Journal of Research in Science Engineering and Technology
Volume 8, Issue 4, November 2020, pp. 19-42

Journal of Research in Science Engineering and Technology

www.researchhub.org

Sustainable Economic Production Quantity under Uncertainty

Shadisadat Mirsharafeddin[1], **John W. Sutherland**[2*]

[1] Faculty of Business and Economics, University of Kassel, Kassel, Germany
[2] Environmental and Ecological Engineering, Purdue University, West Lafayette, USA

Abstract

This paper studies an extension to the economic production quantity (EPQ) model based on the sustainable development goals. Regarding the concept of triple bottom lines (TBL), many studies in the area of supply chain networks and manufacturing systems contributed to the economic, environmental and social impacts, simultaneously. This paper for the first time proposes a sustainable EPQ model under uncertainty. The applicability of the proposed model is approved by a dairy industry in Iran. To show the dynamically of the model, multiple periods are considered for the model and therefore, it provides a plan during different periods to achieve TBL in an EPQ system under demand uncertainty. Another novelty of this paper is to propose a novel hybrid meta-heuristic to address the proposed optimization model. Next, to assess the proposed solution method and the developed model, the empirical result and sensitivity analysis are carried out. Finally, managerial implications and findings from the results provide some practical solutions to achieve the TBL sustainability for EPQ models in a dairy manufacturing case study.

Keywords

Sustainable Economic Production Quantity, Uncertain Demand, Dairy Manufacturing, Hybrid Meta-Heuristic, Particle Swarm Optimization, Red Deer Algorithm

1. Introduction

Today, the significant role of inventory management is undeniable as it assists to have an on-time delivery, avoiding the shortage, and controlling the holding costs, etc. (Poursoltan et al., 2020). Although the traditional inventory systems mainly focused on the economic performance, the recent advances in the inventory systems seek sustainability to guarantee their long-term survival in global

* Corresponding author: Environmental and Ecological Engineering, Purdue University, West Lafayette, USA
E-mail address: j.sutherland@gmail.com

Received 30 August 2020 / Accepted 28 October
DOI: https://doi.org/10.24200/jrset.vol8iss04pp19-41

markets (Karampour et al., 2020). The sustainability mainly applies to the manufacturing systems and supply chain networks based on the concept of *triple bottom line* (TBL) approach (Elkington & Rowlands, 1999). The TBL uses the sustainable development goals conceptually to contribute the economic, environmental and social factors simultaneously (Fathollahi-Fard et al., 2020a). Hence, a tradeoff between these factors sustains the integrity of the overall system based on the concept of TBL.

Optimization is one of efficient tools for the mangers of supply chain networks and manufacturing systems to apply the method of TBL with the use of operations research models and optimization algorithms (Hediger, 2000; Benjaafar et al., 2012). This study provides an optimization model to the TBL method for a manufacturing system modeled by an *economic production quantity* (EPQ) in the dairy industry.

The dairy industry is associated with "*generation*" of a huge amount of wastewater which can be used to create energy and to reduce the environmental emissions (Kirilova & Vakieva-Bancheva, 2017; Fathollahi-Fard et al., 2020b). In this regard, the biochemical oxygen demand is the principal indicator of the wastewater assessment (Battini et al., 2017). Regarding the dairy manufacturing system, the wastewater collected from different salons is sent to the wastewater treatment centers (Fathollahi-Fard et al., 2020b). It results that the environmental pollution in the dairy manufacturing deals with collecting and recycling of the wastewater generated. Hence, this study considers the *environmental sustainability* for an EPQ system.

The social justice as one of the goals of TBL refers to the reduction of work's damages for the human in the manufacturing systems (Nezhadroshan et al., 2020; Fathollahi-Fard et al., 2020a). To achieve the social justice, this study uses the ergonomics which can be defined as the application of human's knowledge characteristics regarding the system designation to optimize human well-being and overall system performance (Battini et al., 2017; Zhu et al., 2018). Therefore, this study uses the ergonomics factors to achieve the *social sustainability* for an EPQ system.

Regarding the definition of the proposed EPQ, the products with deterministic shelf life become outdated and disposal is done at the end of a lifetime for these products (Poursoltan et al., 2020). In this regard, two well-known distribution policies are usually used including the FIFO[1] and LIFO[2] policies. A combination of these policies is very useful to distribute the perishable products in the dairy manufacturing (Poursoltan et al., 2020). It goes without saying that the distribution of the perishable products is quite important as it has a direct impact on sales, price, inventory level, and spoilage cost, deterioration cost, logistics cost, and product availability, which have an impact on profitability (Karampour et al., 2020). In addition, the proposed EPQ model faces with a diverse range of uncertainty as all of the recent EPQ models assumed the uncertainty (Debnath et al., 2019). Demand is one of the most effective factors to decide on the dairy manufacturing decisions. Thus, different forms of demand have investigated. In majority of studies, demand is considered as a crisp number, which cannot present the fluctuation of market demand perfectly (Poursoltan et al., 2020). Given these facts, this study aims to decrease the negative impact of the environmental and adverse effect of social simultaneously and proposing the optimum quantity of perishable manufacturing by developing a sustainable EPQ model under an uncertain demand.

At last but not least, the optimization of a sustainable EPQ model is complex and difficult. This motivated several recent studies to contribute novel intelligent-based optimization algorithms to address the proposed problem (Karampour et al., 2020). Another significant gap among the literature

[1] First-In, First-Out (FIFO)

[2] Last-In, First-Out (LIFO)

works is that most of the recent works tried to improve the current optimization algorithms or to develop new ones. This paper applies a recent nature-inspired meta-heuristic as the *red deer algorithm* (RDA) (Fathollahi-Fard et al., 2020c). In addition, a novel hybrid meta-heuristic as a combination of the RDA and the *particle swarm optimization* algorithm (PSO) (Kennedy & Eberhart, 1995) to solve the proposed multi-objective optimization model by Pareto-based metrics.

The rest of this article is followed by five sections: Section 2 provides an extensive literature review with an identification of the research gaps. Section 3 describes the proposed sustainable EPQ with its formulation. Section 4 implements the solution algorithm and the developed RDA. Section 5 does a comprehensive analysis and discussion on the developed model and a comparison among different meta-heuristics. Finally, the conclusions, practical insights, findings and further studies are presented in Section 6.

2. Literature Review

Incorporating the environmental pollution and the social justice is highly interested during the recent years. In this literature review, most of the recent works contributing to the sustainable manufacturing systems have been reviewed. As one of the first studies, Battini et al. (2014) developed a sustainable *economic order quantity* (EOQ) model linking with the material lot sizes from the purchase order to the end of life cycle inside the buyer plant based on the *life cycle assessment* (LCA) approach. They provided a comparison between a sustainable EOQ model and the traditional inventory systems based on the purchasing decisions. Next, Hovelaque & Bironneau (2015) proposed an inventory policy for the EOQ model to maximize the retailer's profit and to minimize the carbon emissions. Their model contributed to pricing decisions and the price-depended demand under two approaches of exogenous and endogenous prices. In another different study, Kumar & Goswami (2015) investigated a single period EPQ model for the imperfect quality items under uncertain demand. The processing time and imperfect quality items fraction were regarded as fuzzy random variables. They developed an EPQ model restricting the budget and allowable shortages as fuzzy numbers. Next year, Majumder et al. (2016) formulated an EPQ model with partial trade credit policy from suppliers to the retailers and also from the retailers to their customers to capture. Their main supposition was that the demands were considered as dependent upon a time under the left-right fuzzy type. The generalized Hukuhara derivative approach was applied to minimize the inventory cost of the model. In another research, Ghiami & Beullens (2016) presented an EPQ inventory system with deteriorating products and the partial back-ordering approach.

Another important factor which make an effect on the inventory systems, is the perishability. The design of the inventory system for perishable products is highly significant to reduce the expired products and to meet the uncertain demand (Chaudhary et al., 2018). As far as we know, the study of Nandakumar & Morton (1993), was the first optimization model for the perishable inventory with a lifetime. They studied the order quantity of perishable products and evaluated the performance of the system in a very shortsighted bound, also different classification and various considerations in perishable inventory models during the time examined. Recently, the perishability is very active in the inventory management studies. For example, Chang et al. (2016) focused on the pricing strategy of the perishable goods that the prices are set according to freshness, inventory, cost, and other factors. In addition, Chen et al. (2016) proposed EOQ/EPQ model considering stochastic demand and deteriorating characteristics of perishable foods.

Lot-sizing was firstly contributed to the sustainable manufacturing by Battini et al. (2017) who developed an ergonomic lot-sizing by integrating economic aspects to maintain a low level of fatigue and ergonomic risk. They estimated the economic impact of different workload levels with the use of a simulation-optimization-based method.

Recent studies provided some real-life constraints to the EPQ and EOQ models. For example, the production system may go through an imperfect production situation due to the failure or deterioration of machines. In this regard, Kazemi et al. (2018) and Tayyab et al. (2019) considered non-conforming products in their study. Kazemi et al. (2018) developed an EOQ model for the items with imperfect quality and emission costs due to warehousing and waste disposal activities. The holding cost for perfect and imperfect quality items, as well as failure in inspection, was taken into account separately. The results illustrated that the buyer policy leaded to convert by adding emission cost to the imperfect supply process, hence smaller batches tend to decrease the total profit. In another similar contribution, Tayyab et al. (2019) provided an EPQ model with uncertain demand and process information in a multi-stage production process. The defective products are generating in the manufacturing process at an uncertain rate and then reworked them into perfect quality products to reduce wastage quantity. The decomposition principle and signed distance methods linking with the fuzzy theory, were applied to control the uncertainty of demand and the manufacturing process.

Talaizedeh et al. (2018) proposed an EPQ model considering the economic and environmental aspects simultaneously under uncertain demand. Dealing with the shortage is analyzed under three different approaches, including lost sales, back-ordering, and partial back-ordering. The emission of inventory holding obsolesces and production considered. Zadjafar & Gholamian, (2018) revised an EOQ model by integrating the income of selling the waste, organic pollution of several gases, and the effect of emissions on human health. The objectives were the total cost amount and the total pollution quantity and the total quantity of worker's inhalation analyzed in the pulp and paper industry. Furthermore, Debnath et al. (2019) formulated the fuzzy sustainable EPQ to maximize the profit and simultaneously to minimize the carbon emission cost. The demand factor was depended on the product price and stock quantity under a fuzzy environment taken as the trapezoidal type-2 fuzzy variable to present the fluctuation of the market. Due to high complexity of this model, a genetic algorithm (GA) was used to solve the non-linear objective functions.

More recently, Kazemi (2019), provided a case study of a dairy company to analyze and to plan for the demand and supply limitations while almost the peak of demand is on the less supply of milk case study. This urges an exact tradeoff between lost sales and wasted products. In another study, Lin (2019), studied the EPQ inventory model dealing with imperfect production process under backlogged scenario and uncertain demand. Peña-Orozco et al. (2020) studied an inventory control system in a three echelon fruit supply chain. They presented a case study in a citrus supply chain and modeled the behavior of the product's useful life to design the optimal inventory policy. Karampour et al. (2020) studied a green inventory system for perishable products based on the vendor managed inventory contract to minimize the total inventory and transportation costs and the environmental pollution. Contributing to the wastewater assessment, Fathollahi-Fard et al. (2020b) proposed an adaptive Lagrangian relaxation-based algorithm and a two-stage stochastic programming approach. In another study, they (Fathollahi-Fard et al., 2020a) considered the environmental emissions of production, recycling and disposal as well as the job opportunities. A multi-objective stochastic optimization was developed accordingly and solved it by an improved social engineering optimizer as a recent powerful metaheuristic. At last but not least, Poursoltan et al. (2020) proposed an EPQ with deteriorated products, random machine breakdown and stochastic repair time. An approximated method called Newton-Rawson was applied to solve their proposed EPQ.

Having a conclusion about the aforementioned works, we have classified the papers based on the economic factors, the environmental factors including carbon emissions of holding, inventory and purchasing, manufacturing, wastes, disposal and imperfect products as well as the environmental factor for wastewater filtering, collection and recycling. In addition, the social factors and uncertainty are other criteria to evaluate the papers.

Table 1. A comparison with the contributions of this paper with the literature review

		Environmental Factors					
		Carbon Emission					
Sources	Economic Factors	Emission of Ordering, Holding, Inventory and Purchasing	Emission of Manufacturing	Emission of Wastage/Disposal/Obsolesce/ Imperfect Production	Wastewater	Social Factors	Uncertainty
Battini et al. (2014)	□	□		□	□		
Hovelaque & Bironneau (2015)	□	□					
Kumar & Goswami (2015)	□			□			□
Majumder et al. (2016)	□			□			□
Battini et al. (2017)						□	
Kazemi et al. (2018)	□	□		□	□		
Zadjafar & Gholamian, (2018)	□		□	□	□	□	
Taleizadeh et al. (2018)	□	□	□	□	□		□
Debnath et al. (2019)	□	□	□	□	□		□
Tayyab et al. (2019)	□	□					□
Lin (2019)	□	□					□
Karampour et al. (2020)	□	□					
Poursoltan et al. (2020)	□						□
Fathollahi-Fard et al. (2020a)	□				□	□	□
Fathollahi-Fard et al. (2020b)	□				□		□
Current Study	□	□	□	□	□	□	□

As reviewed in Table 1, following findings can be observed:

- Except one paper (Battini et al., 2017) which has contributed to the social factors only, other papers have considered the total cost in their optimization models.
- There are two studies contributed to all the environmental factors (Taleizadeh et al., 2018; Debnath et al., 2019). However, none of them considered the social factors.
- Only two papers applied the TBL concept in their optimization models (Zadjafar & Gholamian, 2018; Fathollahi-Fard et al., 2020a). However, they have not considered all the environmental factors such as environmental emissions of ordering and purchasing.
- Uncertainty has been contributed to the most of recent papers.

- Simultaneous consideration of all the economic, environmental and social factors simultaneously under uncertainty has only presented by the current paper.

In conclusion, this paper proposes a sustainable EPQ which has contributed to all the environmental factors including carbon emissions and wastewater. The proposed problem is also faced with the demand uncertainty and shortage conditions. The last novelty is to propose a hybrid meta-heuristic algorithm as a combination of RDA and PSO.

3. Problem Definition and Formulation

To address the proposed problem, Fig. 1 exposes a schematic view of the problem, which tries to capture economic, social, and environmental tradeoffs through the proposed inventory system as an extension to the EPQ. The inventory system consists of a manufacturer that produces multi-product and stores the additional products in the presence of uncertain customer demand. The products released from the warehouse based on the FIFO method. The advantage of applying the FIFO method is to equalize the physical flow of goods and to minimize the expired products during the storage periods. All types of products manufactured under a single technology. The production costs and storage capacities regarded as invariable within the time horizon. Uncertain demand indicates there is a probability of facing variation between available inventory and actual demand in each period. In a case that the production is more than the demand it can be stored, and, if faced shortage, two different policies can be applied. (i) Lost sales (ii) Fullback orders. Under the first scenario, the unmet demand is lost and cannot respond in the coming periods, while following the second scenario fulfilling the demand in the next periods is possible.

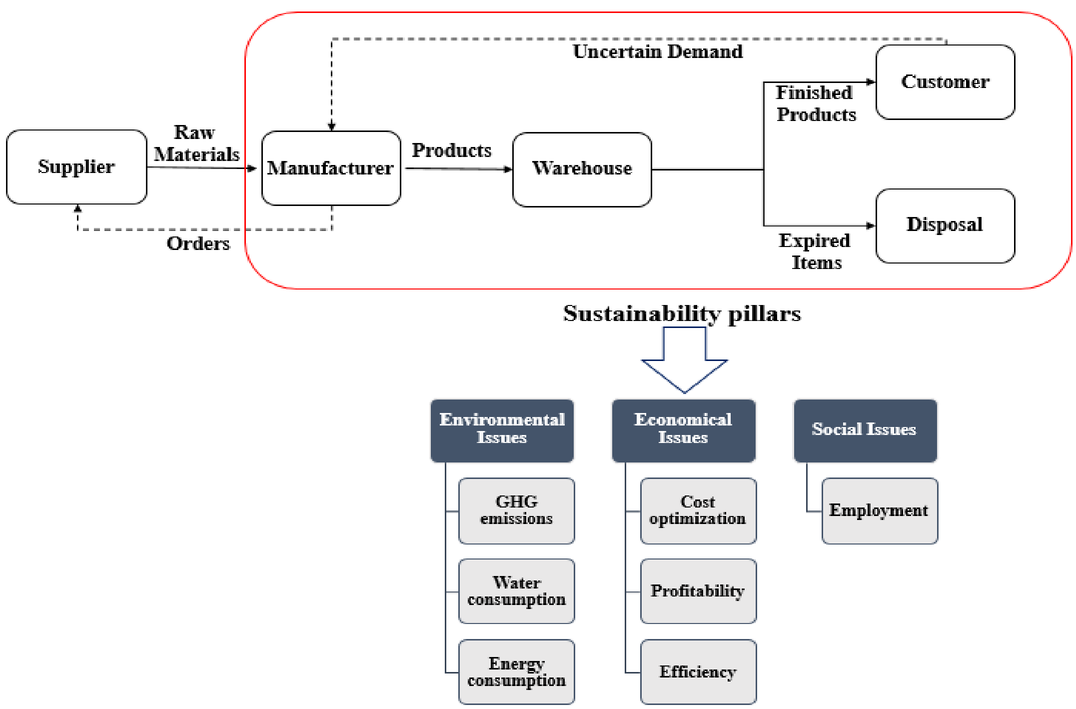


Fig 1. Schematic view of the studied sustainable EPQ model

3.1. Sustainability Factors

This study considers the economic factors with minimizing the total cost and the environmental emissions and the social factors based on the TBL conceptually.

- **Sustainability in the Manufacturing**

An assessment on the environmental emissions in the scope of manufacturing, warehousing, and disposing level, is provided here. As studied in Lee & Lee (2014), sustainable manufacturing can be measured as the manufacturing performance metrics for the production system and product design, concerning the economic, environmental and social aspects. In the current study, we focus on the process plan at the manufacturing level. In the food industry, each cycle of production needs to run the cleaning in place (CIP) operation. The CIP is set based on changing the product type or the cycle time. It means that each change in the product type needs to run the CIP and each run of CIP requires the chemical materials and water and they are time consuming and have a significant cost and we may need to increase the working time. The CIP and cleaning operations are responsible for 70% of the water requirements (Vasilaki et al., 2016). Therefore, this study provides a sustainable manufacturing system with the CIP operations and their balance with the total cost.

- **Sustainability for Disposal Items**

Regarding each run of the machine, there are almost fixed defective items due to imperfect processes and, the warm-up of the machines which produces in larger lot sizes (Nobil et al., 2020). It is supposed that manufacturing in each cycle (between the two CIPs) contains a fixed percentage of defective items for each type of product. The companies are attempting to control the process plan to lead a minimum number of CIP runs and a low level of the defective products. More variety of products makes planning more complicated. In this paper, the CIPs emission and the required working hours are evaluated in our sustainable EPQ model.

- **Sustainability in the Warehousing**

Warehousing is another challenge to achieve the sustainability for our EPQ system. It goes without saying that the carbon emissions related to the warehousing is a significant factor because of the considerable energy requirement for heating, cooling, material handling equipment, etc. (Arikan et al., 2014). The emissions of the warehouse are calculated based on the energy consumption per hour for each product based on the electricity and fuels consumed daily. This study considers the carbon emissions for the warehousing.

- **Sustainability for the Expired Items**

The expired products are referred to the items that passed their allowed shelf life and did not sell out. The expired items are now a hot topic in the area logistics and manufacturing systems (Yu et al., 2021; Zhang et al., 2020; Nezhadroshan et al., 2020). This factor makes the supply network complex and in the case of multi-item models, it increases exponentially as compared with the single-item inventory models (Chaudhary et al., 2018). Keeping the perishable products in the warehouse will make plausible the expiration of products due to overproduction and the demand uncertainties that need to be minimized. In the current study, the fixed lifetime considered for perishable products and if there is another condition for sending the product to markets before reaching a fraction of shelf life, it has been considered in our EPQ model.

- **Sustainability for Balancing Working Hours**

In addition to the aforementioned environmental factors, this study contributes to the working hours as an ergonomic factor. This factor directly covers the social justice conceptually (Liu et al., 2020; Fathollahi-Fard et al., 2020a). If the working hours is stable and suitable regarding the workers, it increases the workers' satisfaction. In another point of view, to have more profits and to reduce the total cost, we need to increase the working hours. In addition, the working hours for production and CIPs, is calculated to keep the minimum turnover of workers during the periods and to charge the less cost to the company.

3.2. Formulation

Here, the proposed sustainable EOQ model is introduced. The proposed model aims to identify the optimum quantity of the production, storage, and working hours to minimize the environmental emissions and the costs of manufacturing, storing and expiring products under two different scenarios. The model also analyzes the working hours. Therefore, a TBL approach is used to meet the standards of the economic, environmental and social factors for an inventory model. Before introducing the developed model, following notations are provided:

Sets:

p   Index of products, $p = \{1, \dots, P\}$
i   Index of time periods, $i = \{1, \dots, I\}$
w   Index of warehouse, w={1, …, W}

Parameters:

D_{pi}: Demand quantity of product p in period i (unit).
S_p: Sales price of product p ($ /unit).
C_p^{pr}: Unit production cost of product p ($ /unit).
C_p^{Se}: Setup cost for producing product p ($ /set up).
C_p^{In}: Inventory holding cost of product p ($ /unit).
b_p: Required space for each unit of product p (m^3/unit).
γ_p: Fraction of imperfect production of product p.
EC_p^{Pr}: The emission cost for producing product p ($ /unit).
EC_p^{w}: The emission cost for inventory holding of product p in warehouse w ($ /unit).
EC_p^{ex}: The emission cost for expired and imperfect of product p ($ /unit).
EC_{CIP}: The emission cost for cleaning in place ($ /Run).
C_w: Total capacity of warehouse w (m^3).
CH: Cost of hiring the workers ($ /man).
CF: Cost of firing the workers ($ /man).
SH: Standard working hours per shift.
T_p: Man- Hour needed for producing product p.
C_{CIP}: Cost of performing the CIP
T_{CIP}: Required Man- Hour for performing the CIP
M: large number
SL_p: The shelf life of product p

Decision variables:

Q_{pi}: Gross production quantity of product p in period i
SA_{pi}: Sales quantity of product p in period i
I_{pi}: Inventory quantity of product p in period i
Q_{pi}^{im}: Imperfect quantity of product p in period i
Q_{pi}^{ex}: Expired quantity of product p in period i
HI_i: Number of hired workers in period i
FI_i: Number of fired workers in period i
X_{pi} will be equal to 1, if the product p produce in period i, 0 otherwise.
Y_{wp}: 1, if warehouse w is appropriate for stocking product p, 0 otherwise

With the use of these notations, the proposed model aims to maximize the total profit of the EPQ system while minimizes the cost of environmental emissions and labor turns over. To generate the framework of a sustainable EPQ system, the proposed model is:

$$Max\ Z_1 = \sum_{p=1}^{P}\sum_{i=1}^{I}([(SA_{pi}.S_p) - (Q_{pi}.C_p^{pr} + C_{CIP}.X_{pi}) - (C_p^{Se}.X_{pi}) - (C_p^{In}.I_{pi}) - (EC_p^{Pr}.Q_{pi} + EC_{CIP}.X_{pi}) - (EC_p^{ex}.Q_{pi}^{ex})] - (\sum_{w=1}^{W} EC_p^{w}.\ I_{pi}.Y_{wp})) \quad (1)$$

The first objective function of the model maximizes the total profit of the sustainable EPQ model. The first term of Eq. (1) is related to sales profit minus the cost, which includes the cost of production, CIP process, setup, inventory and the environmental emission of manufacturing, imperfect generating, CIP process, expired products, and warehousing.

$$MinZ_2 = \sum_{i=1}^{I}(CH.HI_i + CF.FI_i) \quad (2)$$

The second objective function tries to minimize the turn over cost of the workers, which leads to keeping a sustainable number of workers as the social factor based on the working hours.

Following constraints (Eqs. 3 and 4) provide that the total demand of products must be met per period.

$$SA_{pi} \le D_{pi} \quad \forall p, i \quad (3)$$
$$SA_{pi} \ge 0 \quad \forall p, i \quad (4)$$

Eqs. (5) to (7) determine the production quantity per period.

$$Q_{pi} - Q_{pi}^{im} \ge D_{pi} - I_{pi-1} \quad \forall p, i > 1 \quad (5)$$
$$Q_{pi} \le X_{pi}.M \quad \forall p, i \quad (6)$$
$$Q_{pi} \ge 0 \quad \forall p, i \quad (7)$$

Eqs. (8) to (10) covers the assumptions of the shelf life products. Based on this assumption, the products cannot be delivered to the market after the end of the shelf life and will be treated as the expired product.

$$Q_{pi}^{ex} = 0 \quad \forall p, i \le SL_p \quad (8)$$
$$Q_{pi}^{ex} \ge I_{pi-SL_p} - \left[\sum_{\acute{i}=i-(SL_p-1)}^{i}(SA_{p\acute{i}} + Q_{p\acute{i}}^{ex})\right] \quad \forall p, i > SL_p \quad (9)$$
$$Q_{pi}^{ex} \ge 0 \quad \forall i, p \quad (10)$$

Eq. (11) guarantees that imperfect quantity during the production is determined based on a fraction of production.

$$Q_{pi}^{im} = \gamma_p . Q_{pi} \qquad \forall p, i \tag{11}$$

There is the capacity limitation as given in Eq. (12).

$$\sum_{p=1}^{P} b_p . Y_{wp} \left(Q_{pi} - Q_{pi}^{im} + I_{pi-1} - SA_{pi} - Q_{pi}^{ex} \right) \leq C_w \qquad \forall i, w \tag{12}$$

Eqs. (13), (14) and (15) state that the equilibrium of product flow and the initial inventory of products respectively.

$$I_{pi+1} = Q_{pi+1} - Q_{pi+1}^{im} + I_{pi} - SA_{pi+1} - Q_{pi}^{ex} \qquad \forall p, i \neq 1 \tag{13}$$

$$I_{p1} = 0 \qquad \forall p \tag{14}$$

$$I_{pi} \geq 0 \qquad \forall p, i \tag{15}$$

As given in Eqs. (16) to (19), the requirement of hiring or firing the workers depends on production quantity, and shift working hours which presented in the following equations.

$$SH.\left[\left(Q_{pi} . T_p \right) + X_{pi} . T_i^{CIP} \right] - \sum_{i=1}^{I} (HI_i - FI_i) \geq HI_i \qquad \forall i, p \tag{16}$$

$$SH.\left[\left(Q_{pi} . T_p \right) + X_{pi} . T_i^{CIP} \right] - \sum_{i=1}^{I} (HI_i - FI_i) \geq -FI_i \qquad \forall i, p \tag{17}$$

$$HI_i \geq 0 \qquad \forall i \tag{18}$$

$$FI_i \geq 0 \qquad \forall i \tag{19}$$

Finally, the binary decision variables are indicated in Eq. (20).

$$X_{pi}, Y_{wp} \in \{0,1\} \qquad \forall p, i \tag{20}$$

3.2.1. Sustainable EPQ Model Considering Lost Sales

Here, an extension to the main model introduced earlier, is provided. In this case, the unmet demand in each period is respected as lost sales and cannot be back-ordered. The penalty cost for lost customers is charging in each period. The optimal production quantity is directed by the trade-off between inventory holdings and lost sales costs considering the related environmental cost components. Following parameters are added to the main notations:

C_i^p: The cost of lost sales of product p in period i

LS_{pi}:The lost sale quantity of product p in period i

C_g: The loss cost of the unsatisfied demand

Finally, the basic model is rewritten as follows:

$$Max\ Z_1 = \sum_{p=1}^{P} \sum_{i=1}^{I} (\left[\left(SA_{pi} . S_p \right) - \left(Q_{pi} . C_p^{pr} + C_{CIP} . X_{pi} \right) - \left(C_p^{Se} . X_{pi} \right) - \left(C_p^{In} . I_{pi} \right) - \left(EC_p^{Pr} . Q_{pi} + EC_{CIP} . X_{pi} \right) - \left(EC_p^{ex} . Q_{pi}^{ex} \right) - C_p^{L} . LS_{pi} \right] - \left(\sum_{w=1}^{W} EC_p^{w} .\ I_{pi} . Y_{wp} \right)) \tag{21}$$

$$Min\ Z_2 = \sum_{i=1}^{I} (CH . HI_i + CF . FI_i) \tag{22}$$

The represented objective model given in Eq. (21) maximizes the total profit of the sustainable EPQ model under lost sales conditions while the second objective as given in Eq. (22) tries to keep a sustained level of workers during the periods. The constraints of the model are the same as the basic model as follows:

$$SA_{pi} \leq D_{pi} - LS_{pi} \qquad \forall p, i \tag{23}$$

$$SA_{pi} \geq 0 \qquad \forall p, i \tag{24}$$

$$Q_{pi} \leq X_{pi} . M \qquad \forall p, i \tag{25}$$

$$Q_{pi} \geq 0 \qquad \forall p, i \tag{26}$$

$C_p^L = (S_p - C_p^{pr}) + (C_g) \quad \forall p$ (27)
$D_{pi} - (Q_{pi} - Q_{pi}^{im} + I_{pi-1} - Q_{pi}^{ex}) \leq LS_{pi} \quad \forall p, i$ (28)
$LS_{pi} \geq 0 \quad \forall p, i$ (29)
$Q_{pi}^{ex} = 0 \quad \forall p, i \leq SL_p$ (30)
$Q_{pi}^{ex} \geq I_{pi-SL_p} - \left[\sum_{i=i-(SL_p-1)}^{i} (SA_{pi} + Q_{pi}^{ex})\right] \quad \forall p, i > SL_p$ (31)
$Q_{pi}^{ex} \geq 0 \quad \forall i, p$ (32)
$Q_{pi}^{im} = \gamma_p . Q_{pi} \quad \forall p, i$ (33)
$\sum_{p=1}^{P} b_p . Y_{wp} (Q_{pi} - Q_{pi}^{im} + I_{pi-1} - SA_{pi} - LS_{pi} - Q_{pi}^{ex}) \leq C_w \quad \forall i, w$ (34)
$I_{p1} = 0 \quad \forall p$ (35)
$I_{pi+1} = Q_{pi+1} - Q_{pi+1}^{im} + I_{pi} - SA_{pi+1} - Q_{pi}^{ex} \quad \forall p, i \neq 1$ (36)
$SH. [(Q_{pi} . T_p) + X_{pi} . T_i^{CIP}] - \sum_{i=1}^{I} (HI_i - FI_i) \geq HI_i \quad \forall i, p$ (37)
$SH. [(Q_{pi} . T_p) + X_{pi} . T_i^{CIP}] - \sum_{i=1}^{I} (HI_i - FI_i) \geq -FI_i \quad \forall i, p$ (38)
$HI_i \geq 0 \quad \forall i$ (39)
$FI_i \geq 0 \quad \forall i$ (40)
$X_{pi}, Y_{wp} \in \{0,1\} \quad \forall p, i$ (41)

3.2.2. Sustainable EPQ model considering full backordering

The model given in Section 3.2.1 is reformulated by the full backordering supposition. Based on this model, the unsatisfied demand is considered fully back-ordered, likewise, the defined amount of cost is charged for deliveries by the delay. Following parameters have been added into the main model:

Parameters:
C_b: Backordering cost of products
B_{pi}: the backordered quantity of product p in period i

Binary variables:
X_{pi}^B : 1, if backordered product p is responded in period i, 0 otherwise.

Based on these definitions, the final model is adjusted as follows:

$$Max\ Z_1 = \sum_{p=1}^{P} \sum_{i=1}^{I} \Big(\big[(SA_{pi} . S_p) - (Q_{pi} . C_p^{pr} + C_{CIP} . X_{pi}) - (C_p^{Se} . X_{pi}) - (C_p^{In} . I_{pi}) - (EC_p^{Pr} . Q_{pi} + EC_{CIP} . X_{pi}) - (EC_p^{ex} . Q_{pi}^{ex}) - C_b . B_{pi} \big] - \big(\sum_{w=1}^{W} EC_p^{w} .\ I_{pi} . Y_{wp}) \big) \Big) \quad (42)$$

$$Min\ Z_2 = \sum_{i=1}^{I} (CH . HI_i + CF . FI_i) \quad (43)$$

s.t.

$SA_{pi} \leq D_{pi} - B_{pi} + \sum_{t=1}^{i-1} B_{pt} . (1 - X_{pt}^B) \quad \forall p, i$ (44)
$SA_{pi} \geq 0 \quad \forall p, i$ (45)
$Q_{pi} \leq X_{pi} . M \quad \forall p, i$ (46)
$Q_{pi} \geq 0 \quad \forall p, i$ (47)
$D_{pi} - (Q_{pi} - Q_{pi}^{im} + I_{pi-1} - Q_{pi}^{ex} - B_{pi-1}) \leq B_{pi} \quad \forall p, i$ (48)
$B_{pi} \geq 0 \quad \forall p, i$ (49)
$B_{p1} = 0 \quad \forall p$ (50)
$\sum_{p=1}^{P} b_p . Y_{wp} . (Q_{pi} - Q_{pi}^{im} + I_{pi-1} - SA_{pi} - B_{pi} - Q_{pi}^{ex}) \leq C_w \quad \forall i, w$ (51)
$Q_{pi}^{ex} = 0 \quad \forall p, i \leq SL_p$ (52)
$Q_{pi}^{ex} \geq I_{pi-SL_p} - \left[\sum_{i=i-(SL_p-1)}^{i} (SA_{pi} + Q_{pi}^{ex})\right] \quad \forall p, i > SL_p$ (53)
$Q_{pi}^{ex} \geq 0 \quad \forall i, p$ (54)

$$Q_{pi}^{im} = \gamma_p . Q_{pi} \qquad \forall p, i \tag{55}$$

$$I_{p1} = 0 \qquad \forall p \tag{56}$$

$$I_{pi+1} = Q_{pi+1} - Q_{pi+1}^{im} + I_{pi} - SA_{pi+1} - Q_{pi}^{ex} \qquad \forall p, i \tag{57}$$

$$I_{pi} \geq 0 \qquad \forall p, i \tag{58}$$

$$SH.\left[\left(Q_{pi}.T_p\right) + X_{pi}.T_i^{CIP}\right] - \sum_{i=1}^{I}(HI_i - FI_i) \geq HI_i \qquad \forall i, p \tag{59}$$

$$SH.\left[\left(Q_{pi}.T_p\right) + X_{pi}.T_i^{CIP}\right] - \sum_{i=1}^{I}(HI_i - FI_i) \geq -FI_i \qquad \forall i, p \tag{60}$$

$$HI_i \geq 0 \qquad \forall\, i \tag{61}$$

$$FI_i \geq 0 \qquad \forall\, i \tag{62}$$

$$X_{pi}, X_{pi}^{B} \in \{0,1\} \qquad \forall p, i \tag{63}$$

4. Solution Method

The EPQ optimization problem is generally classified as an extension to the assignment problems. The assignment or the allocation optimization problems are NP-hard (Kazemi et al., 2018; 2019; Fathollahi-Fard et al., 2020d). Therefore, the literature is very rich in using heuristics and meta-heuristics in the area of RRS. Although the PSO algorithm was previously utilized in this research area (Taleizadeh et al., 2018; Nobil et al., 2020), there is no study to employ the RDA as a recent nature-inspired algorithm. In addition to this new contribution, this study utilizes a new hybrid meta-heuristic as a combination of RDA and PSO.

Here, we firstly show the encoding plan to solve the proposed problem. Then, a multi-objective version of RDA which is rarely introduced, is provided and finally, the proposed hybrid meta-heuristic is provided.

4.1. Encoding Plan

Meta-heuristics use a continuous search space. An encoding plan is necessary to show that how a feasible solution can be generated for the fitness evaluation (Fathollahi-Fard et al., 2020a; 2020c; 2020d). A two-stage solution presentation based on random key technique is considered here. Fig. 2 shows the encoding scheme for our decision variables of the developed optimization model.

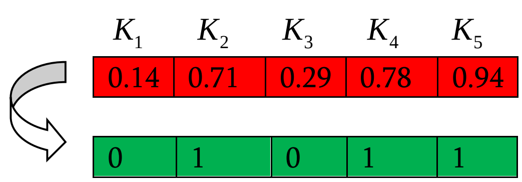


Fig. 2. Selection of optimal order

In this example, assume that we have five possible orders and we want to select the optimal one. For each response, a uniform number is selected from the logic of the meta-heuristics. Then, the highest values are selected to be one. The criterion to stop the selection is the shelf life of the product. After each order is selected, its cost is calculated to check the first and second objective functions.

4.2. Multi-Objective Version of RDA

Evolutionary algorithms are another well-known classification of the metaheuristics. These algorithms are also nature-inspired algorithms. However, from the current to the next generation, only a group of animals who are probably stronger than other ones, will keep and other agents will be removed. As another evolutionary metaheuristic, Fathollahi-Fard et al. (2020c) recently proposed the Red Deer Algorithm (RDA) inspired by an amazing behaviors of males and females in a breeding season.

This algorithm studies the behavior of red deers with regards to roaring, fighting and mating behaviors. These animals are naturally living in British Isles mainly in Scotland. In this regard, the scientists called them as the Scottish Red Deer (*Cervus Elaphus Scoticus*) (Fathollahi-Fard et al., 2020c). In a breeding season, the males which are also known as stags roar loudly and repeatedly to attract the females so-called hinds. Based on this feature of the males, the hinds select their preferable stag and he will create his territory and harem. The harem is a group of hinds and a commander as the head of this group manage and control them. The fighting act is always existed among males. Stags and commanders do a fighting and the winner will achieve the territory and harem. This competition among males is the main activity. The last part of this season is the mating behaviors among males and hinds and as a result, the new red deers will born for the next breeding season. Among all roaring, fighting and mating processes, the evolutionary concept to confirm that only strangest will always keep in nature and this rule is existed among red deers.

Fathollahi-Fard et al. (2020c) modeled these facts as another evolutionary algorithm. They generated the first population of red deers as the random solutions. This population is divided into males and hinds. Then, males roar and based on their power, a group of them will be selected as the commanders and the others are stags. Next, a fight between commanders and stags occurs. After that for each commander, a harem will be generated by some random hinds. The number of hinds in a harem is directly related to the power of the commander. After that the commoner has this ability to mate with a number of his hinds in the harem and a few hinds in another harem. The stags which have not this chance to be a commander can mate with one hind which is closest to him geographically. After the mating, an offspring is created for each mating. Finally, for the next generation, the males will be selected as the best solutions among all available solutions and the hinds will be selected by an evolutionary mechanism like the roulette wheel selection method.

With these features, the authors developed an interesting and successful metaheuristic and called it RDA. According to the best of our knowledge, no paper uses the RDA in the area of the RRS problems. Since our problem is multi-objective optimization, the non-dominated solutions must be considered as the outputs of the algorithm. The main difference of the proposed multi-objective RDA, is the selection of the next generation and the concept of crowding distance to select the males and hinds. To have a brief illustration of multi-objective RDA, its pseudo-code is available as seen in Fig. 3.

```
Initialize the Red Deers population.
Create the Pareto-based solutions and the non-dominates as the best one.
Form the hinds (N_hind) and male RDs (N_male).
X*=the best solution as one of the non-dominated solutions.
while (t< maximum number of iterations)
   for each male RD
     A local search near his position.
     Update the position if better than the prior ones (it means if it is dominated or not).
   end for
   Update the non-dominated solutions.
   Sort the males and also form the stags and the commanders.
   for each male commander
       Fight between male commander and stag.
       Update the position of male commander and stag.
   end for
   Form harems.
   for each male commander
       Mate male commander with the selected hinds of his harem randomly.
       Select a harem randomly and name it k.
       Mate male commander with some of the selected hinds of the harem.
   end for
   for each stag
       Calculate the distance between the stag and all hinds and select the nearest hind.
       Mate stag with the selected hind.
   end for
   Select the next generation with roulette wheel selection and crowding distance.
   Update the non-dominated solutions.
   Update the X* if there is better solution.
   t=t+1;
end while
return X* and the non-dominated solutions
```

Fig. 3. The pseudo-code of multi-objective RDA

4.3. Proposed Novel Hybrid Meta-Heuristic

Here, the main novelty from the solution algorithm as a novel hybrid of RDA and PSO is introduced. As can be referred to the main paper of PSO (Kennedy & Eberhart, 1995), each particle in PSO will be updated according to the position of the best and local solutions. We have hybridized this concept to improve the RDA as the main loop of the proposed algorithm and called it as HRDPSOA.

In the proposed novel hybrid meta-heuristic, except mating operators, all parts of the algorithm is similar to the RDA. For each mating, we have considered the males as the global solution and the hinds as the local solutions and then updated the offspring. Based on this strategy, we have combined RDA and PSO. The details of this hybrid meta-heuristic are given in Fig. 4 as a pseudo-code.

```
Initialize the Red Deers population.
Create the Pareto-based solutions and the non-dominates as the best one.
Form the hinds (N_hind) and male RDs (N_male).
X*=the best solution as one of the non-dominated solutions.
while (t< maximum number of iterations)
  for each male RD
    A local search near his position.
    Update the position if better than the prior ones (it means if it is dominated or not).
  end for
  Update the non-dominated solutions.
  Sort the males and also form the stags and the commanders.
  for each male commander
      Fight between male commander and stag.
      Update the position of male commander and stag.
  end for
  Form harems.
  for each male commander
      Consider this male as the global solution in PSO
      Consider the hinds as local solutions in PSO
      Mate male commander with the selected hinds of his harem randomly.
      Select a harem randomly and name it k.
      Based on these global and local solutions, mate male commander with some of the selected hinds of the
harem.
  end for
  for each stag
      Calculate the distance between the stag and all hinds and select the nearest hind.
      Consider the male as the global and the hind as the local solution.
      Then, mate stag with the selected hind.
  end for
  Select the next generation with roulette wheel selection and crowding distance.
  Update the non-dominated solutions.
  Update the X* if there is better solution.
  t=t+1;
end while
return X* and the non-dominated solutions
```

Fig. 4. The pseudo-code of hybrid of RDA and PSO (HRDPSOA)

5. Computational Results

Here, we provide a comprehensive analysis to show the performance of the developed hybrid meta-heuristic and the efficiency and applicability of the deployed final model. We firstly address our case study in a dairy manufacturing in Iran and our benchmarks. Then, tuning, validation and comparison of the meta-heuristics are done to approve the performance of the developed hybrid algorithm. Finally, some sensitivity analyses are performed to do some tests on the efficiency of the developed model. Note that all the tests are solved by MATLAB2013a and GAMS software in a computer with 1.7GB CPU and 6.0GB RAM.

5.1. Case study and Benchmarks

Nowadays, the dairy products are very important in the human diet and the food industry is one of the economic drivers in the Europe and other developed markets (Wijnands et al., 2007; Milani et al., 2011). In this study, we apply our model and the meta-heuristics for a real case study and a set of benchmarks from the literature (Taleizadeh et al., 2018). A dairy industry in Iran is considered as a case study and the company of Kaleh is selected. Kaleh brand was established in 1991 with the aim of improving and upgrading the food basket of the Iranian people. As a result of the activities carried out in this collection over the past years, this brand has been ranked 48th in the world in the food industry, a popular and top brand and for 7 years the only exporter of samples in dairy products in Iran. It goes without saying that Kaleh was started its activity with daily absorption of 3 liters of milk and today it has more than 2500 tons of daily milk absorption. This causes the daily production of more than 2650 tons of dairy products. In this production process, 4,000 people work daily in different sectors to get the final products to consumers. Due to security reasons, we cannot provide more details about our case study and the interested readers can ask the additional details via an email to the corresponding author.

In addition to a case study from Kaleh Company as a well-known dairy manufacturing case study, we employ 10 benchmarks from a similar model (Taleizadeh et al., 2018) as noted in Table 1. Therefore, the model given in Section 3.2.2 is solved by a real case study and 10 benchmark tests. It should be noted that the algorithms comparison is based on the benchmarks and the sensitivity analysis is done by the data of our case study in Kaleh Company.

5.2. Tuning, Validation, and Comparison

Here, we firstly tune the parameters of the metaheuristics before solving the test problems. The Taguchi experimental design method was applied and the results of the algorithms' calibration (Ebrahimi & Rezaeian, 2015) are given in Table 2. Note that due to page limitation, the details of the algorithms' tuning are not reported here.

Table 2. Algorithms' tuning

Algorithm	**Parameter**	**Value**
PSO	Maximum number of iteration (MaxIt)	500
	Number of Population (nPop)	100
	Rate of weight damper (W)	0.9
	Coefficient of the global solution (C1)	2
	Coefficient of the local solution (C2)	2
RDA	Maximum number of iteration (MaxIt)	500
	Number of Population (nPop)	100
	Percentage of fighting (gamma)	0.8
	Percentage of mating in harms (alpha)	0.6
	Percentage of mating our of harems (betta)	0.6
HRDPSOA	Maximum number of iteration (MaxIt)	500
	Number of Population (nPop)	100
	Coefficient of the global solution (C1)	2
	Coefficient of the local solution (C2)	2
	Percentage of fighting (gamma)	0.8
	Percentage of mating in harms (alpha)	0.7
	Percentage of mating our of harems (betta)	0.5

Based on these 10 test studies, the validation of the algorithms and an extensive comparison are provided. With regards to the exact solver by the GAMS software, the epsilon constraint method is utilized. One objective would be optimized and the second objective is considered as a constraint with an allowable bound (Fathollahi-Fard et al., 2020d; Karampour et al., 2020). We provided the non-dominated solutions for the first problem as reported in Table 3. These solutions are also depicted in Fig. 5.

Table 3. Non-dominated solutions for the first test problem from Taleizadeh et al. (2018)

Epsilon constraint		PSO		RDA		HRDPSOA	
z_1	z_2	z_1	z_2	z_1	z_2	z_1	z_2
31040	775	31180.4	785.2	31885.6	808	31978.5	807
32018	804	31570	790.5	32009	812	31993.5	814
32040	820	31862	814.6	32017	837	32009	817
		32015	828	32027	840	32016	821

	32020	833	32035	845	32029	825
					32038	829

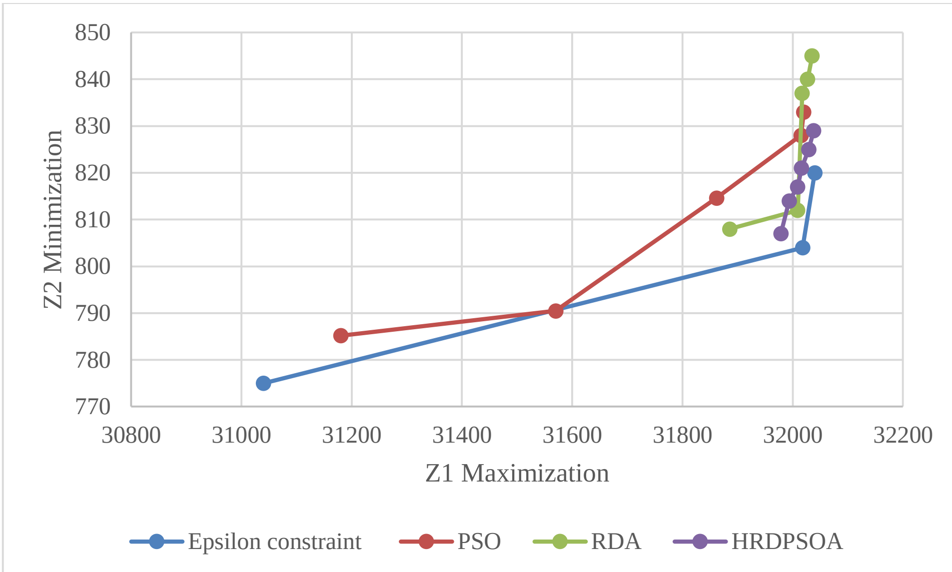


Fig. 5. Non-dominated solutions for the first problem

The results indicated in Table 3 and Fig. 4 confirm that the solutions of HRDPSOA and RDA are highly efficient. They outperform PSO comprehensively. It should be noted that in comparison with the solutions of the exact solver, the solutions of all meta-heuristics are efficient and validated.

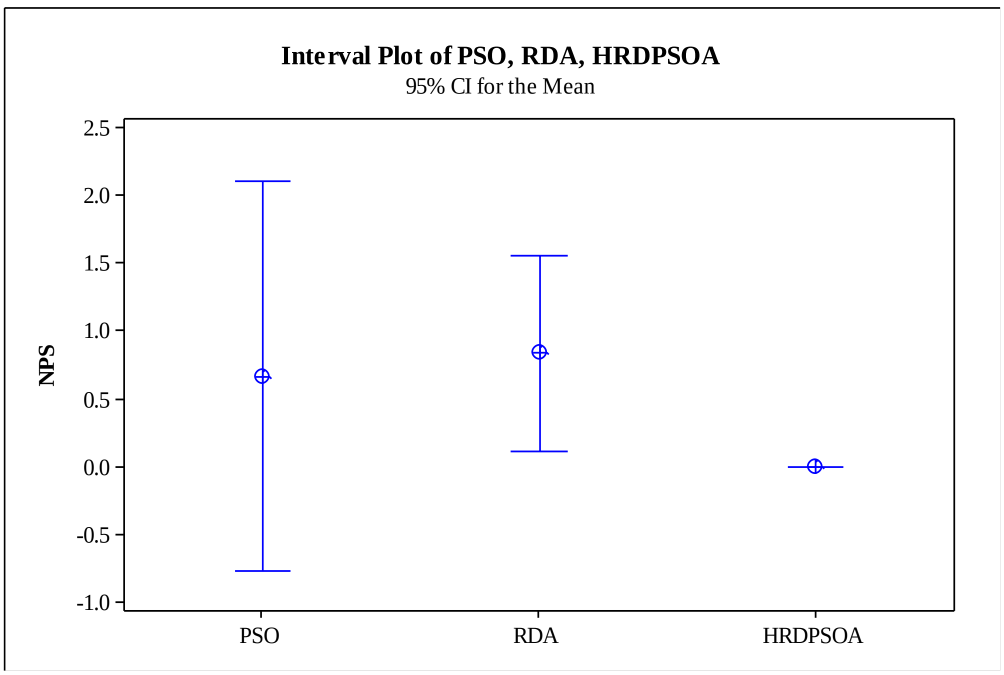
To compare the algorithms, we have utilized four assessment metrics including the number of Pareto solutions (NPS), mean ideal distance (MID), spread of non-dominance solution (SNS), and maximum spread (MS). Except MID, for other metrics, a higher value brings a better capability of the algorithm (Fathollahi-Fard et al., 2020d; 2020a; Karampour et al., 2020). Table 4 provides the results of the meta-heuristics for the assessment metrics. It should be noted that all the algorithms are run for 10 times and the average of the results are provided in the reports. The best values are bold in Table 4.

Table 4. Results of the assessment metrics

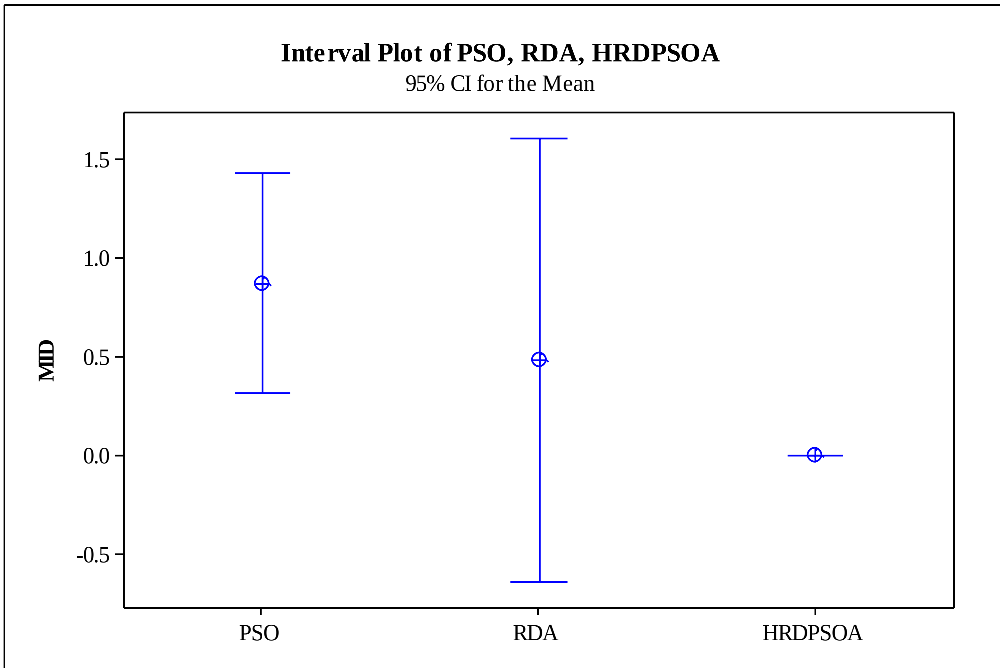
		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
	PSO	5	10	14	15	**18**	16	18	14	**20**	18
NPS	RDA	5	9	16	**17**	16	14	16	**20**	18	16
	HRDPSOA	**6**	**10**	**18**	**17**	17	**18**	**20**	18	16	**20**
	PSO	2.9316	3.7218	4.0318	**2.8172**	3.283	4.372	3.823	3.2288	3.4852	4.3881
MID	RDA	3.0418	2.9103	3.2864	3.2832	4.273	**3.281**	4.201	4.393	4.3882	4.2041
	HRDPSOA	**2.7581**	**2.6418**	**3.1082**	4.3821	**3.032**	3.928	**3.2837**	**2.382**	**3.2034**	**2.9231**
	PSO	23086	20882	3021	3998	4294	3092	3892	3278	**5305**	3902
SNS	RDA	21495	18045	**4046**	4263	**5021**	4397	3617	3822	5220	4201
	HRDPSOA	**26041**	**30166**	3604	**4833**	4374	**4822**	**4903**	**4318**	4683	**4520**
	PSO	19844	25028	22884	20743	23289	24931	22041	**27031**	21302	22033
MS	RDA	18655	20814	24015	26032	26042	**25041**	28403	27832	22033	24392
	HRDPSOA	**20184**	**30219**	**28918**	**28943**	**25043**	22041	**28732**	23012	**25044**	**26032**

The result figuring Table 4 generally confirm that the proposed HRDPSOA is better than PSO and RDA. To show this robustness via statistical tests, we normalize the results of Table 4 and use the interval plot as depicted in Fig. 6.

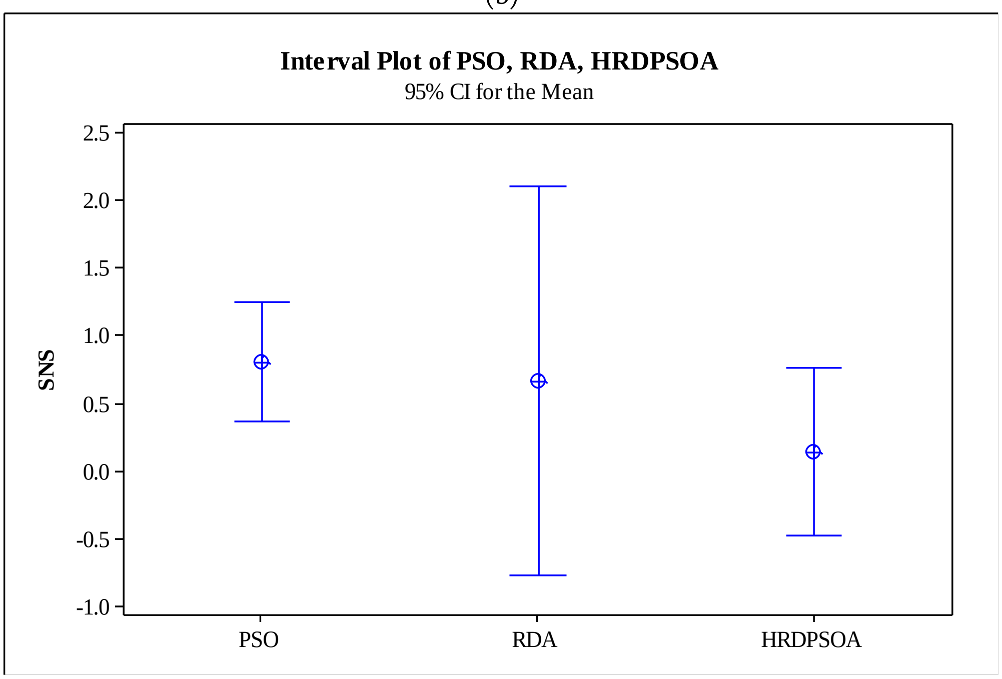
As shown in Fig. 6(a), HRDPSOA is highly better than RDA in the criterion of NPS metric. The RDA is also better than PSO in this metric. Based on the criterion of MID metric (Fig. 6(b)), HRDPSOA outperforms the PSO and consequently, the PSO is slightly better than RDA in this metric. Regarding the SNS metric (Fig. 6(c)), the results are similar to the MID metric. HRDPSOA is significantly better than PSO and RDA. As indicated in Fig. 6(d), the results are similar to the NPS metric. HRDPSOA outperforms the RDA and PSO respectively. It goes without saying that the computational time of the algorithms are very similar and the proposed hybrid meta-heuristic is a little inefficient and based on the quality criterion as given in the assessment metrics, the proposed HRDPSOA is very strong and efficient in this paper.



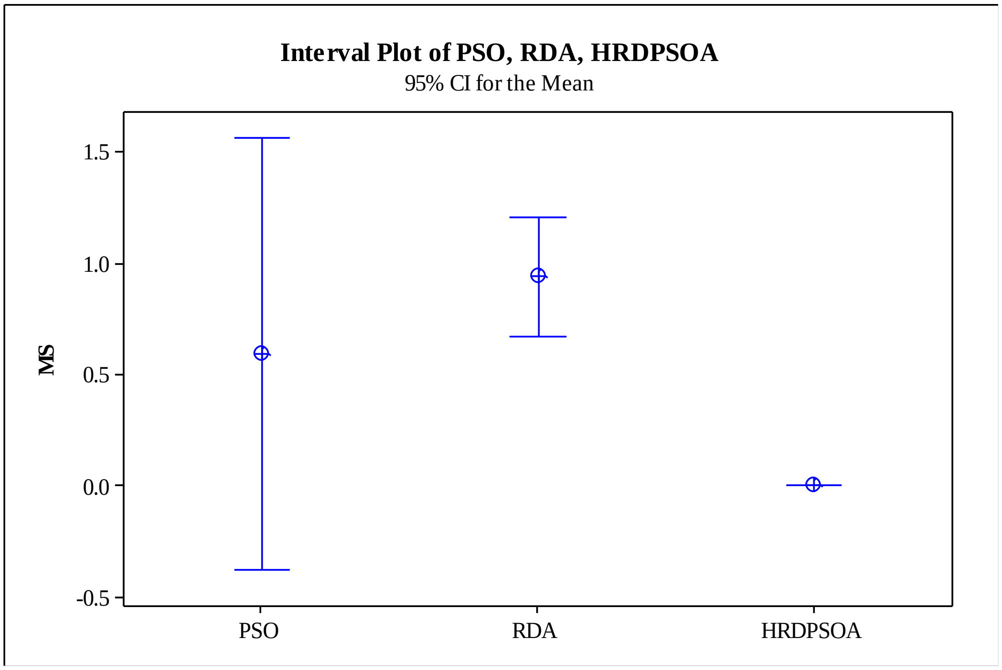
(a)


Interval Plot of PSO, RDA, HRDPSOA
95% CI for the Mean
MID
1.5
1.0
0.5
0.0
-0.5
PSO
RDA
HRDPSOA

(b)


Interval Plot of PSO, RDA, HRDPSOA
95% CI for the Mean
SNS
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
PSO
RDA
HRDPSOA

(c)



(d)

Fig. 6. Interval plots for NPS(a), MID(b), SNS(c) and MS(d)

5.3. Sensitivity Analysis

Since the first objective of the developed model and the base model given in Taleizadeh et al. (2018) has the same constraints, we firstly provide a comparison with their profits. Fig. 7 provides this sensitivity analysis. This shows that our model achieves more profits in all the test studies. This confirms the high efficiency of the model based on the costs and environmental emissions.

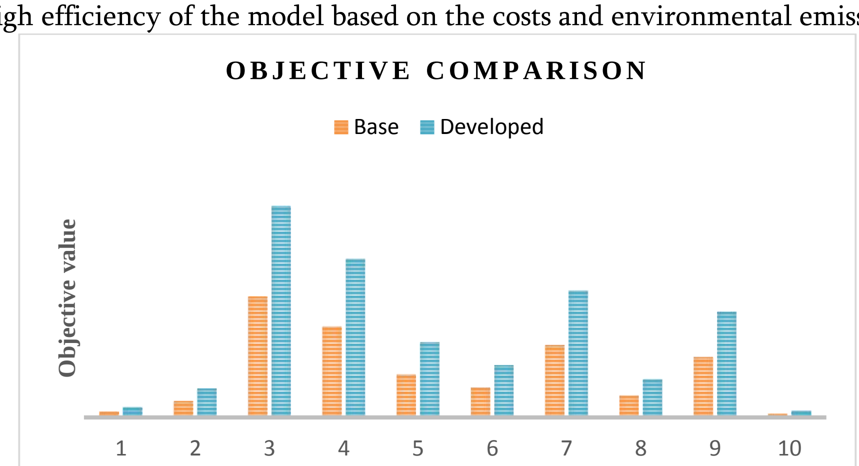


Fig. 7. The first objective function comparison between this study and Taleizadeh et al. (2018)

We also do some sensitivity analyses on the behavior of the objective functions with regards to changes on the shelf life of the products. The main real supposition of the developed sustainable EPQ is the perishability of the products. For our real case study in Kaleh Company, this sensitivity is done. We assume that the shelf life of the products has been increased from 10 days to 3 months. Based on the changes on the average of shelf life products distribution, both objectives are run and among the non-dominated solution generated by our hybrid meta-heuristic as the best algorithm in this study, the average of the objectives is reported. The results of this sensitivity analysis are reported in Table 5 and the behavior of the objectives is depicted in Fig. 8.

Table 5. Results of sensitivity analysis on the shelf life of the products

Number of cases	Shelf life of the products in the average	Z_1	Z_2
C1	10 days	6302.5	1320
C2	1 month	6780.7	1429
C3	2 months	7844.1	1538
C3	3 months	8173.2	1642

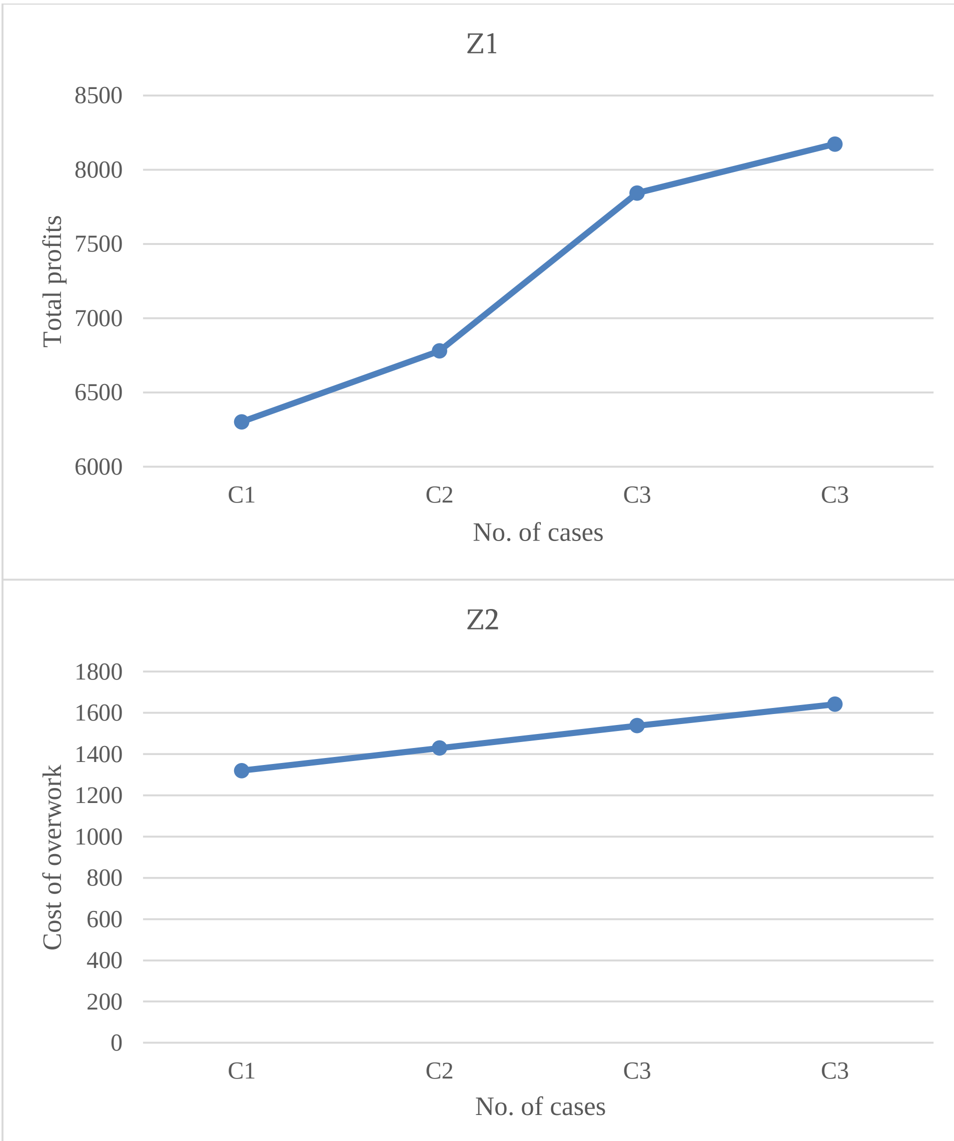


Fig. 8. Sensitivity analysis on the shelf life of the products

The results of the sensitivity analysis confirm that the perishability is very significant in our system. Although an increase in the shelf life of the products, increases the total profits in our system. However, it increases the overwork costs for the workers which makes our system far from the social sustainability.

6. Conclusion, Practical Insights, and Further Research

In this paper, a sustainable EPQ model was developed to determine the optimal quantity of manufacturing for the perishable products under all three pillars of sustainability simultaneously (the TBL approach). The model was subjected to backorder and lost sale as well. Hence, a bi-objective model was provided for solving the problem and assumed deterioration function during storage plus generating defective items for the time of manufacturing. The demand was recognized as a stochastic parameter and finally, we addressed the final model considering lost sales and full backordering by a hybrid meta-heuristic as a combination of RDA as a recent nature-inspired algorithm and PSO as a powerful swarm-based method. The applicability of the proposed model and algorithm was shown in a real case study in Iran from the Kaleh dairy industry. Then, the proposed hybrid algorithm was tuned, validated and compared with its individuals and some sensitivity analyses are done to study the perishability of the developed sustainable EPQ model. From these results, these findings could be helpful for managers to make quick decisions and analyses about the optimum manufacturing and its economic, environmental and social factors, simultaneously.

In conclusion, this paper presents a sustainable EPQ models under two scenarios that would be advantageous for companies in maximization of the total profit, diminishing the environmental pollution, and improving the social justice in the manufacturing systems. A novel hybrid meta-heuristic is also developed. Although this study was so practical and efficient for a real-world setting, many other suppositions can be added for further research. The vehicle routing optimization makes the proposed problem more practical and complex than the current format of this paper. Adding more social factors such as job opportunities can be another interesting addition for future studies. At last but not least, other novel heuristics and meta-heuristics can be suggested for our proposed model and the proposed novel hybrid meta-heuristic can be ordered for solving other complex optimization problems.

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