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RESEARCH ARTICLE

Sustainable fuzzy inventory for concurrent fabrication and material depletion modeling with random substandard items

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Abstract

This study aims to develop a fuzzy inventory model for sustainable concurrent fabrication and material depletion model with randomly selected substandard items. An Economic Production Quantity (EPQ) model was developed using a single-valued neutrosophic number. Substandard items were modeled as random variables. To determine the optimal production strategy, the model was solved numerically using Python's SciPy library to obtain the production quantity, amount of fabrication, capacity of vehicle, fabrication period, depletion period, preventive measures, duration of vehicle and the total cost. The models parameters were estimated using relevant historical data and industry reports. During the fabrication period the demand is uncertain a single-valued triangular neutrosophic number $F_b = \langle(5,980,6000,6500);0.98,0.04,0.03\rangle$ is used to handle uncertain demand and defuzzification is used to demonstrate the crisp value of demand. A numerical example solved with Python shows a total cost of $235,271.60, offering important insights into the model's economic implications.

Keywords: Neutrosophic fuzzy number, Python, Sustainability, Depletion, Substandard items, Fabrication.

Introduction

In recent years business landscapes are changing rapidly. The complex dynamic situation between fabrication and material depletion is very crucial for the organisations trying to increase their potential and maintain a competitive in business. Concurrent fabrication and material depletion emerged as a vital strategy to match supply with demand in real-time, reducing the likelihood of overproduction or underproduction. Nowadays many researchers evolved in inventory models considering concurrent fabrication and material depletion. Sharifi and Taghipour (2019) illustrated an inventory model which integrated production and consumption [1], then Chen B, Jiang J, Zhang J, Zhou Z. shows a learning-based approach to order the inventory systems with lost sales and uncertain supplies [2]. Rahman (2020) established the optimal strategy of an inventory system for perishable goods with hybrid demand dependent on selling price and stock for perishable goods with advance payment-related discount facilities under preservation technology [3]. The importance of sustainability is increasing in inventory models and has accentuate the use of sustainability in production planning. To minimize the environmental impacts integrating sustainable practices into concurrent fabrication and material depletion models for maintaining operational efficiency.

Neutrosophic fuzzy logic is utilized to provide an extensive framework for providing complex systems with advanced analytics. Srinivas and Prabakaran (2020) illustrated that the uncertainty and imprecision can be handled potentially by the neutrosophic fuzzy logic [4]. In decision-making Das S, Roy BK, Kar MB, Kar S, Pamučar D. developed a neutrosophic fuzzy set and its application [5]. However, the organization struggle to optimize the fabrication and inventory management systems in the presence of random substandard items during the fabrication process. These flawed products may result from a number of causes, including human error, machine malfunctions, or flaws in the raw materials. If they are not addressed, they may result in large financial losses, harm to a

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brand's reputation, a decline in consumer confidence, and a reduction in the effectiveness of the supply chain as a whole. Random defective goods should be taken into account in production and inventory management models, according to recent studies. For example, a deteriorating inventory model with an inspection procedure to deal with damaged items was created by Khakzad and Gholamian (2020) [6]. A sustainable production inventory model with a greening degree and two determinants of defective products was also proposed [7].

The development of an improved and practical framework for handling random substandard items in environmental production systems is required because, despite the meaningful contributions made by previous studies on concurrent fabrication and material depletion, there are still a number of research gaps. earlier studies has mostly concentrated on creating inventory models that increase production plan and inventory control while neglecting the effects of occurring subpar products, which is unrealistic in practical situations. Also, research on faulty goods has been found on oversimplified assumptions, such as unchanging substandard rates, neglecting the power of substandard products on inventory control and production scheduling, and failing to account for the entanglement of actual production systems. In order to overcome these situations, this work makes use of Python's capabilities for simulation and random number generation to produce a dynamic and realistic model that accounts for the uncertainties related to randomly defective objects.

This study intends to give a more efficient method for managing random defective items in sustainable production systems, this study aims to provide a more effective approach for optimizing production planning, inventory management, and quality control.The proposed model utilizes neutrosophic fuzzy logic, which was introduced by Florentin Smarandache in 1998 as a generalization of fuzzy logic. Neutrosophic fuzzy logic is also an extension of intuitionistic fuzzy logic, which was introduced by Krassimir Atanassov in 1983. The neutrosophic fuzzy logic approach satisfies the condition that the truth membership value, indeterminacy membership value, and falsity membership value should be between 0 and 1, and the sum of these values should be between 0 and 3 [8]. To date, no studies have examined the effectiveness of a neutrosophic fuzzy logic approach for sustainable fabrication and material depletion models with random substandard items in Python. By integrating neutrosophic fuzzy logic, Python simulation, and sustainability considerations, this study provides a more realistic and effective approach for optimizing production planning, inventory management, and quality control in the presence of random defective items, ultimately contributing to the development of more sustainable and resilient production systems.

A numerical example is illustrated to demonstrate the effectiveness of the proposed model. The following sections comprise the remainder of this paper. Basic definitions, notations, and assumptions are presented in Section 2, mathematical modeling is described in Section 3, a numerical example is demonstrated in Section 4, and conclusions are provided in Section 5.

Methodology

Basic definitions

Fuzzy sets was first introduced to tackle uncertainty and vagueness for decision making problems by Zadeh in 1965. In this section, we covered neutrosophic fuzzy set concepts and basic operations.

Definition (i) Srinivas, S., & Prabakaran, K. (2024)

Suppose a non-empty set χ exists. A neutrosophic set $B \in \chi$ is of the form $B = \{(y, Q(y), R(y), S(y)) : y \in \chi\}$, where each element $y \in \chi$ of the set B is a subset of χ, $0 \le Q(y) + R(y) + S(y) \le 3$. χ has only one element B, which is knoSwn as a neutrosophic number, which can be represented by $B = (Q(y), R(y), S(y))$. The functions $Q(y), R(y), S(y) : \chi \to [0,1]$ define the degree of truth membership, the degree of indeterminacy membership, and the degree of falsity membership, respectively.

Definition (ii) Srinivas, S., & Prabakaran, K. (2024)

Let $S, T \in \chi$. Then their operations are defined as,

$$1. (Q_1(y), R_1(y), S_1(y)) + (Q_2(y), R_2(y), S_2(y)) = \begin{pmatrix} Q_1(y) + Q_2(y) - Q_1(y)Q_2(y), \\ R_1(y)R_2(y), S_1(y)S_2(y) \end{pmatrix}$$

$$2. (Q_1(y), R_1(y), S_1(y)).(Q_2(y), R_2(y), S_2(y)) = \begin{pmatrix} Q_1(y)Q_2(y), R_1(y) + R_2(y) \\ -R_1(y)R_2(y), \\ S_1(y) + S_2(y) - S_1(y)S_2(y) \end{pmatrix}$$

$$3. \lambda(Q_1(y), R_1(y), S_1(y)) = (1 - (1 - Q_1(y))\lambda, R_1(y)\lambda, S_1(y)\lambda), \lambda \in R$$

$$4. (Q_1(y), R_1(y), S_1(y))\lambda = (Q_1(y)\lambda, 1 - (1 - R_1(y))\lambda, (1 - S_1(y))\lambda), \lambda \in R$$

Definition 2.1.3 Srinivas, S., & Prabakaran, K. (2024)

The truth, indeterminacy, and falsehood membership functions of the single-valued triangular fuzzy neutrosophic number $b = ((b_1, b_2, b_3); \gamma_b, \eta_b, \rho_b)$ is a neutrosophic set on R, are defined as follows.

$$Q_1(y) = \begin{Bmatrix} \gamma_b\left(\frac{y - b_1}{b_2 - b_1}\right) & for\, b_1 \le y \le b_2 \\ \gamma_b & for\ y = b_2 \\ \gamma_b\left(\frac{b_3 - y}{b_3 - b_2}\right) & for\, b_2 \le y \le b_3 \\ 0 & for\ otherwise \end{Bmatrix}$$

$$R_1(y)=\begin{cases}\dfrac{b_2-y+\eta_b(y-b_1)}{b_2-b_1} & for\ b_1\le y\le b_2\\ \eta_b & for\ \ x=b_2\\ \dfrac{y-b_2+\eta_b(b_3-y)}{b_3-b_2} & for\ b_2\le y\le b_3\\ 1 & for\ otherwise\end{cases}$$

$$S_1(y)=\begin{cases}\dfrac{b_2-y+\rho_b(y-b_1)}{b_2-b_1} & for\ b_1\le y\le b_2\\ \rho_b & for\ \ x=b_2\\ \dfrac{y-b_2+\rho_b(b_3-y)}{b_3-b_2} & for\ b_2\le y\le b_3\\ 1 & for\ otherwise\end{cases}$$

Where $\gamma_b,\eta_b,\rho_b\in[0,1],b_1,b_2,b_3\in R\ and\ b_1\le b_2\le b_3$

Definition

The fuzzy value is transformed into crisp data using the scoring algorithm

$$F(b)=\frac{1}{12}\left((b_1+2b_2+b_3)(2+\gamma_b-\eta_b-\rho_b)\right)$$

is a triangular neutrosophic number with single value $\gamma_b,\eta_b,\rho_b\in[0,1]$, $b_1,b_2,b_3\in R\ and\ b_1\le b_2\le b_3$

Notations

P_t – The rate of fabrication per unit time
D_t – The rate of demand per unit time
C_a – Cost of acquisition per unit time
S_u – The storage unit of an item per unit time
F_C – Initial costs per unit fabricated in a sub-cycle
C_m – Cost of preventive maintenance in a operation
P_d – The price per unit for disposing of a damaged item
T_e – The cost of transportation per export unit
E_f – The cost of emissions during fabrication for each unit of item
E_h – Emission cost in storage unit for an item each unit of time
E_t – Transportation emission cost
E_m – Emission cost for preventive maintenance
P_C – A single sub-cycle's fabrication period for the machine
P_m – The preventive maintenance period of operation for a single sub-cycle
F_b – The proportion of each batch's faulty products
N – Number of freight needed to get the batch to clients

Decision variables

Q_f – The quantity fabricated in a single cycle.
A_{fs} – The amount of fabrication in a single sub-cycle
V_C – Vehicle capacity
F_p – The fabricating period of a single cycle
C_t – Depletion time in a single cycle
y – The amount of preventive measures conducted in a single cycle.
V_t – The vehicle's duration of travel

Assumptions

1. Damaged items are taken as a random variable.
2. Multi-shipment period is taken.
3. The immediate accounting approach is used to calculate carbon emissions.
4. A cent percentage inspection process is done.
5. Demand is uncertain
6. Inventory management includes preventive maintenance plan.

Model formulation

Demand is met during the production cycle. The things produced in a single cycle are consumed during both the demand and production periods of that cycle. During the fabrication period the product A_{fs} is produced at a time P_C then the inspection period starts at a time P_m, while the inspection period damaged items Q_f $(1-F_b)A_{fs}$ are checked and removed P_d .The level of transportation is predetermined by corporate policy and the shipment period per vehicle is V_t with the capacity V_C. Additionally, there is an assumption that the system produces defective objects after the fabrication period F_p the defective objects are collected and disposed by the completion of the fabrication process. In this period to avoid the shortages in fabrication and holding time. Considering F_b A_{fs} is the damaged item in each fabrication unit, demand of the product is uncertain so the value of demand is determined by Neutrosophic fuzzy number, depletion of demand during maintenance and fabrication is satisfied by $(1-F_b)A_{fs}$

Each sub cycle has the following equation: $(1-F_b)A_{fs}-D_tP_m\succ 0$ (1)

Entire cycle is the sum of the fabrication and the demand

$$C=F_p+C_t \quad (2)$$

By applying the linear gradient formula $\tan\delta=P_t-D_t=\dfrac{A_{fs}}{P_c}$ (3)

Where $A_{fs}=(P_t-D_t)P_c$. The fabrication time is calculated as $F_p=y(P_c+P_m)$ (4)

Preventive maintenance is described as $y=\dfrac{Q_f}{(P_t-D_t)P_c}$ (5)

By applying the linear gradient formula $\tan\beta=\dfrac{(1-F_b)\rho}{C_t}$ (6)

Demand per unit of time is denoted as $C_t = \frac{(1-F_b)\rho}{D_t}$ (7)

$$C_t = \frac{y\left[(1-F_b)(P_t - D_t)P_c - (1-F_b)D_tP_m\right]}{D_t} \quad (8)$$

Shipment period is denoted by dividing the demand by number of shipment

$$S_p = \frac{1}{N}\left[\frac{y\left[(1-F_b)(P_t - D_t)P_c - (1-F_b)D_tP_m\right]}{D_t}\right] \quad (9)$$

The capacity of vehicle is denoted as

$$V_C = \frac{(1-F_b)\left[y(P_t - D_t)P_c - yD_tP_m\right]}{N} \quad (10)$$

Setup cost $S_C + \frac{Q_f}{(P_t - D_t)P_c}F_C$ (11)

Acquisition cost $A_C = C_aQ_f$ (12)

Discharging charges per unit cycle is denoted as

$$D_tC_a = P_dF_b\frac{Q_f}{(P_t - D_t)P_c}\left[(P_t - D_t)P_c - D_tP_m\right] \quad (13)$$

Shipment Cost $S_t = NT_e$ (14)

In this model the fabrication and demand are met at the same time. So there is the possibility of shortage occurrence. To overcome this situation, $(1-F_b)A_{fs} - D_tP_m \succ 0$ should be reliable. Before and after implementation of maintenance operations is as follows

$$\rho_1 = j(P_t - D_t)P_c - (j-1)D_tP_m$$

$$\forall j = 1,\ldots,y$$

$$\rho_2 = j(P_t - D_t)P_c - (j-1)D_tP_m$$

$$\forall j = 1,\ldots,y$$

The average inventory level throughout the manufacturing period is given as

$$A_i = \sum_{j=1}^{y}\left[\left(\frac{\rho_{j1} + \rho_{(j-1)^2}}{2}\right)P_c + \left(\frac{\rho_{j1} + \rho_{(j-1)^2}}{2}\right)P_m\right]$$

Solving the above equation

$$A_i = \frac{1}{4}\left[\begin{array}{l}\frac{2Q_f^2}{(P_t - D_t)} - \frac{2Q_fD_tP_m\left(Q_f - (P_t - D_t)P_c\right)}{(P_t - D_t)^2P_c} \\ + \frac{2Q_fP_cP_m\left(Q_f - (P_t - D_t)P_c\right)}{(P_t - D_t)P_c} - \frac{2Q_f^2D_tP_m^2}{(P_t - D_t)^2P_c^2}\end{array}\right] \quad (15)$$

Carrying cost during fabrication time

$$C_h = S_u\left[\begin{array}{l}\frac{2Q_f^2}{(P_t - D_t)} - \frac{2Q_fD_tP_m\left(Q_f - (P_t - D_t)P_c\right)}{(P_t - D_t)^2P_c} \\ + \frac{2Q_fP_cP_m\left(Q_f - (P_t - D_t)P_c\right)}{(P_t - D_t)P_c} - \frac{2Q_f^2D_tP_m^2}{(P_t - D_t)^2P_c^2}\end{array}\right] \quad (16)$$

Carrying cost during demand time

$$C_d = S_u\left(\frac{N-1}{2N}\right)\left(\frac{(1-F_b)\left[Q_f - \frac{Q_f}{(P_t - D_t)P_c}D_tP_m\right]^2}{D_t}\right) \quad (17)$$

Sustainability cost $S_{ec} = E_fD_t$ (18)

Carrying emission cost

$$E_h\left(\begin{array}{l}\frac{Q_f^2}{2(P_t - D_t)} - \frac{Q_fD_tP_m\left(Q_f - (P_t - D_t)P_c\right)}{2(P_t - D_t)^2P_c} \\ + \frac{Q_fP_m\left(Q_f - (P_t - D_t)P_c\right)}{2(P_t - D_t)P_c} - \frac{Q_f^2D_tP_m^2}{2(P_t - D_t)^2P_c^2} + \\ \left(\frac{N-1}{2N}\right)\left(\frac{(1-F_b)\left[Q_f - \frac{Q_f}{(P_t - D_t)P_c}D_tP_m\right]^2}{D_t}\right)\end{array}\right) \quad (19)$$

Emission cost during transportation $T_s = E_tN$ (20)

Emission cost for preventive maintenance

$$PM_e = E_m\frac{Q_f}{(P_t - D_t)P_c} \quad (21)$$

Total cost

$$\begin{array}{l}TC(Q_f) = S_c + \frac{Q_f}{(P_t - D_t)P_c}F_C + \frac{Q_f}{(P_t - D_t)P_c}C_m + C_aQ_f \\ +P_dF_b\frac{Q_f}{(P_t - D_t)P_c}\left[(P_t - D_t)P_c - D_tP_m\right] \\ +NT_e + S_u\left[\begin{array}{l}\frac{Q_f^2}{2(P_t - D_t)} - \frac{Q_fD_tP_m\left(Q_f - (P_t - D_t)P_c\right)}{2(P_t - D_t)^2P_c} \\ + \frac{Q_fP_m\left(Q_f - (P_t - D_t)P_c\right)}{2(P_t - D_t)P_c} - \frac{Q_f^2D_tP_m^2}{2(P_t - D_t)^2P_c^2}\end{array}\right] \\ +S_u\left(\frac{N-1}{2N}\right)\left(\frac{(1-F_b)\left[Q_f - \frac{Q_f}{(P_t - D_t)P_c}D_tP_m\right]^2}{D_t}\right) \\ +E_fD_t + E_h\left(\begin{array}{l}\frac{Q_f^2}{2(P_t - D_t)} - \frac{Q_fD_tP_m\left(Q_f - (P_t - D_t)P_c\right)}{2(P_t - D_t)^2P_c} \\ + \frac{Q_fP_m\left(Q_f - (P_t - D_t)P_c\right)}{2(P_t - D_t)P_c} - \frac{Q_f^2D_tP_m^2}{2(P_t - D_t)^2P_c^2} + \\ \left(\frac{N-1}{2N}\right)\left(\frac{(1-F_b)\left[Q_f - \frac{Q_f}{(P_t - D_t)P_c}D_tP_m\right]^2}{D_t}\right)\end{array}\right)\end{array}$$

Multiply $\frac{1}{T_c}$ to the total cost of the system

$$TC(Q_f)\times\frac{1}{T_c}=\frac{1}{[P_tP_c-F_bP_tP_c+F_bD_tP_c+F_bD_tP_m]}\left\{\frac{S_CD_tP_c(P_t-D_t)}{Q_f}\right.$$

$$+F_cD_t+C_mD_t+C_aD_tP_c(P_t-D_t)+\frac{NT_eD_tP_c(P_t-D_t)}{Q_f}$$

$$+P_dF_bD_tP_c(P_t-D_t)\left(1-\frac{D_tP_m}{P_c(P_t-D_t)}\right)+\frac{NE_tD_tP_c(P_t-D_t)}{Q_f}$$

$$+E_mD_t+S_u\left[\frac{Q_fD_tP_c}{2}-\frac{D_t^2P_m(Q_f-(P_t-D_t)P_c)}{2(P_t-D_t)}\right.$$

$$\left.+\frac{D_tP_m(Q_f+(P_t-D_t)P_c)}{2}-\frac{Q_fD_t^2P_m^2}{2P_c(P_t-D_t)}\right]$$

$$+\frac{E_fD_t^2P_c(P_t-D_t)}{Q_f}+S_u\left(\frac{N-1}{2N}\right)(1-F_b)(P_t-D_t)Q_fP_c\left(1-\frac{D_tP_m}{P_c(P_t-D_t)}\right)^2$$

$$+E_h\left[\frac{Q_fD_tP_c}{2}-\frac{D_t^2P_m(Q_f-(P_t-D_t)P_c)}{2(P_t-D_t)}+\frac{D_tP_m(Q_f+(P_t-D_t)P_c)}{2}\right.$$

$$\left.\left.-\frac{Q_fD_t^2P_m^2}{2P_c(P_t-D_t)}+\left(\frac{N-1}{2N}\right)(1-F_b)(P_t-D_t)Q_fP_c\left(1-\frac{D_tP_m}{P_c(P_t-D_t)}\right)^2\right]\right\}$$

Differentiating the overall cost with respect to Q_f we obtain

$$Q_f^*=\sqrt{\frac{D_tP_c(P_t-D_t)\left[S_C+NT_eD_t+E_fD_t+NE_t\right]}{(E_h+S_u)\left[\left(\frac{N-1}{2N}\right)(1-F_b)(P_t-D_t)P_c\left(1-\frac{D_tP_m}{P_c(P_t-D_t)}\right)^2\right]+(E_h+S_u)\left[\frac{D_tP_c}{2}-\frac{D_t^2P_m}{2(P_t-D_t)}+\frac{D_tP_m}{2}-\frac{D_t^2P_m^2}{2P_c(P_t-D_t)}\right]}} \quad (21)$$

Results and discussion

Traditional inventory models have primarily overlooked the impact of randomly occurring defective items, instead depending on the logical presumption that every item produced is of perfect quality.[7] Random substandard items in the production cycle present a significant challenge for manufacturing organisations looking to optimise production and inventory management.[8] The findings of this study demonstrate how efficiently the suggested sustainable concurrent fabrication and material depletion model manages random substandard items, producing significant outcomes like production quantity, fabrication amount, vehicle capacity, fabrication period, depletion period, preventive measures, and vehicle duration. The economical implications of the concept are shown with a numerical example that was solved using Python and yielded a total cost of $235,271.60. The results illustrate how single-valued triangular neutrosophic numbers may effectively handle variable demand during the production phase and offer important insights into the effects of random substandard goods on sustainable concurrent fabrication and material depletion models.

Numerical example

To illustrate the application of the proposed model. Numerical example is presented it includes Acquisition cost, Shipment Cost, Carrying cost, Sustainability cost, Emission cost, Setup cost, Preventive Maintenance cost are formulated. The following parameters are taken from Fallahi A, Azimi-Dastgerdi A, Mokhtari H.[8] The following are the parameters taken for solution procedure $P_t=12,000, C_a=50$

$$P_d=3, S_C=1,500, F_C=3, C_m=200$$

$$S_u=0.15, T_e=500, P_C=0.5, P_m=0.02, N=5$$

$$E_f=30, E_h=10, E_t=40, E_m=25$$

Here the demand of the fabrication and depletion model is uncertain. Neutrosophic fuzzy number is incorporated to deal with uncertainty. The triangular neutrosophic fuzzy number for demand is given as $F_b=\langle(5,980,6000,6500);0.98,0.04,0.03\rangle$. The rate of damaged items are taken as a random variable. Using python programming the numerical example is solved and the optimal values are shown in Table 1. we obtained the production quantity $Q_f^*=11303.63$, amount of fabrication $A_{fs}=3031.8$, capacity of vehicle $V_c=2031.897$, fabrication period $S_p=0.34$, depletion period $S_p=0.34$, preventive measures $y=3.73$, duration of vehicle $S_p=0.34$, and the total cost of $235,271.60 of the model.

Conclusion

This study has made a significant contribution to the field of sustainable manufacturing by developing sustainable concurrent fabrication and material depletion model with randomly selected substandard items. The proposed model has demonstrated its effectiveness in addressing the complexities of uncertain demand using neutrosophic fuzzy number and random substandard items, providing valuable insights into the economic implications of sustainable manufacturing practices. The key outputs of the model, including production quantity, fabrication period, depletion period, and total cost, have important implications for manufacturers seeking to optimize their production processes, minimize costs, and reduce their environmental footprint. The integration of substandard items as random variables and demand as single-valued triangular neutrosophic fuzzy numbers has enhanced the model's accuracy and applicability, making it a valuable tool for decision-makers in the manufacturing sector. A numerical example, solved using Python programming, has demonstrated the potential of the proposed model to yield significant cost savings, with a total cost of $235,271.60. This study's findings have significant implications for the development of more sustainable and resilient production systems. This model could be improved in the future by adding trade-credit considerations, stochastic processes, and multi-item models, which would present chances for more study and advancement.

Data availability statement

The data used in this paper were obtained from [10] Fallahi A, Azimi-Dastgerdi A, Mokhtari H. A sustainable production-inventory model joint with preventive maintenance and multiple shipments for imperfect quality items. Scientia Iranica. 2023 Jun 1;30(3):1204-23. https://doi.org/10.24200/sci.2021.55927.4475

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Conflict of interest

The author declare no conflict of interest.

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