the application of SCM to SMEs in the Gulf countries. It was discovered in [64] that supplier matters considerably affected the SCM applications in UK aerospace SMEs. The research study [65] referred to financing limitations as the dominant problem affecting the supply chain in SMEs.

3. Research gaps and objectives

According to the literature review presented above, several topics were frequently studied in the past and indeed, the number of publications in several specific fields remains on the rise. It is, however, clear that less attention has been paid to the integration of several topics into a single frame in order to investigate the reworking of imperfect quality goods in a two-level supply chain from the SMEs' points of view. To be specific, the available literature does not cover the issue of optimal decision for an optimal inventory model in two-level SMEs based on which different shipping strategies were screened to make a decision about imperfect items considering shortage as well as new products. To contribute to filling the identified research gap and establishing a joint two-level supply chain for SMEs considering the imperfect quality items, rework, new products, shortages, and screening, this study revisited the model of [15]. As stated before, the model presented [15] is one of the perfect models considered in this research that has received favorable attention from different researchers. In addition, the significant extension of the basic model of [15] was incorporated into this study. Here, [11,29,66–68] were taken into account and then extended to examine an optimal decision-making in a two-level supply chain for large companies. This in turn would help us study an optimal inventory model better in the two-level supply chain for SMEs under different assumptions and evaluate the effect of the rework process on the optimal policies of this work. To be specific, the current study took into account some scenarios that might occur in the real-world supply chain of decision-making for SMEs including different types of imperfect items, inspection process, rework process, and decision-making in the two-level supply chain in SMEs. In addition, attempts were made to address the research question of how policy-makers in SMEs should modify their inventory decision metrics when intending to rework imperfect goods in the supply chain.

The current research also developed an optimal inventory model in a two-level supply chain for SMEs considering the reworking of new products and price-dependent demand. The other main contributions of this study are listed below:

1. An inventory model in a two-level supply chain is proposed for SMEs with a single manufacturer and a single buyer;
2. Imperfect quality items are proposed and reworked by the buyer in the supply chain of SMEs, being quite close to a real-world situation;
3. A model is established considering two different practical situations:
   (a) The manufacturer and the buyer make decisions independently about their issues such as inventory level, number of shipments, end price, order quantity, etc. to maximize their profit;
   (b) The manufacturer and the buyer make an integrated decision about their issues together to gain a joint maximum profit.
4. The price-dependent demand is highlighted as a common concern in a two-level supply chain of SMEs;
5. The difficulties of specific productions are pointed out in the real world. In this regard, the imperfect productions are classified into two categories of scrape and reworkable;
6. Finally, a sensitivity analysis is carried out to provide some management insights.

4. Hypotheses and symbols

In this section, the assumptions and symbols of the proposed model are discussed.

4.1. Symbols

The symbols used in the model were described in two parts of the parameters and decision variables:

$D(p)$	Demand function
α	Scaling factor of the demand function
β	Index of price elasticity of the demand function
S	Vendor's setup cost
A	Buyer's ordering cost
p	Sales price per unit for the buyer (Decision variable)
Q	Order quantity (Decision variable)
n	Number of shipments (Decision variable)
b	Backorders (Decision variable)
h_v	Vendor's inventory holding cost
h_b	Buyer's inventory holding cost
h_{rw}	Rework's inventory holding cost
π	Backordering cost
C	Unit production cost
C'	Unit rework cost
C_{Ib}	Buyer's screening cost
C_w	Vendor's warranty cost for defective units
F	Fixed transportation cost per shipment
V	Unit variable cost for handling or receiving an item
y	Rate of defectives being uniformly distributed
Y	Mean rate of defectives
var	Variance of defective rate
$W(Y)$	Unit purchase price
m	Maximum unit purchase price, which is charged for defect-free shipments

K	Reduction slope of the purchase price
x_b	Screening rate of the buyer
R	Production rate
ρ	Ratio of the market demand rate to the production rate $q = D/R$
T	Order cycle
ETP_B	Buyer's expected profit ($/year) under independent optimization
ETP_V	Vendor's expected profit ($/year) under independent optimization
ETP_I	Expected total system profit ($/year) under independent optimization
EJTP	Expected Joint Total Profit
$EJTP_{WS}$	Expected joint total profit ($/year) for the case without shortage

4.2. Assumptions

The assumptions of the proposed model are given below:

1. A two-level supply chain for SMEs with a vendor (manufacturer), a distributor, and a new product is suggested;
2. The demand rate is a decreasing function of the selling price, $D(p) = \alpha p^{-\beta}$, $\alpha > 0, \beta > 1$, and β is the price flexibility index [69,70];
3. In the case of the presence of imperfect quality products in the shipment that are not reworkable, the distributor faces shortage;
4. Each shipment delivered to the distributor includes a number of imperfect quality products; y is the rate of imperfect quality products comprised of two rates of y_1 (scrap products) and y_2 (reworkable imperfect products); in other words, $y = y_1 + y_2$;
5. The purchase price to be paid by the distributor to the manufacturer (W) is a decreasing function of the mean rate of the imperfect quality products: $w(Y) = m - KY$, $(m > K > 0)$, $Y = y_1 + y_2$ assuming that $W(Y)$ is greater than the production cost per unit;
6. Each shipment delivered to the distributor is inspected 100% by the distributor at a screening rate of x_b and perfect products are separated from the imperfect quality ones. In order to avoid shortage during the screening process, the screening rate is considered to be higher than the demand rate and the lowest number of perfect products per shipment is equal to that of demands at that time. Of note, this number is constant and definite;
7. The expected number of perfect products in each shipment is equal, which is equal $Q(1 - y)$ to the demand during the order period of T [71];
8. The screening process is considered error-free; hence, the first- and second-type errors should be removed;
9. At the end of screening, the distributor pays the purchase prices of both perfect and reworked products to the producer in one payment. If any imperfect products that cannot be reworked are found, these products are returned to the producer through one single shipment;
10. In order to avoid the complexity of the model, it is assumed that the shortages caused by the distributor are compensated in the next shipment before the beginning of the screening and all these products are considered perfect.

5. Material and methods

The proposed model is an inventory model for SMEs with imperfect quality products and backorders. The existence of imperfect quality products in the production system incurs costs and damages; therefore, manufacturers and distributors adopt different policies to eliminate these products from the supply chain, one of which is to rework imperfect quality products. In addition to reducing the scrap and raw material wastes, reworking imperfect quality products can partly compensate for the manufacturer and distributor's losses caused by these items. Imperfect quality products can, at the same time, result in shortage for the distributor, which also imposes additional costs of lost orders to the distributor. Therefore, reworking the returned products can play a significant role in reducing the costs within a supply chain and help increase the profit.

All members of the supply chain in the SMEs, including the manufacturer-distributor, adopt preventive policies to reduce the production rate of imperfect quality products mainly because of the costs these products impose on the production system. Among these policies, reworking is the most significant one. In real-world production systems, it is inevitable to manufacture imperfect quality products during the production process of producing new products. In this respect, to establish a real inventory model, the proposed model was expected to increase the total joint profit of all supply chain members and obtain the optimal amount of order, number of shipments, and selling price considering the imperfect quality products as well as the rework procedure required to recycle these items. The main objective of this study is to provide an integrated inventory model for a two-level supply chain in the SMEs with a manufacturer, a distributor, and a new product, assuming that the distributor is held responsible for screening and reworking procedures. A numerical test was then conducted to evaluate the efficiency of the model and profit rate improvement. Finally, a sensitivity analysis of the results was carried out to determine the economic efficiency of reworking imperfect quality products.

5.1. Inventory model with allowable shortages

In this section, the inventory model is presented considering two conditions of allowable shortages and without shortages for independent and joint optimizations of the supply chain of SMEs. In the unintegrated model of the supply chain of SMEs, there is no integration or coordination among the members; hence, they make their own pricing decisions independently. As a result, the profits of the manufacturer (seller) and distributor are maximized independently. In this case, the distributor makes sales and order decisions independently to maximize his or her own profits. Therefore, the expected profit for the distributor in the SMEs in the independent optimization model can be calculated as follows:

$$ETP_B(p,Q,b)=[p-w(Y)-CI_B-C'(Y_1+Y_2)]\alpha p^{-\beta} - \frac{(A+F)\alpha p^{-\beta}}{Q(1-Y_1)} - \frac{h_b Q(1-Y_1)}{2} - \frac{h_{rw}Q(Y_1+Y_2)}{2} - \frac{(\pi+h_b)b^2}{2Q(1-Y_1)} + bh_b. \quad (1)$$

The manufacturers in the independent optimization model make decisions in order to maximize their profits and reduce the costs of production, transportation, and operating and acts independently from other members of the supply chain members. In this case, the manufacturer's profit is expressed as follows:

$$ETP_V(n) = [w(Y) - C - C_w(Y_1+Y_2)]\alpha p^{-\beta} - \frac{S\alpha p^{-\beta}}{nQ(1-Y_1)} - \frac{h_v Q}{2}[(2-n)\rho + n - 1]. \quad (2)$$

When the members of the supply chain (distributor-manufacturer) make decisions independently, their purpose is to maximize their own profits separately. In this situation, the expected benefits of the entire supply chain system for SMEs are calculated through the following equation:

$$ETP_I = \mathrm{ETP}_B(p,Q,b) + ETP_V(n). \quad (3)$$

Here, the inventory models with and without shortages are investigated in the case that the manufacturer and distributor decisions are dependent on each other. In this respect, the joint expected benefit in each unit can be expressed as follows:

$$EJTP(p,Q,n,b) = \big[p - CI_B - V - C - (Y_1 - Y_2)(C_w + C')\big]\alpha p^{-\beta} - \frac{\alpha p^{-\beta}}{Q}\left[A + F + \frac{S}{n}\right] - \frac{Q}{2}\{h_b(1-Y_1) + h_{rw}(Y_1+Y_2) - h_v[(2-n)\rho + n - 1]\} - \frac{(\pi+h_b)b^2}{2Q(1-Y_1)} + bh_b. \quad (4)$$

They aim to maximize Eq. (4) and find the optimal values for p, b, n, and Q variables. The optimum value of b can be calculated as:

$$b^* = \frac{h_b Q(1-Y_1)}{\pi + h_b}. \quad (5)$$

Eq. (5) is given in [15] based on which the value of b^* can be obtained. By replacing Eq. (5) into Eq. (4), we have:

$$EJTP(p,Q,n) = \big[p - CI_B - V - C - (Y_1 - Y_2)(C_w + C')\big]\alpha p^{-\beta} - \frac{\alpha p^{-\beta}}{Q}\left[A + F + \frac{S}{n}\right] - \frac{Q}{2}h_b\left\{(1-Y_1) + \frac{h_b(1-Y_1)}{\pi + h_b} + h_{rw}(Y_1+Y_2) + h_v[(2-n)\rho + n - 1]\right\}. \quad (6)$$

The second-order partial derivative of Eq. (6) with respect to Q is:

$$\frac{\partial^2 EJTP(p,Q,n)}{\partial Q^2} = \frac{2\alpha p^{-\beta}\left(A + F + \frac{S}{n}\right)}{Q^3} < 0. \quad (7)$$

Therefore, the optimum value of Q for fixed values of n, and p can be calculated as follows:

$$\frac{\partial EJTP(p,Q,n)}{\partial Q} = 0,$$

$$Q^* = \sqrt{\frac{2\alpha p^{-\beta}\left[A + F + \frac{S}{n}\right]}{H(n)}}. \quad (8)$$

For the sake of simplicity, it can be rewritten as follows:

$$H(n) = h_b\left[(1-Y_1) + \frac{h_b(1-Y_1)}{\pi + h_b)}\right] + h_{rw}(Y_1+Y_2) + h_v[(2-n)\rho + n - 1]. \quad (9)$$

The expected joint total profit as a function of p and n is calculated by substituting Eq. (9) into Eq. (6):

$$EJTP(p,n) = \big[p - CI_B - V - C - (Y_1 + Y_2)(C_w + C')\big]\alpha p^{-\beta} - \sqrt{2\alpha p^{-\beta}\left[A + F + \frac{S}{n}\right] H(n)}. \qquad (10)$$

For a specific value of p, $EJTP(p,n)$ can be maximized by minimizing the following expression:

$$EJTP' = 2\alpha p^{-\beta}\left[A + F + \frac{S}{n}\right] H(n). \qquad (11)$$

First, it is assumed that n is a continuous variable [15]; then, n value can be calculated by solving Eq. (2):

$$\frac{\partial EJTP'}{\partial n} = 0. \qquad (12)$$

Given the complexity of the equations, the MATLAB software was employed to solve them. The optimum value of p is calculated based on Eq. (10).

5.2. Inventory model in joint optimization without shortages

This section elaborates the integration of inventory model without shortages. The expected joint total profit without shortages can be expressed as follows:

$$EJTP_{WS}(p,Q,n) = \big[p - CI_B - V - C - (Y_1 - Y_2)(C_w + C')\big]\alpha p^{-\beta} - \frac{\alpha p^{-\beta}}{Q}\left[A + F + \frac{S}{n}\right] - \frac{Q}{2}\{h_b(1 - Y_1) + h_{rw}(Y_1 + Y_2) + h_v[(2-n)\rho + n - 1]\}. \qquad (13)$$

Moreover, the optimal value of Q can be calculated as follows:

$$\frac{\partial EJTP}{Q} = 0,$$

$$Q^* = \sqrt{\frac{2\alpha p^{-\beta}\left[A + F + \frac{S}{n}\right]}{H(n)}}. \qquad (14)$$

Upon substituting Eq. (14) into Eq. (13), we have:

$$EJTP_{WS}(p,n) = \big[p - CI_B - V - C - (Y_1 + Y_2)(C_w + C')\big]\alpha p^{-\beta} - \sqrt{2\alpha p^{-\beta}\left[A + F + \frac{S}{n}\right] H(n)}. \qquad (15)$$

To simplify the equations, $H(n)$ is defined as follows:

$$H(n) = h_b(1 - Y_1) + h_{rw}(Y_1 + Y_2) + h_v[(2-n)\rho + n - 1]. \qquad (16)$$

For a specific value of p, $EJTP_{WS}(p,n)$ is maximized after the following expression reaches its own optimal value:

$$EJTP' = 2\alpha p^{-\beta}\left[A + F + \frac{S}{n}\right] H(n), \qquad (17)$$

where (n) value can be calculated as follows:

$$\frac{\partial EJTP'_{WS}}{\partial n} = 0,$$

$$n^* = \sqrt{\frac{S[h_b(1 - Y_1) + h_{rw}(Y_1 + Y_2) + 2\rho h_v + h_v]}{\rho h_v(A + F)(\rho - 1)}}. \qquad (18)$$

The value of (p) can be calculated using Eq. (15):

$$\frac{\partial EJTP(p,n)}{\partial p} = 0,$$

$$\frac{\partial EJTP_{WS}(p,,n)}{\partial p} = \alpha p^{-\beta} - \alpha\beta p^{-\beta-1}\big[p - CI_B - V - C - (Y_1 + Y_2)(C_w + C')\big] - \frac{\beta p^{-\beta/2^{-1}}\sqrt{2\alpha\left[A + F + \frac{S}{n}\right] H(n)}}{2}. \qquad (19)$$

MATLAB software can be employed to do the work and solve the equations.

6. Solution algorithm

This section introduces an algorithm to find optimum values for the inventory model without shortage. This algorithm functions based on the algorithms provided in the previous studies conducted by Rad and khoshalhan [15,68,72]. Chen and Kang [68] used a similar solution procedure to propose a price-negotiation system based on the differences in the total profit of the three models. Rad et al. [15] employed a solution algorithm to find an optimal solution to one of their models. The solution procedure can be summarized as follows:

1. Computing n from Eq. (11) using MATLAB software.
2. Computing p based on Eq. (10).
3. Computing Q using Eq. (7).
4. Computing b based on Eq. (4).
5. Calculating the value of $EJTP(p^n, Q^n, b^n, n)$ using Eq. (4).
6. Calculating n=n+1 for steps (2) to (5) too, hence $EJTP(p^n, Q^n, b^n, n)$.

7. If $EJTP(p^n, Q^n, b^n, n) \geq EJTP(p^{(n-1)}, Q^{(n-1)}, b^{(n-1)}, n)$, step (6) is repeated again, where the optimal values are equal as follows:

$$EJTP(p^*, Q^*, b^*, n^*) \geq EJTP\left(p^{(n-1)}, Q^{(n-1)}, b^{(n-1)}, n-1\right).$$

7. Results

The numerical example presented in this section is similar to the studies conducted by Rad et al. [15] as well as Chen and Kang [68].

$$A = 100, \quad F = 100, \quad S = 1200,$$

$$C = 2.5, \quad V = 1, \quad CW = 11,$$

$$CI_b = 0.1, \quad \pi = 1.5, \quad P = 0.8,$$

$$h_v = 0.25, \quad M = 9, \quad K = 20,$$

$$\alpha = 30000, \quad \beta = 1.25, \quad h_{rw} = 0.96,$$

$$D(p) = 30000p - 1.25, \quad W(Y) = 9 - 20Y,$$

$$PI = \frac{EJTP - ETP_I}{ETP_I} \times 100, \tag{20}$$

$$\Delta\% = \frac{EJTP_{WS} - EJTP}{EJTP} \times 100. \tag{21}$$

PI is the percentage of profit improvements in the supply chain with integration for SMEs in the study of Rad et al. [15]. Here, EJTP is considered the joint total profit and the Expected Total Profit Improvement (ETPI) rate without shortage is expressed by $\Delta\%$. Based on the obtained results, it can be concluded that the optimal EJTP improvement rate is 9.91%, which is higher than 5.5% calculated when the supply chain members act independently.

7.1. Theoretical analysis

Based on the mentioned equations and obtained results, the following findings may be pointed out:

i. Reduction in the selling prices leads to a reduction in the optimal size of the orders (Eq. (8));

ii. Reduction in the optimal size of the shortage leads to a reduction in the selling prices (Eq. (8));

iii. If the distributor increases the cost of shortage, the value of $H(n)$, selling prices, and total cost will increase. This, in turn, will reduce the optimal order size and shortage (Eqs. (5) and (8)). These changes are more severe when demand is sensitive to price changes than when the demand rate is fixed;

iv. The average impact of imperfect quality products Y with the optimal value of shortage b^* can be expressed as follows:

7.1.1. Independent optimization for supply chain members in SMEs

The optimal shortage value is considered the denominator of the fraction, and the value of b^* increases upon increasing the value of Y. When demand is fixed, the optimal amount of shortage decreases upon increasing the value of Y. On the contrary, when demand is sensitive to price changes, the selling prices and optimal amount of shortage may either increase or decrease depending on the conditions.

7.1.2. Joint optimization for supply chain members in SMEs

The optimal shortage value is calculated using Eq. (5) and analyzed as described in the previous section. It can be concluded that the optimal shortage value would either increase or decrease upon increasing the value of Y.

7.1.3. Sensitivity analysis for flexibility index (β)

According to the results listed in Table 1, in cases where no shortage is allowed for independent and joint optimizations, the values of PI (percentage of improvement in the EJTP) and I (percentage of improvement in the ETPI without shortage) increase with an increase in the value of β. It can be concluded that both unallowable shortage and coordination in the supply chain in SMEs with the possibility of reworking new products play an important role in solidifying the market position of the firms and boosting the overall customer satisfaction, especially when market demand in SMEs is highly sensitive to price changes. This case is more common in competitive markets in SMEs where new products have little discrepancy and customers focus on the price. Under this condition, the integration of supply chains in SMEs and reworking of new products help eliminate shortage and improve the position of organizations and enterprises in the market. As observed in Table 1 and confirmed by previous researches, the more sensitive the demand is to the price, the lower the optimal selling prices will be.

7.2. Sensitivity analysis of the effects of β changes on $\Delta\%$

According to Figure 1, with an increase in the value of β when all imperfect quality products are reworkable and no shortage occurs in the system, the EJTP for SMEs will be much greater than when the system suffers from shortage due to non-reworkable products, meaning that in a situation where all imperfect quality products are reworkable, doing so will bring about higher total profit. It is also evident that in markets where the demand is sensitive to price changes, when

Table 1. Joint optimization and independent optimization (non-integrated).

	Joint optimization										
	Model with shortage					No shortage model					
β	p	Q	b	n	EJTP	p	Q	n	EJTP_{WS}	PI	$\Delta\%$
1.05	89.2	1081	390.09	13	227520	87.1	662	13	227700	2.43	0.079
1.10	46.05	1390	501.53	13	185010	44.89	1002	13	185370	4.27	0.19
1.25	20.73	1718	619.71	13	111310	20.18	1651	13	111920	9.91	0.54
1.50	12.98	1671	602.65	13	51260	12.7	2205	13	51891	22.31	1.23
2.00	8.38	1363	491.75	13	16972	8.16	2906	13	17321	64.87	2.05

	Independent optimization (non-integrated)				
β	p	Q	b	n	ETPI
1.05	205.17	526.24	193.704	11	222120
1.10	106.97	790.62	291.01	11	177420
1.25	47.7	1309.9	482.15	11	101270
1.50	29.15	1781.7	655.82	11	45381
2.00	19.63	2281.3	839.71	11	10294

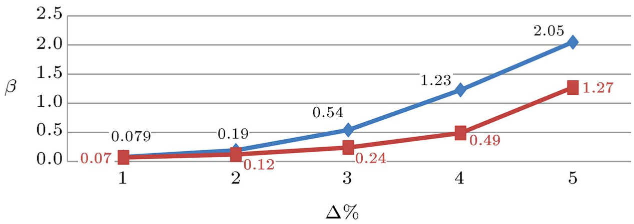

Figure 1. Index of price elasticity of the demand function.

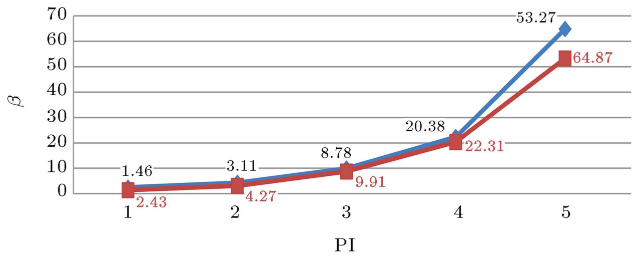

Figure 2. Index of price elasticity of the demand function.

the distributor manages to rework the returned products and eliminate all shortages, the total profit and optimal value of orders increase in proportion to the value of β. Based on these results, it can be concluded that the equations proposed by previous studies are not suitable in cases where imperfect quality products can be reworked, especially when the market demand is highly sensitive to prices.

Figure 1 shows the impact of changes in the β values on $\Delta\%$. The improvement rate of Expected Total System Profit (ETPI) without shortage is expressed by $\Delta\%$ and β represents the index of price elasticity of the demand function.

7.3. Sensitivity analysis of the effects of β changes on PI

As observed in Figure 2, when the supply chain members optimize their operations independently, allowable rework on imperfect quality products will result in augmented total profit. The results also indicate that the possibility of reworking in both independent and joint profit models in SMEs would lead to an increase in the total profits. The amount of increase in PI in the model proposed in this study is greater than the same value in a similar model proposed by Rad et al. [15]. Product rework is allowable in our proposed model, as well. In this regard, doing rework on imperfect products in both cases of independent and joint optimization of inventory models has led to an increase in the total profit of the supply chain of SMEs. The EJTP of the supply chain reaches its highest value when all imperfect quality products in the system are reworked and the system experiences no shortage. In this case, in markets where demand is sensitive to price changes, increasing the value of β may lead to an increase in the optimal order size.

Figure 2 shows the impact of changes in the β value on *PI*, where *PI* is the percentage of profit improvements in the integrated supply chain of the SMEs and β is the index of price elasticity of the demand function.

7.4. Sensitivity analysis for expected rates of imperfect quality products $Y = E(Y)$

In this section, the rates of imperfect quality products are the same as those of the numerical example used in the study of Rad et al. [15]. As described in

Table 2. Sensitivity analysis of average of imperfect products rate.

	β	p	Q	b	n	EJTP
Y_1	0	29.72	1338	0	12	101930
Y_2	0.17					
Y_1	0.17×0.25	29.73	1318	42.425	14	101820
Y_2	0.17×0.75					
Y_1	0.17×0.5	29.74	1299	39.439	13	101710
Y_2	0.17×0.5					
Y_1	0.17×0.75	29.86	1211	15.453	12	101590
Y_2	0.17×0.25					

the previous sections, the rate of imperfect quality products in the equations given in this study is $Y = Y_1 + Y_2$ whose values are shown in Table 2. The two variables Y_1 and Y_2 were employed to determine the values of EJTP and decision variables. As observed earlier, an increase in the value of Y_1 (the average rate of scrap products) and a decrease in the value of Y_2 (the average rate of reworkable imperfect products) may lead to an increase in the expected joint total profit of the supply chain system. To be specific, it was assumed that in the case of the model, shortage might occur for manufacturing scrap products in the system; as a result, an increase in Y_1 would case an increase in b. Obviously, given the model assumptions and the fact that scrap quality products are costly for the system, increasing the amount of scrap products per shipment would reduce the purchase price. According to the results of Table 2, with an increase in the average rate of reworkable imperfect quality products, the expected joint total profit in the case of unallowable shortage, Δ%, would increase, too. In addition, the impacts of the average rate of reworkable imperfect quality products on decision variables varied.

Integration of the supply chain always leads to a decrease in the average price of imperfect quality products, hence an increase in the total profit. In case the supply chain members, i.e., the manufacturer and buyer, optimize their inventory models independently or they receive shipments containing a high percentage of imperfect quality products, it can be a very profitable business for the distributor on condition that the manufacturer quotes a low selling price. Of note, previous researches have also reached this conclusion [66,73].

8. Discussion and conclusions

The current study aimed to present a supply chain inventory model for Small- and Medium-sized Enterprises (SMEs) consisting of one distributor and one manufacturer. In this regard, the product shortage, backorders, rework, and demand sensitivity to price were incorporated in the proposed model which is based on such variables as the expected total system profit (ETPI), optimal selling prices, number of orders, amount of shortage, calculation of the number of shipments, and both joint and independent inventory model optimization by the distributor and manufacturer. The results of numerical tests and sensitivity analysis were employed to evaluate the impacts of various factors on the ETPI. The obtained results revealed that the optimal scenario was the one with no shortage, and the distributor performed rework on the new faulty products, especially when the demand sensitivity to price, backorder costs, and average rate of imperfect quality products were high. According to the findings, the integration of the manufacturer and distributor's decisions with the possibility of rework by the distributor in the SMEs, may significantly improve the total profit.

Evidently, supply chain integration in SMEs, especially when demand is sensitive to price changes would greatly increase the total profit recorded by supply chain members.

When the supply chain members in SMEs act independently in terms of optimization, distributors often tend to purchase from manufacturers that generate a high rate of imperfect products, while manufacturers tend to offer a lower purchase price based on the average rate of imperfect quality products per total production.

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