# Rework Warehouse Inventory Model for Product Distribution with Quality Conservation in Neutrosophic Environment

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**Abstract**

In general, companies are investing a lot of energy and time in conserving the quality of the products. The customers use the attribute of quality as the measuring index of the efficiency of these companies. Quality sustenance is not a phase, but it is a process which must be carried out till the product reaches the end consumer. This is possible by expanding the mechanisms of quality conservation to the spheres of product distribution in addition to product production. In view of it, this research work develops an inventory model with the idea of rework warehouse for the first time. The model formulated in this paper is discussed in a crisp sense and later extended to neutrosophic environments with the intention of making it more accommodative to various business constraints. The numerical example presented in this paper substantiates the proposed model with the application of Particle Swarm optimization. Sensitivity analysis is made with modifications with the changes of crisp and neutrosophic parameters. The model introduced in this work supports decision makers in deriving optimal solutions to the inventory problem associated with quality constraints and this work shall also be extended with the inclusion of other cost parameters, assumptions and constraints associated with product distribution.

**Keywords:** Rework warehouse; Neutrosophic; Inventory model; Quality

## 1. Introduction

The production process is both continuous and cyclic in nature. It is perpetual to fulfil the demands of the customers and cyclic to enable production eco-friendly. Inventory management is crucial for incessant product production and quality sustenance is significant for upholding product branding. The production sectors are occupied with various responsibilities not just confined to the production domain but also to product distribution. It is indeed a great challenge for the manufacturing sectors to preserve the quality of the products from the time of production to the time of distribution. Production and distribution are the two key facets for every successful manufacturing firm. The production aspects shall be monitored by employing effective strategies and distribution aspects shall be effectively handled through warehouses. Every production firm upkeeps warehouses for stocking either raw materials, semi-finished or finished products to facilitate product distribution process. Warehouse management is a vital function of the manufacturing firms to expedite product stocking before distribution. In addition to product storage, product protection is another significant function of warehouses. The finished products are transported from the production centers to the warehouses before being delivered to the



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customers through distribution centers. Thus, the warehouses are serving as junction points between production and distribution centers.

Generally, the products after quality check are moved to the warehouses but the conservation of quality is not guaranteed at the epoch of the products reaching the warehouses due to collateral transportation and locomotion damages. Since quality conservation is not guaranteed, it is essential for the warehouses to perform an additional function of quality restoration through rework to aid inventory management. The warehouses have to be embedded with the facilities of reworking the defective items to avoid returning products back to the production centers for repairs. Thus, this paper proposes the integration of the concept of rework warehouse with inventory model which has several benefits for effective product distribution with quality conservation. Researchers have formulated various inventory models associating warehouses, remanufacturing, repairing service and quality constraints. There are several models available in literature but the inventory models with rework warehouses have not been conceptualized. This has motivated the authors to introduce a new genre of neutrosophic based inventory models encompassing warehouses with additional features of reworking defective items for quality restoration. Inventory models comprise several cost parameters contributing to total costs, total revenue, and total profit. As distortions and fluctuations lie in cost estimation, the representations of neutrosophic sets are used to tackle the problems of such kinds. Neutrosophic based inventory models are more comprehensive and accommodating to catch up with such indeterminate circumstances.

This research work also put forth the following research questions.

(i) Why do manufacturing firms require rework warehouses?
(ii) How do these warehouses contribute to quality sustenance?
(iii) Do these workhouses support product distribution?

The contents of the paper are structured as follows. Section 2 presents the state of art of inventory models with warehouses and remanufacturing, section 3 describes the necessity of augmenting warehouses with reworking facilities, section 4 presents the basics of neutrosophic sets, section 5 comprises crisp and neutrosophic model development, section 6 validates the models with PSO optimization techniques, section 7 compares the efficiency of the models with sensitivity analysis, section 8 sketches the industrial implications of the proposed models, and the last section concludes the work.

## 2. Literature Review

Inventory management is essential for all the production activities to be incessant. Inventory modelling is required to maintain appropriate inventory levels. Harris proposed the inventory model based on economic order quantity. Taft later extended the model to the production-based scenario. The inventory models are extended and developed further by the inventory researchers to meet the production demands. One of the core important aspects that earned the concern of the production sectors is 'Quality control', which shall also be referred to as Quality sustenance or Quality maintenance. How shall the quality of the products be conserved? Every production sector aims to produce quality products with quality input and quality production technology. But the question of conserving the quality of the products till the period it reaches the end customer hurdles the production sectors. Although these sectors are aware of the strategies of quality conservation from a theoretical perspective, it is quite challenging for them to put into practice. The production of defective products shall be identified after inspection and then be reworked. This is one of the ways of handling defective items during and after production. Researchers have devised inventory models to handle defective items. To mention some of the recent works, Guatam et al. recommended salvaging damaged products for a secondhand market or considering recycling utilising third-party services [1]. Prior to the goods reaching the buyers, Anil Kumar et al. contemplated either repairing the faulty products or refunding the money with penalties [2]. A model created by Sarkar et al. calls for a second inspection of the reworked items [3]. According to Lok et al., defective goods are either replaced with more expensive, locally sourced goods of comparable quality or shipped for repairs at an extra expense to the makeup margin [4]. Yang et al. created an inventory model where sellers transfer damaged goods to secondary markets where they sell for less money [5]. These are some of the contributions of inventory models to handle defective items.

The production sectors manitain warehouses to stock their products before distributing to their end customers. There are many different types of warehouses such as Public warehouse, Private warehouse, Contract Warehouse, Climate controlled-warehouse, Smart warehouses, Reverse logistics warehouses and so on. Depending upon their reqirement the production sector maintains one, two or even multiple warehouses [6-12]. Hartley is the first to introduce the two-warehouse inventory model [13].



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The warehouses also play as centres of collecting and delivering back the returned defective products from the customers. From these warehouses the defective products are sent to the production centres for remanufacture and repair services and again the corrected products are sent back to the warehouses for redistribution[14,15,16].

The above discussed inventory models are discussed in fuzzy by the researcehrs, some of the recent contributions of fuzzy inventory model are two warehouses model by Malik et al [17], repairal treatment of imperfect items by Tahami et al [18], single stage back order model by Dinagar et al [19], scrap cum defective items with inspection by Garg et al [20]. The warehouse and defectives handling inventory models are also developed with neutrosophic representations as extensions of fuzzy based models. The philosophy of neutrosophy developed by Smarandache play a key role in designing inventory models with the inclusion of indeterminate parameters [21]. Mullai et al framed a neutrosophic backorder inventory model with triangular neutropshic numbers and a model to handle shortages [22]. Surya et al developed neutrosophic models to deal with multi items an defective products [23]. Martin et al [24] and Mohanta et al [25] developed a smart inventory model with neutrosophic parameters. Mullai et al [26], Othman et al [27] formulated neutrosophic based models with neutrosophic random variables. Garg et al [28] and Sugapriya et al [29] designed a container inventory model with neutrosophic bipolar representations. Rajeswari et al used octagonal fuzzy neutrosphic number in model development [30]. Sarkar et al developed neutrosophic based green inventory management model [31]. Researchers have also combined programming approaches with neutrosophic based inventory modelling. Neutrsophic fuzzy geometric programming approach in overage management by Jayanthi et al [32], Neutrosophic programming in shortage based models by Das et al [33], Artificial bee colony algorithm in defectives handling by Supakar et al.[34] Bhavani et al integrated particel swarm optimization algorithm in constructing neutrosophic model to handle defective and deteriorating items [35]. The following are the key findings of the above described literature with respect to the developemnt of the inventory models.

(i) The inventory models on warehouses and defective handling are ample and many new inventory models are modelled with several constraints and optimized using different approaches.
(ii) The number of neutrosophic based inventory models are very limited in the areas of managing defective items and not much contribution to warehouse-based inventory models.
(iii) The concept of rework warehouse is not dealt with inventory model to the best of our search.

Also, from the deep analysis in the perspective of modelling cost parameters of warehouses and defective items-based inventory models especially with two-way process, it is inferred that the costs associated with two-way transportation and other sub costs burdens the production sectors. As the chances of quality distortion is unpredictable and occurrences of defects in products are quite inevitable, it is essential for the production sectors to devise alternate strategies for minimizing defects and maximizing quality. The production sectors shall augment the infrastructure of the warehouse with the provisions of reworking the minor defects and major defects to some extent. It is essential to equip the warehouses with reworking capacities to minimize the costs and risks associated with the two-way transportation. Also, the chances of indeterminacy will be high at such instances, hence, to handle such challenging aspects, an inventory model with rework warehouse is formulated with neutrosophic cost parameters. Adding to it, the PSO algorithm is used as a solving approach for obtaining optimal values. As this algorithm yields promising and more convincing results, this algorithm is adopted in this research work.

## 3. Significance of Rework Warehouse

A warehouse is a building that is predominantly used in storage of materials. It also helps in accomplishing the functions of tracking and distribution of the products. Generally as the production centres are located in the outskirts, the manufacturing industries are spending huge amounts of money for transporting the products to the market places. But certainly some spaces are required to stock the products temporarily before delivering the products to the end customer. This is why these manufacturing industries are investing in either owning or renting warehouses based on their requirements. Let us imagine a situation where the products are unpacked from manufacturing centres, it is quite a common practice of these firms to conduct quality inspection to identify the defective products before transporting them to the warehouses. But still, there are several chances for these perfectly packed products to become physically damaged at times of loading and unloading. There are also chances for these products to get damaged during the time of transportation. In Spite of sealed packaging, there is a probability of these products getting damaged during product locomotion to warehouses and also the human errors of handling may contribute to product damage while stocking products in the warehouses. Thus it is observed that the chances of occurrence of product damages are high in the following instances

(i) Loading and unloading of products during locomotion of the products to the warehouses
(ii) Human errors in handling products in warehouses
(iii) Packaging errors



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As customers are expecting quality products, many of the firms are conducting quality checks before product delivery to avoid product returns. If the defective products are identified, they are immediately sent back to the production firms for repair. This causes additional expenses for the firms. Suppose if the defects are of minor kind it certainly causes a huge financial burden for these firms. If the warehouses have the provision of repairing these errors, then the additional transportation and other associated expenses incurred shall be nullified. This is why the manufacturing sectors need to have rework warehouses for quality check and quality restoration. If these warehouses consist of provisions of handling these defects then the products will be delivered on time with quality conserved. The advantages of these kind of rework warehouses are described as follows:

**(i) Quality Restoration**

Quality is the most essential and expected key feature of the products. The rework warehouses facilitate in restoring the quality of the products by mending the defects present in the products. Quality conservation is one the significant attributes of rework warehouses

Thus the rework warehouses are highly competent in smoothening product distribution with the above described characteristics. The arguments discoursed in favour of rework warehouses substantiates its vital role in quality conservation and product distribution.

**(ii) Effective Inventory Management**

The rework warehouses play a vital role in effective inventory management at times of product distribution. If the defective items are not repaired, then it will certainly affect the quantity of the products to be delivered to the end customers. If the defective products are continually treated then the inventory remains undisturbed.

**(iii) Customer Credentials**

The production firms shall acquire the credentials of the customers if rework warehouses are in practice. As these kinds of warehouses facilitate prompt delivery of quality products the chances for the firms gaining customer loyalty is very high.

**(iv) Economic Benefits**

The warehouses embedded with the facilities of reworking the defective items prevents financial burden. The costs of transportation of warehouses to production centres and then back to customers will be saved and it shall be utilized for establishing the provision of repairing the defective items in the warehouses. Thus these warehouses have economic benefits.

**(v) Environmental Benefits.**

As these rework warehouses avoid transportation of the defective items back to the production centres, it certainly serves as ecofriendly initiative. The production sectors are hurdled with many environmental problems caused by transportation. The rework warehouses will certainly help in alleviating the carbon effects.

**(vi) Social Benefits**

The firms are given opportunities to exercise their citizenship responsibilities through these rework warehouses. The effective functioning of these warehouses contribute to the social sustainability of these firms to a great extent. As the industrial sectors are called for creating carbon neutral communities, the establishment of such warehouses are one of the finest ways of achieving the sustainable development goals.

## 4. Fundamentals of Neutrosophic Sets.

This section presents the basic definitions of neutrosophic sets.

### 4.1 Neutrosophic Sets

A truth-membership function, an indeterminacy-membership function, and a falsity-membership function, each of which is defined from X→ [0,1], each separately characterise a neutrosophic set.

### 4.2 Arithmetic Operations of Neutrosophic Sets

Let $X = <(\alpha_1, \beta_1, \gamma_1, \delta_1): \vartheta_A, \mu_A, \rho_A>$ and $Y= <(\alpha_2, \beta_2, \gamma_2, \delta_2): \vartheta_B, \mu_B, \rho_B>$ be two single valued neutrosophic numbers and σ not equal to 0, then

1) $X + Y = <(\alpha_1 + \alpha_2, \beta_1 + \beta_2, \gamma_1 + \gamma_2, \delta_1 + \delta_2): \vartheta_A \wedge \vartheta_B, \mu_A \vee \mu_B, \rho_A \vee \rho_B>$



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2) X-Y = $<(\alpha_1 - \delta_2, \beta_1 - \gamma_2, \gamma_1 - \beta_2, \delta_1 - \alpha_2): \vartheta_A \wedge \vartheta_B, \mu_A \vee \mu_B, \rho_A \vee \rho_B >$

3) XY$=< (\alpha_1\alpha_2, \beta_1\beta_2, \gamma_1\gamma_2, \delta_1\delta_2): \vartheta_A \wedge \vartheta_B, \mu_A \vee \mu_B, \rho_A \vee \rho_B > (\delta_1 > 0, \delta_2 > 0)$

$=< (\alpha_1\delta_2, \beta_1\gamma_2, \gamma_1\beta_2, \delta_1\beta_2): \vartheta_A \wedge \vartheta_B, \mu_A \vee \mu_B, \rho_A \vee \rho_B > (\delta_1 < 0, \delta_2 > 0)$

$=< \delta_1\delta_2, \gamma_1\gamma_2, \beta_1\beta_2, \alpha_1\alpha_2: \vartheta_A \wedge \vartheta_B, \mu_A \vee \mu_B, \rho_A \vee \rho_B > (\delta_1 < 0, \delta_2 < 0)$

4) X/Y $=< (\alpha_1/\delta_2, \beta_1/\gamma_2, \gamma_1/\beta_2, \delta_1/\beta_2): \vartheta_A \wedge \vartheta_B, \mu_A \vee \mu_B, \rho_A \vee \rho_B > (\delta_1 > 0, \delta_2 > 0)$

$=< \delta_1/\delta_2, \gamma_1/\gamma_2, \beta_1/\beta_2, \alpha_1/\alpha_2: \vartheta_A \wedge \vartheta_B, \mu_A \vee \mu_B, \rho_A \vee \rho_B > (\delta_1 < 0, \delta_2 > 0)$

$=< (\delta_2/\alpha_1, \gamma_2/\beta_1, \beta_2/\gamma_1, \beta_2/\delta_1): \vartheta_A \wedge \vartheta_B, \mu_A \vee \mu_B, \rho_A \vee \rho_B > (\delta_1 < 0, \delta_2 < 0)$

5) $\sigma X =< (\sigma\alpha_1, \sigma\beta_1, \sigma\gamma_1, \sigma\delta_1): \vartheta_A, \mu_A, \rho_A > \quad (\sigma > 0)$

$=< (\sigma\delta_1, \sigma\gamma_1, \sigma\beta_1, \sigma\alpha_1): \vartheta_A, \mu_A, \rho_A > \quad (\sigma < 0)$

6) $X^{-1} =< \left(\frac{1}{\delta_1}, \frac{1}{\gamma_1}, \frac{1}{\beta_1}, \frac{1}{\sigma_1}\right): \vartheta_B, \mu_B, \rho_B > X \neq 0$

**4.3 Defuzzification of Neutrosophic set**

The respective score value K(X) by defuzzifying a single value trapezoidal neutrosophic number $X =< (\alpha, \beta, \gamma, \delta): \vartheta, \mu, \rho >$ is given by $K(X) = \frac{1}{12}[\alpha_1 + \beta_1 + \gamma_1 + \delta_1] \times (2 + \vartheta - \mu - \rho)$

## 5. Model Development

In this section an inventory model is formulated with rework warehouse mangement. The model intends to handle the defective items in the warehouse by identifying the defects of two kinds which could be handled by tooling and non-tooling manners of repairing.

**5.1 Notations:**

$z$: Lot size is received from the production place

$p$: Production Cost per unit

$D$ : Demand rate of the product

$P$: Total Percentage of re-workable items

$P_{R_1}$ : Percentage of re-workable items in the lot which has minor defects which can be handled without tooling.

$P_{R_2}$ : Percentage of re-workable items in the lot which has major defects which can be handled with tooling.

$t_1$ : Inspection period

$t_2$ : Period till receiving the reworked minor defective items

$t_3$ : Period till receiving the reworked major defective items

$t_4$ : Remaining period to consume the entire inventory

$Y_1$ : Inventory level after the inspection period

$Y_2$ : Inventory level after separating the minor and major reworkable items

$Y_3$ : Inventory level just before receiving the reworked minor defective items

$Y_4$ : Inventory level just after receiving the reworked minor defective items

$Y_5$ : Inventory level just before receiving the reworked major defective items

$Y_6$ : Inventory level just after receiving the reworked major defective items

$S_p$ : Selling price per unit of good quality items

$H_c$ : Holding cost per unit

$I$ : Inspection cost per unit

$r$ : Inspection rate

$l_1$ : Rework rate of minor defective items



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$l_2$ : Rework rate of major defective items

$T$ : Cycle length

**5.2 Assumptions:**

1) The quantity of good items is sufficient to satisfy the demand phase during the inspection period $t_1$
2) The quantity of good items and minor repaired items are sufficient to satisfy the demand phase during the period $t_2$
3) $\frac{yP_{R_1}}{l_1} < \frac{yP_{R_2}}{l_2}$

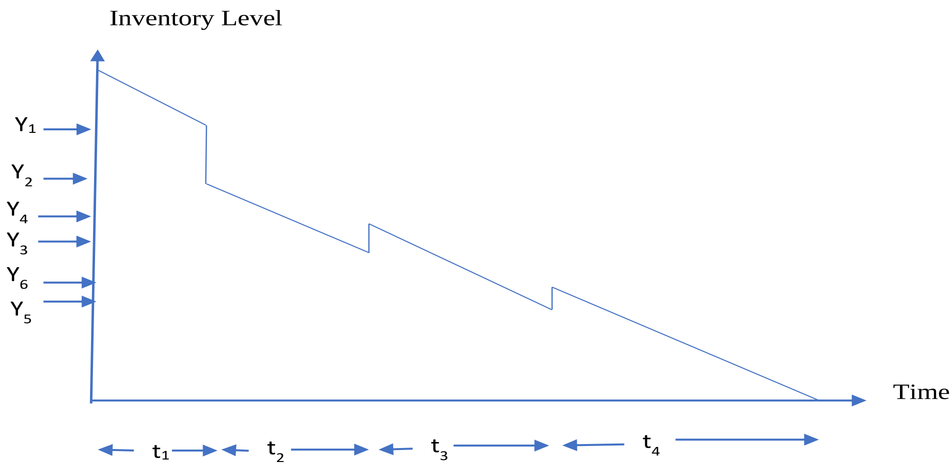


Figure 1: Pictorial Representation of the System

**5.3 Problem Description**

The lot is received on time $t$=0. The inspection process takes place during the time $t_1$. The defective materials are sorted out into minor and major defective items during this period. The rework rate of the minor defective item is $l_1$ and that of the major defective item is $l_2$. The rework of the defective products is initiated after time $t_1$. The minor defective items are completely reworked and are upgraded to the inventory at the end of time $t_2$. The major defective items are completely reworked and are upgraded to the inventory at the end of time $t_3$. The whole inventory is then used up during the time period $t_4$. T is taken to represent the whole cycle length.

At the end of the inspection period, the inventory level is $Y_1$. The inventory level after the removal of major defective items and minor defective item is $Y_2$.The inventory level just before the addition of the reworked minor defective items is $Y_3$. The inventory level after the removal of major defective items and after the addition of reworked items which had minor defects is $Y_4$. The inventory level just before the addition of reworked major defective items is $Y_5$. Inventory level after the addition of reworked items which had major defects is $Y_6$.

**5.4 Determination of profit per cycle**

The total net revenue and total profit per cycle is determined by

$t_1 = \frac{z}{r}$.

$t_2 = \frac{zP_{R_1}}{L_1}$.

$t_3 = \frac{zP_{R_2}}{L_2} - \frac{zP_{R_1}}{L_1}$.

$t_4 = \frac{Y_6}{D}$.

$Y_1 = \left(1 - \frac{D}{r}\right) z$.

$Y_2 = Y_1 - P = \left(1 - P - \frac{D}{r}\right) z$.



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$Y_3 = \left(1 - P - \frac{D}{r} - \frac{DP_{R_1}}{L_1} - \frac{DP_{R_2}}{L_2}\right) z.$

$Y_4 = \left(1 - P_{R_2} - \frac{D}{r} - \frac{DP_{R_1}}{L_1} - \frac{DP_{R_2}}{L_2}\right) z.$

$Y_5 = \left(1 - P_{R_2} - \frac{D}{r} - \frac{DP_{R_2}}{L_2}\right) z.$

$Y_6 = \left(1 - \frac{D}{r} - \frac{DP_{R_2}}{L_2}\right) z.$

Procurement cost = $F_T + pz$

Rework cost = $R_1 P_{R_1} z + R_2 P_{R_2} z$

Inspection Cost = $Iz$

Final Random Inspection Cost = $R_I$

Packaging Cost = $P_C$

Holding Cost $= H_C * \left[\frac{z^2 P_{R1} P_{R2}}{l_1} - \frac{z^2 P P_{R1}}{l_1} - \frac{z^2 P_{R2}{}^2}{l_2} - \frac{z^2 D P_{R2}{}^2}{2 l_2{}^2} + \frac{z^2}{2D}\right]$

$T = t_1 + t_2 + t_3 + t_4$

$T = \frac{z}{D}$

The Total Cost = $\text{PC}(z) + \text{IC}(z) + \text{HC}(z) + \text{RC}(z)$ + Final Random Inspection Cost + Packaging Cost

The Total Average Cost =

$$= \frac{F_T D}{z} + pD + R_1 P_{R_1} D + R_2 P_{R_2} D + ID + \frac{DH_c z P_{R_1} P_{R_2}}{l_1} - \frac{DH_C zPP_{R_1}}{l_1} - \frac{DH_C zP_{R_2}{}^2}{l_2} - \frac{D^2 z H_C P_{R_2}{}^2}{2 l_2{}^2} + \frac{zH_C}{2} + R_I + P_C$$

The total revenue gained is $S_p z$

The total net revenue per cycle is $\frac{S_p z}{T}$

The total profit per cycle is

$$\frac{S_p z}{T} - \left(\frac{F_T D}{z} + pD + R_1 P_{R_1} D + R_2 P_{R_2} D + ID + \frac{DH_c z P_{R_1} P_{R_2}}{l_1} - \frac{DH_C zPP_{R_1}}{l_1} - \frac{DH_C zP_{R_2}{}^2}{l_2} - \frac{D^2 z H_C P_{R_2}{}^2}{2 l_2{}^2} + \frac{zH_C}{2} + R_I + P_C\right)$$

## 6. Model Validation

The above developed inventory model is optimized using PSO and then later extended to neutrosophic model.

### 6.1 Particle Swarm Optimization:

Particle Swarm Optimization (PSO) was first introduced by Kennedy and Eber Feld at the Conference on Evolutionary Computing in the year 1995. It is then used to solve various problems involving complex optimization. The idea of PSO algorithm mimics the idea of navigation of bird flocks/ school of fish. To find the potential source of food, the birds search for the food randomly in different directions and communicate with each other to identify if the Potential source of food is identified. Similarly, in PSO, the particle is compared with the bird and the swarm of particles is compared with the bird flocks.

The fitness value of each particle is then *t* determined. As a fitness value is calculated, it is compared to the particle's previous best fitness value and the swarm's previous best fitness value, and the personal best and global best places are adjusted as needed. If a stopping criterion is not fulfilled, the velocity and position are updated, resulting in the formation of a new swarm.



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Position of particle i at time is denoted by $x_i(t) \in X$

Velocity of particle i at time t is denoted by $v_i(t) \in X$

The updated value of position and velocity at time t+1 is given by

$$v_i(t+1) = wv_i(t) + r_1c_1\big(P_i(t) - x_i(t)\big) + r_2c_2(g(t) - x_i(t))$$

$$x_i(t+1) = x_i(t) + v_i(t+1)$$

**6.2 Algorithm for Particle Swarm Optimization:**

Step 1: Set the PSO parameters and the decision variable bounds.

Step 2: Generate a population of particles having random positions and speeds.

Step 3: Determine every particle's fitness value.

Step 4: Evaluate each particle's fitness to its pbest. Save the better one as pbest.

Step 5: Assess the present gbest position to the preceding gbest position.

Step 6: Using eq, alter the velocity of every particle.

Step 7: Using eq, alter the position of every particle.

Step 8: If the stopping requirement is fulfilled, go to Step 9, otherwise proceed to Step 3.

Step 9: Retrieve the position and fitness of the gbest.

Step 10: Stop

**6.3 Numerical Example with crisp parameters**

Example: Consider a scenario in which the inventory items bought from production center are subjected to damage due to improper packaging. The items cannot be sent back as the production center is located very far. The items are received in the rework warehouse.

The following are the values of the parameters in crisp sense.

| $F_T$ | $D$ | $p$ | $R_1$ | $PR_1$ | $R_2$ | $PR_2$ | $I$ |
|---|---|---|---|---|---|---|---|
| 1000 | 60000 | 25 | 10 | 0.05 | 20 | 0.02 | 0.5 |

| $H_C$ | $l_1$ | $l_2$ | $R_I$ | $P_C$ | $P$ | $S_P$ |
|---|---|---|---|---|---|---|
| 5 | 20000 | 10000 | 10 | 20 | 0.07 | 50 |

Using PSO algorithm we get the following output values

$z$ = 4984.964, $T$ = 0.083083-year, Total Average Cost = 1584102 Rs, Total Profit per cycle = 1415898 Rs

The same example is discussed under neutrosophic environment with neutrosophic values of the parameters of the inventory model. The theory of neutrosophy was developed by Smarandache. Neutrosophic sets comprise truth, indeterminacy, and falsity values. These sets handle both the instances of uncertainty and indeterminacy. It is not possible to expect inventory management to be deterministic as it is occupied by impreciseness too. In the above-described example of inventory management, the chances of parameter values to be of deterministic nature are very less, the values are represented as neutrosophic sets as follows.

**6.4 Numerical Example with Neutrosophic parameters**

Let us consider an inventory system with neutrosophic parametric values.



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$F_T$ = (1000,1100,1200,1300): 0.8 0.1 0.2; $F_T$ = 958.333
$D$ = (60000,66000,72000,78000); 0.602453 0.2 0.4; $D$ = 46056.42
$p$ = (25,27.5,30,32.5); 0.7 0.3 0.4; $p$ = 19.166
$R_1$= (10,11,12,13); 0.8 0.1 0.2; $R_1$ =9.5833
$P_{R_1}$ = (0.05,0.055,0.06,0.065); 0.6 0.2 0.5; $P_{R_1}$ = 0.03641
$R_2$= (20,22,24,25); 0.9 0.1 0.3; $R_2$= 19.166
$P_{R_2}$ = (0.02,0.022,0.024,0.026); 0.8 0.4 0.1; $P_{R_2}$ = 0.01763
$I$ =(0.5,0.55,0.6,0.65); 0.7 0.2 0.3; $I$ =0.42166
$H_C$= (5,5.5,6,6.5); 0.7 0.2 0.5; $H_C$ =3.833
$l_1$ = (20000,22000,24000,26000);0.8 0.3 0.4; $l_1$ =16100
$l_2$ = (10000,11000,12000,13000);0.9 0.2 0.3; $l_2$ =9200
$R_I$ = (10,11,12,13); 0.6 0.2 0.5; $R_I$ =7.2833
$P_C$ = (20,22,24,26); 0.8 0.1 0.1; $P_C$ =19.933
$P$ = (0.07,0.077,0.084,0.091); 0.9 0.1 0.3; $P$ = 0.06708
$Sp$ = (50,55,60,62); 0.9 0.1 0.1; $Sp$ =51.075

z= 4850.678, T= 0.10532year, Total Average Cost = 936433.5 Rs, Total Profit per cycle = 1415898 Rs.

## 7. Sensitivity Analysis and Discussions

In this sub-section, the sensitive analysis is made with moderations in crisp and neutrosophic parametric values.

Table 1: Change in $F_T$ (Crisp)

| % Change in $F_T$ | $F_T$ | z | T | TAC | Total Profit/ Cycle |
|---|---|---|---|---|---|
| -20% | 800 | 4458.687 | 0.074311 | 1581561 | 1418439 |
| -10% | 900 | 4729.152 | 0.078819 | 1582867 | 1417133 |
| 0 | 1000 | 4984.964 | 0.083083 | 1584102 | 1415898 |
| 10% | 1100 | 5228.274 | 0.087138 | 1585277 | 1414723 |
| 20% | 1200 | 5460.754 | 0.091013 | 1586400 | 1413600 |

The parameter $F_T$ (Crisp) is analyzed by varying its values by intervals of 10% increasingly and decreasingly and the change in T and Total Profit/cycle is determined. It is represented in Table 7.1.

It is found that the value of T decreases as $F_T$ decreases and the value of T increases as $F_T$ increases. The total profit per cycle increases as $F_T$ decreases and decreases as $F_T$ increase. It is represented in Figure 7.1.

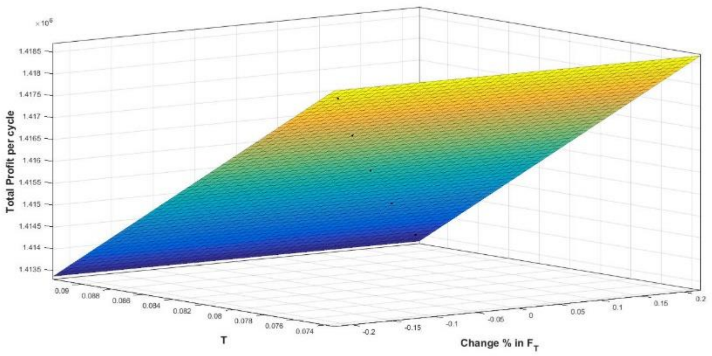


Figure 2: Pictorial Representation of Total Profit per cycle with respect to $F_T$ (Crisp)

Table 2: Change in $D$ (Crisp)

| % Change in $D$ | $D$ | z | T | TAC | Total Profit/ Cycle |
|---|---|---|---|---|---|
| -20% | 48000 | 4437.729 | 0.092453 | 1269663 | 1130337 |



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| | | | | | |
|---|---|---|---|---|---|
| -10% | 54000 | 4717.648 | 0.087364 | 1426923 | 1273077 |
| 0 | 60000 | 4984.964 | 0.083083 | 1584102 | 1415898 |
| 10% | 66000 | 5241.871 | 0.079422 | 1741212 | 1558788 |
| 20% | 72000 | 5490.097 | 0.076251 | 1898259 | 1701741 |

The parameter *D* (Crisp) is analyzed by varying its values by intervals of 10% increasingly and decreasingly and the change in T and Total Profit/cycle is determined. It is represented in Table 7.2.

It is found that the value of T decreases as *D* increases and the value of T increases as *D* decreases. The total profit per cycle increases as *D* increases and decreases as *D* decreases. It is represented in Figure 7.2.

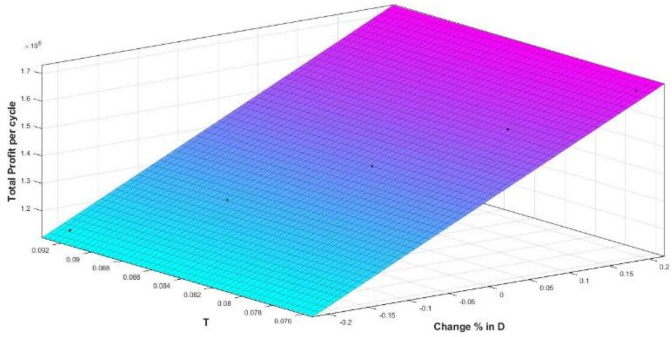


Figure 3: Pictorial Representation of Total Profit per cycle with respect to *D* (Crisp)

Table 3: Change in $P_{R_1}$ (Crisp)

| % Change in $P_{R_1}$ | $P_{R_1}$ | z | T | TAC | Total Profit/ Cycle |
|---|---|---|---|---|---|
| -20% | 0.04 | 4977.24 | 0.082954 | 1578140 | 1421860 |
| -10% | 0.045 | 4981.097 | 0.083018 | 1581121 | 1418879 |
| 0 | 0.05 | 4984.964 | 0.083083 | 1584102 | 1415898 |
| 10% | 0.055 | 4988.84 | 0.083147 | 1587084 | 1412916 |
| 20% | 0.06 | 4992.724 | 0.083212 | 1590065 | 1409935 |

The parameter $P_{R_1}$ (Crisp) is analyzed by varying its values by intervals of 10% increasingly and decreasingly and the change in T and Total Profit/cycle is determined. It is represented in Table 7.3.

It is found that the value of T increases as $P_{R_1}$ increases and the value of T decreases as $P_{R_1}$ decrease. The total profit per cycle increases as $P_{R_1}$ decreases and decreases as $P_{R_1}$ increases. It is represented in Figure 7.3.

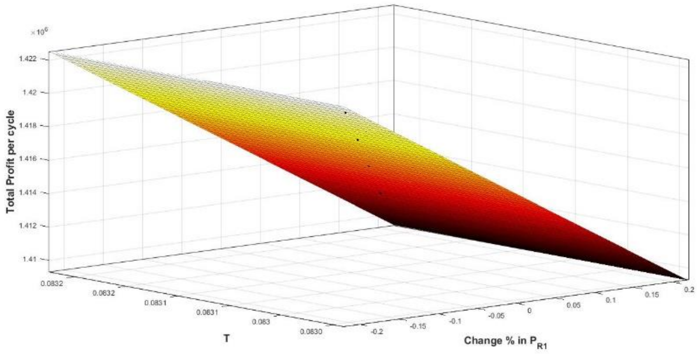


Figure 4: Pictorial Representation of Total Profit per cycle with respect to $P_{R_1}$ (Crisp)



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Table 4: Change in $P_{R_2}$ (Crisp)

| % Change in $P_{R_2}$ | $P_{R_2}$ | z | T | TAC | Total Profit/ Cycle |
|---|---|---|---|---|---|
| -20% | 0.016 | 4970.288 | 0.082838 | 1584173 | 1415827 |
| -10% | 0.018 | 4977.116 | 0.082952 | 1584140 | 1415860 |
| 0 | 0.02 | 4984.964 | 0.083083 | 1584102 | 1415898 |
| 10% | 0.022 | 4993.845 | 0.083231 | 1584060 | 1415940 |
| 20% | 0.024 | 5003.775 | 0.083396 | 1584012 | 1415988 |

The parameter $P_{R_2}$ (Crisp) is analyzed by varying its values by intervals of 10% increasingly and decreasingly and the change in T and Total Profit/cycle is determined. It is represented in Table 7.4.

It is found that the value of T increases as $P_{R_2}$ increases and the value of T decreases as $P_{R_2}$ decrease. The total profit per cycle increases with increasing change in parameter and decreases with decreasing change in parameter. It is represented in Figure 7.4.

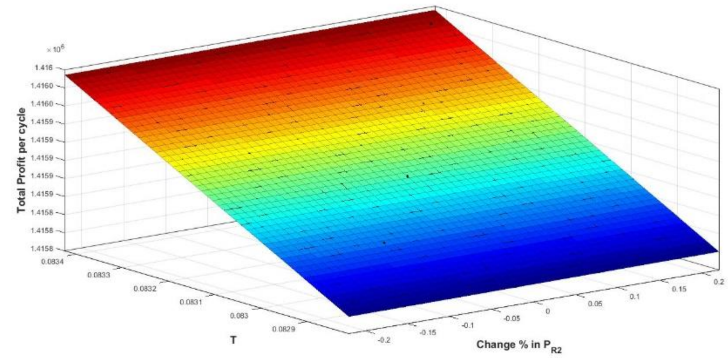


Figure 5: Pictorial Representation of Total Profit per cycle with respect to $P_{R_2}$ (Crisp)

Table 5: Change in $H_c$ (Crisp)

| % Change in $H_c$ | $H_c$ | z | T | TAC | Total Profit/ Cycle |
|---|---|---|---|---|---|
| -20% | 4 | 5573.359 | 0.092889 | 1581561 | 1418439 |
| -10% | 4.5 | 5254.613 | 0.087577 | 1582867 | 1417133 |
| 0 | 5 | 4984.964 | 0.083083 | 1584102 | 1415898 |
| 10% | 5.5 | 4752.977 | 0.079216 | 1585277 | 1414723 |
| 20% | 6 | 4550.629 | 0.075844 | 1586400 | 1413600 |

The parameter $H_c$ (Crisp) is analyzed by varying its values by intervals of 10% increasingly and decreasingly and the change in T and Total Profit/cycle is determined. It is represented in Table 7.5.

It is found that the value of T decreases as $H_c$ increases and the value of T increases as $H_c$ decrease. The total profit per cycle decreases as the parameter increases and it decreases when the value of parameter decreases. It is represented in Figure 7.5.



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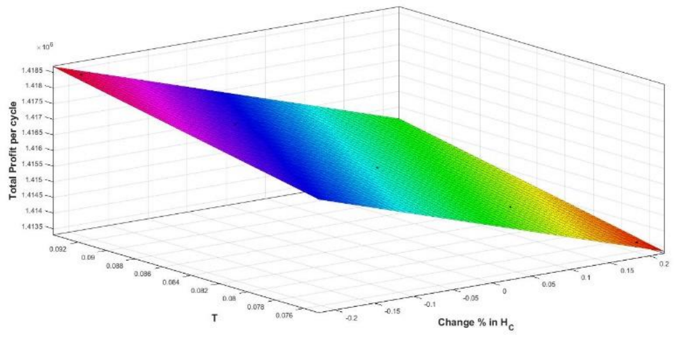


**Figure 7.5 Pictorial Representation of Total Profit per cycle with respect to $H_C$ (Crisp)**

**Table 7.6 Change in $l_1$ (Crisp)**

| **% Change in $l_1$** | **$l_1$** | **z** | **T** | **TAC** | **Total Profit/ Cycle** |
|---|---|---|---|---|---|
| -20% | 16000 | 4994.67 | 0.083244 | 1584056 | 1415944 |
| -10% | 18000 | 4989.271 | 0.083155 | 1584082 | 1415918 |
| 0 | 20000 | 4984.964 | 0.083083 | 1584102 | 1415898 |
| 10% | 22000 | 4981.448 | 0.083024 | 1584119 | 1415881 |
| 20% | 24000 | 4978.525 | 0.082975 | 1584134 | 1415866 |

The parameter $l_1$ (Crisp) is analyzed by varying its values by intervals of 10% increasingly and decreasingly and the change in T and Total Profit/cycle is determined. It is represented in Table 7.6.

It is found that the value of T increases as $l_1$ decreases and the value of T decreases as $l_1$ increases. The total profit per cycle slightly increases with negative changes in parameter and slightly decreases with positive change in parameter. It is represented in Figure 7.6.

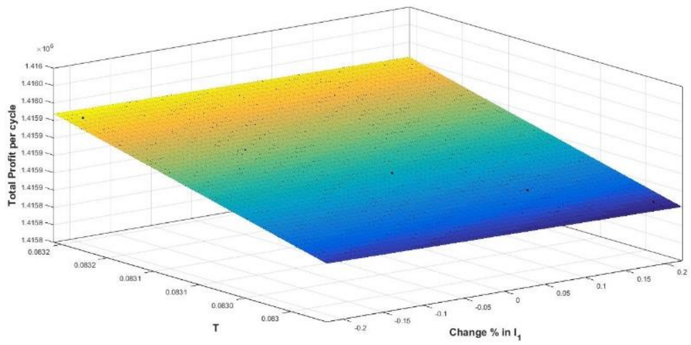


Figure 6: Pictorial Representation of Total Profit per cycle with respect to $l_1$(Crisp)

Table 6: Change in $l_2$ (Crisp)

| **% Change in $l_2$** | **$l_2$** | **z** | **T** | **TAC** | **Total Profit/ Cycle** |
|---|---|---|---|---|---|
| -20% | 8000 | 5009.14 | 0.083486 | 1589386 | 1416014 |
| -10% | 9000 | 4995.088 | 0.083251 | 1584054 | 1415946 |
| 0 | 10000 | 4984.964 | 0.083083 | 1584102 | 1415898 |
| 10% | 11000 | 4977.405 | 0.082957 | 1584139 | 1415861 |
| 20% | 12000 | 4971.598 | 0.08286 | 1584167 | 1415833 |



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The parameter $l_2$ (Crisp) is analyzed by varying its values by intervals of 10% increasingly and decreasingly and the change in T and Total Profit/cycle is determined. It is represented in Table 7.7.

It is found that the value of T increases as $l_2$ decreases and the value of T decreses as $l_2$ increases. The total profit per cycle increases with decrease in the parameter and decreases with increase in the parameter. It is represented in Figure 7.7.

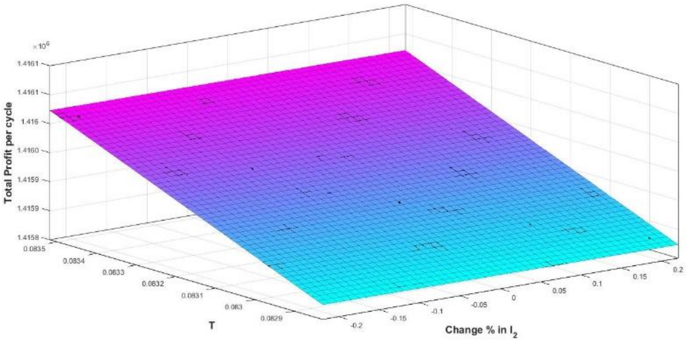


Figure 7: Pictorial Representation of Total Profit per cycle with respect to $l_2$(Crisp)

Table 7: Change in $F_T$ (Neutrosophic)

| % Change in $F_T$ | $F_T$ | z | T | TAC | Total Profit/ Cycle |
|---|---|---|---|---|---|
| -20% | 766.666 | 4338.577 | 0.094201 | 934512.3 | 1417819 |
| -10% | 862.5 | 4601.758 | 0.099916 | 935499.6 | 1416832 |
| 0 | 958.333 | 4850.678 | 0.10532 | 936433.5 | 1415898 |
| 10% | 1054.166 | 5087.434 | 0.110461 | 937321.8 | 1415010 |
| 20% | 1150 | 5313.653 | 0.115373 | 938170.5 | 1414161 |

The parameter $F_T$ (Neutrosophic) is analyzed by varying its values by intervals of 10% increasingly and decreasingly and the change in T and Total Profit/cycle is determined. It is represented in Table 7.8.

It is found that the value of T decreases as $F_T$ decreases and the value of T increases as $F_T$ increases. The total profit per cycle increases as $F_T$ decreases and decreases as $F_T$ increase. It is represented in Figure 7.8.

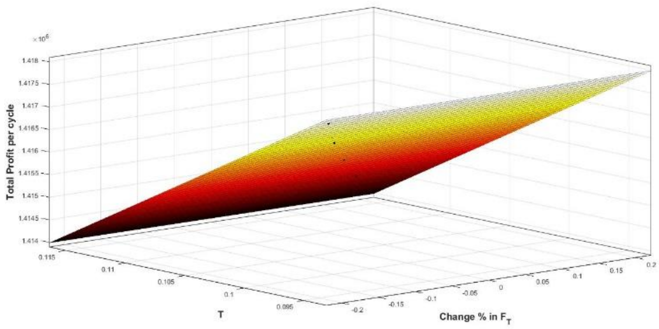


Figure 8: Pictorial Representation of Total Profit per cycle with respect to $F_T$ (Neutrosophic)

Table 8: Change in $D$ (Neutrosophic)

| % Change in $D$ | $D$ | z | T | TAC | Total Profit/ Cycle |
|---|---|---|---|---|---|



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| | | | | | |
|---|---|---|---|---|---|
| -20% | 36845.14 | 4326.3 | 0.117418 | 750917 | 1130949 |
| -10% | 41450.78 | 4594.96 | 0.110853 | 843704.4 | 1273394 |
| 0 | 46056.42 | 4850.678 | 0.10532 | 936433.5 | 1415898 |
| 10% | 50662.06 | 5094.99 | 0.100568 | 1029114 | 1558451 |
| 20% | 55267.7 | 5330.106 | 0.096442 | 1121750 | 1701047 |

The parameter $D$ (Neutrosophic) is analyzed by varying its values by intervals of 10% increasingly and decreasingly and the change in T and Total Profit/cycle is determined. It is represented in Table 7.9.

It is found that the value of T decreases as $D$ increases and the value of T increases as $D$ decreases. The total profit per cycle increases as $D$ increases and decreases as $D$ decreases. It is represented in Figure 7.9.

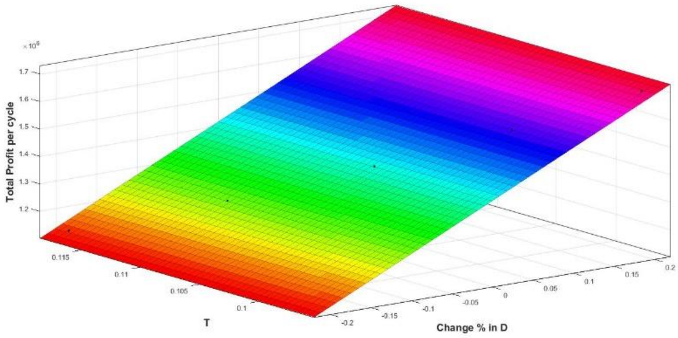


Figure 9: Pictorial Representation of Total Profit per cycle with respect to $D$ (Neutrosophic)

Table 9: Change in $P_{R_1}$ (Neutrosophic)

| % Change in $P_{R_1}$ | $P_{R_1}$ | z | T | TAC | Total Profit/ Cycle |
|---|---|---|---|---|---|
| -20% | 0.02913 | 4845.583 | 0.10521 | 933239.5 | 1419092 |
| -10% | 0.032775 | 4848.132 | 0.105265 | 934838.7 | 1417493 |
| 0 | 0.03641 | 4850.678 | 0.10532 | 936433.5 | 1415898 |
| 10% | 0.0400 | 4853.197 | 0.105375 | 938008.6 | 1414323 |
| 20% | 0.0437 | 4855.797 | 0.105431 | 939631.9 | 1412700 |

The parameter $P_{R_1}$ (Neutrosophic) is analyzed by varying its values by intervals of 10% increasingly and decreasingly and the change in T and Total Profit/cycle is determined. It is represented in Table 7.10.

It is found that the value of T increases as $P_{R_1}$ increases or and decreases if $P_{R_1}$ decreases. The total profit per cycle increases as $P_{R_1}$ decreases and increases as $P_{R_1}$ decrease. It is represented in Figure 7.10.

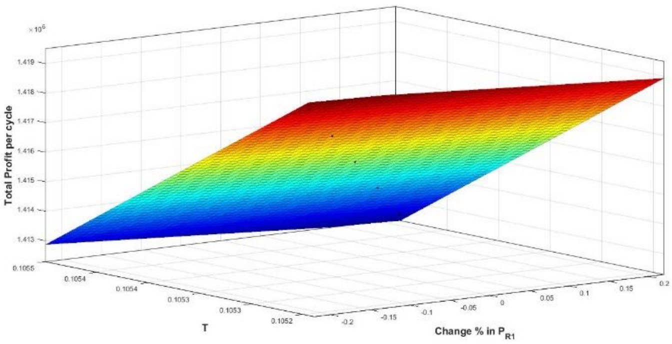


Figure 10: Pictorial Representation of Total Profit per cycle with respect to $P_{R_1}$ (Neutrosophic)



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Table 10: Change in $P_{R_2}$ (Neutrosophic)

| % Change in $P_{R_2}$ | $P_{R_2}$ | Z | T | TAC | Total Profit/ Cycle |
|---|---|---|---|---|---|
| -20% | 0.014104 | 4842.604 | 0.105145 | 936463.9 | 1415868 |
| -10% | 0.015867 | 4846.272 | 0.105225 | 936450.1 | 1415882 |
| 0 | 0.01763 | 4850.678 | 0.10532 | 936433.5 | 1415898 |
| 10% | 0.019393 | 4855.258 | 0.10542 | 936416.4 | 1415915 |
| 20% | 0.021156 | 4860.585 | 0.105535 | 936396.4 | 1415935 |

The parameter $P_{R_2}$ (Neutrosophic) is analyzed by varying its values by intervals of 10% increasingly and decreasingly and the change in T and Total Profit/cycle is determined. It is represented in Table 7.11.

It is found that the value of T increases as $P_{R_2}$ increases and the value of T decreases as $P_{R_2}$ decrease. The total profit per cycle does not vary much as $P_{R_2}$ increases or decreases. It is represented in Figure 7.11.

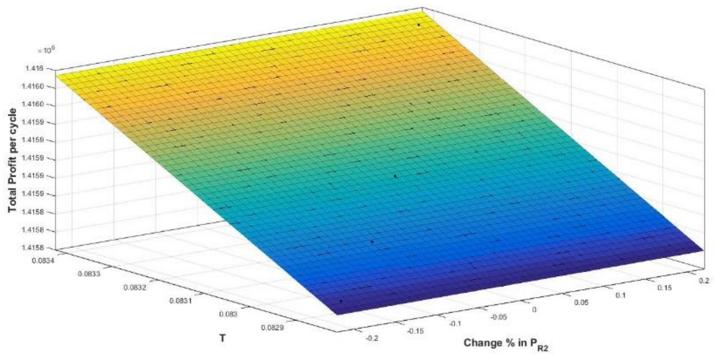


Figure 11: Pictorial Representation of Total Profit per cycle with respect to $P_{R_2}$ (Neutrosophic)

Table 11: Change in $H_C$ (Neutrosophic)

| % Change in $H_c$ | $H_c$ | z | T | TAC | Total Profit/ Cycle |
|---|---|---|---|---|---|
| -20% | 3.0666 | 5423.046 | 0.117748 | 934512.8 | 1417819 |
| -10% | 3.45 | 5112.842 | 0.111013 | 935500.4 | 1416831 |
| 0 | 3.8333 | 4850.678 | 0.10532 | 936433.5 | 1415898 |
| 10% | 4.2166 | 4624.776 | 0.100415 | 937322.5 | 1415009 |
| 20% | 4.6 | 4427.851 | 0.09614 | 938171.3 | 1414160 |

The parameter $H_c$ (Neutrosophic) is analyzed by varying its values by intervals of 10% increasingly and decreasingly and the change in T and Total Profit/cycle is determined. It is represented in Table 7.12.

It is found that the value of T decreases as $H_c$ increases and the value of T increases as $H_c$ decrease. The total profit per cycle decreases as $H_c$ increases and vice versa. It is represented in Figure 7.12.



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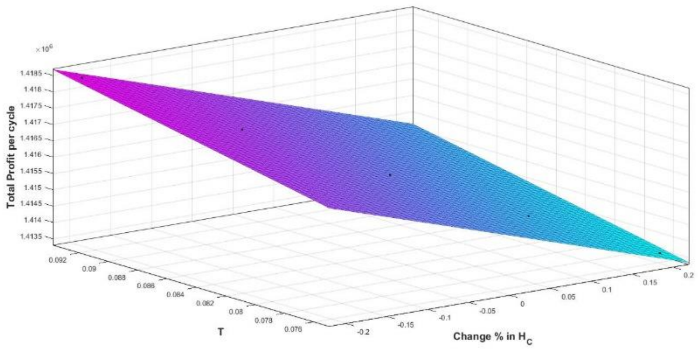


Figure 12: Pictorial Representation of Total Profit per cycle with respect to $H_c$ (Neutrosophic)

Table 12: Change in $l_1$ (Neutrosophic)

| **% Change in $l_1$** | **$l_1$** | **z** | **T** | **TAC** | **Total Profit/ Cycle** |
|---|---|---|---|---|---|
| -20% | 12880 | 4856.882 | 0.105455 | 936410.3 | 1415921 |
| -10% | 14490 | 4853.327 | 0.105378 | 936423.6 | 1415908 |
| 0 | 16100 | 4850.678 | 0.10532 | 936433.5 | 1415898 |
| 10% | 17710 | 4848.17 | 0.105266 | 936442.9 | 1415889 |
| 20% | 19320 | 4846.24 | 0.105224 | 936450.2 | 1415881 |

The parameter $l_1$ (Neutrosophic) is analyzed by varying its values by intervals of 10% increasingly and decreasingly and the change in T and Total Profit/cycle is determined. It is represented in Table 7.13.

It is found that the value of T decreases $l_1$ increases and T increases as the parameter decreases. The total profit per cycle does not vary much when $l_1$ changes. It is represented in Figure 7.13.

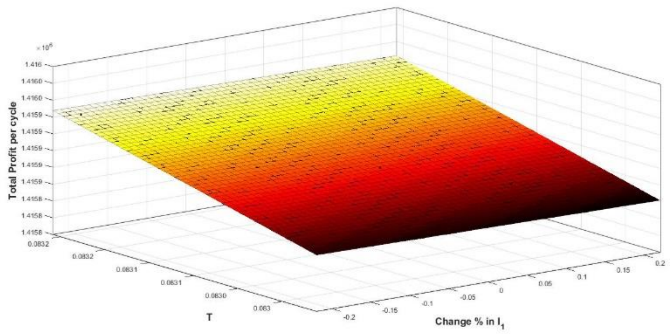


Figure 13: Pictorial Representation of Total Profit per cycle with respect to $l_1$ (Neutrosophic)

Table 13: Change in $l_2$ (Neutrosophic)

| **% Change in $l_2$** | **$l_2$** | **z** | **T** | **TAC** | **Total Profit/ Cycle** |
|---|---|---|---|---|---|
| -20% | 7360 | 4863.324 | 0.105595 | 936386.2 | 1415945 |
| -10% | 8280 | 4855.882 | 0.105433 | 936414 | 1415918 |
| 0 | 9200 | 4850.678 | 0.10532 | 936433.5 | 1415898 |
| 10% | 10120 | 4846.443 | 0.105228 | 936449.4 | 1415882 |
| 20% | 11040 | 4843.322 | 0.105161 | 936461.2 | 1415870 |



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The parameter $l_2$ (Neutrosophic) is analyzed by varying its values by intervals of 10% increasingly and decreasingly and the change in T and Total Profit/cycle is determined. It is represented in Table 7.14.

It is found that the value of T increases as $l_2$ decreases and the value of T decreases a $l_2$ increases. The total profit per cycle does not vary much as $l_2$ increases or decreases. It is represented in Figure 7.14.

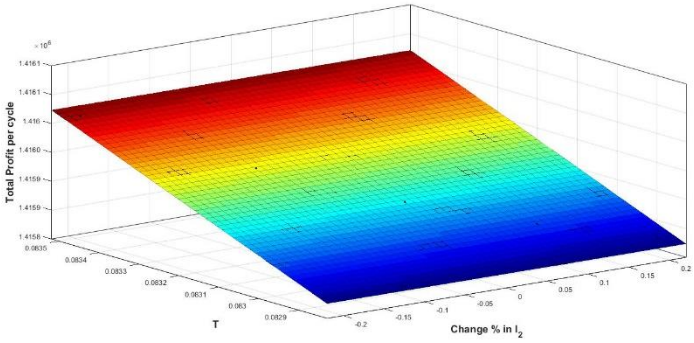


Figure 14: Pictorial Representation of Total Profit per cycle with respect to $l_2$ (Neutrosophic)

## 8. Industrial Implications

The model developed in this article is indeed a great breakthrough in the process of minimizing defective items. The products that become defective during the time of production shall be identified in screening and later be repaired or remanufactured based on the necessities. Business firms are investing huge amounts of money in quality sustenance and minimization of defective items during production time, moreover the defective products are returned after reaching the customers which still burdens the production sectors. This kind of situation shall be avoided if rework warehouses are put in practice.

The rework warehouse not only functions as storage space for the products but also it performs the functions of identification and repair of the defects. Business firms with rework warehouses will evade instances of delivery defective products to the customers. The effective functioning of rework warehouses will mitigate the generation of defective items and increase customer satisfaction. These warehouses will also handle the occurrence of unexpected defects in the products during transportation. As it is not possible to forecast the causes of defective items, the business firms must make suitable arrangements for handling the defective items during the production run time and also throughout the time span of the products reaching the customers.

Business firms have to redesign warehouses as repairing stations to enhance the efficiency of inventory management without defective items. The business firm has to rethink and make provisions of transforming rework warehouses into channels of quality sustenance and quality conservation. The model discussed under both crisp and neutrosophic environments will facilitate the business decision makers to handle the situation of inventory management more effectively.

## 9. Conclusion

This research work proposes an inventory model with rework warehouse management. The development of the inventory model caters to the demands of the business firm in tackling the defective products. This model appears to be a strategy to gain customer loyalty and to increase customer satisfaction. The model developed in this article has a lot of significance in the real industrial setup. The implications of this model will duly favour the business managerial people to revamp and augment the warehouses. The proposed model is validated with a numerical example based on crisp and neutrosophic parametric values. The application of the PSO algorithm simplifies the numerical computations and facilitates obtaining precise results. The sensitivity analysis made with respect to the changes in the crisp and neutrosophic parameters assist in comprehending and analysing the changes of the moderation over the total profit of the model. The neutrosophic results reflect the realistic nature of the model parameter values, and the comparative analysis results are also more alike. The developed model shall be extended with the inclusion of several other cost parameters pertaining to rework warehouse management. Also, the model can be made more accommodative with the addition of different kinds of defects and respective costs.



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