Windows Application on Inventory Management with Dynamic Pricing on Perishable products

M.Tech Project Report

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CERTIFICATE

This is to certify that the Dissertation Report entitled, "WINDOWS APPLICATION ON INVENTORY MANAGEMENT WITH DYNAMIC PRICING ON PERISHABLE PRODUCTS" submitted by Mr. Bimal Kumar Sahoo to Indian Institute of Technology, Kharagpur, India, is a record of bona fide Project work carried out by him under my supervision and guidance and is worthy of consideration for the award of the degree of Master of Technology in Industrial and Systems Engineering of the Institute. The Dissertation Report has fulfilled all the requirements as per the regulations of the institute and in my opinion reached the standard for submission.

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ABSTRACT

This report is based on a dynamic inventory management model for perishable products like fresh food, pharmaceuticals, and dairy products. The model is expected to assist retail shops to maximize their profit using dynamic pricing based on the quality/freshness of the products set on a planning horizon. In this project, fruits like ‘apples’ in the retail stores are considered. The dataset used in this report is synthetically generated. The parameters were calculated through survey reports from multiple local stores after which various probability distributions are assumed, for example the normal distribution, and the Exponential distribution to replicate the customer behavior. This report compares three different heuristics based on the concepts of Genetic Algorithm, Particle Swarm Optimisation Algorithm, and the Ant Colony Optimisation algorithm . These models are generated considering the dynamic pricing of products based on the freshness of the product calculated using the expiry date of the product. The customer behavior is incorporated using the utility function of the food items; customers are assigned a randomized minimum utility value using which the buying of the product by the customer is determined. Multiple sensitivity analysis is conducted based on parameters like discount factor, utility parameters, reorder quantity under multiple scenarios. MATLAB is used to create a stand-alone windows application capturing the past sales data in excel format. The application can implement the three heuristic algorithms used in the project. Then display the result as the reorder time, reorder inventory, discount factor, and the maximum expected profit/minimum expected loss that the retail store is likely to incur using the given model.

1. INTRODUCTION

In traditional inventory problems, things are supposed to have an indefinite shelf life, but the majority of objects lose their initial values over time, and some of them do so more quickly than others, which is referred to as degradation. The majority of degrading products retain their original quality for a period of time before losing their freshness as time passes.

Perishable products are those that have a short shelf life, usually with an expiration date, such as juice, fruits, medications, imported commodities, and the like, or things that decay quickly, such as fruits, grains, and dairy products.
These items require thorough examination because even minor mishandling might result in financial losses for the organization. The issue of perishable product inventory management, where if a quality decline is not identified before the expiration date, there is a risk of a safety incident. Such things include food, drinks, and medications, to name a few. Each perishable object often has a label attached to it that identifies the item's expiration date, or lifetime, after which it is no longer appropriate for its intended use.

To reduce the negative impact of degradation and boost system profit, retailers tend to raise inventory depletion rates. Marketing plans include increasing inventory depletion rates, and there is a clear relationship between demand rate and consumer satisfaction. One of the essential aspects that requires equal attention to other logistical operations on inventory management is selling price. Because the selling price is such an important component of the chain, a retailer must constantly give a fair selling price to its consumers by modifying the purchasing cost of the corresponding items.

Enticing clients to acquire things at a lower price, i.e. with a price decrease as the product approaches its expiration date, is an excellent technique to reduce losses.
As a result, not only does the quantity sold rise, but fewer items are thrown away owing to expiration. Additionally, lowering the price of items as they approach expiration might drive greater demand, enhancing the net profitability of retail stores.

2. LITERATURE REVIEW

Offering a price reduction that grows as the product approaches its expiration date is one technique for shops to persuade customers to buy a perishable product and so improve revenues. This will save money on inventory by reducing the need to dispose of obsolete inventory or return the goods to the manufacturer. Elmaghraby and Keskinocak conduct a study of the literature (2003) and existing practices in inventory dynamic pricing.

Wu, Ouyang, and Yang (2006) were the first to assume non-instantaneous degradation, which was found to be applicable for numerous product deterioration patterns. Soni and Patel (2012) have looked at the best price and inventory practices for non-immediately degrading commodities. Soni and Patel (2013) enhanced this model by including imprecise degradation of free time and a believability restriction.

Few studies have compared dynamic pricing to continuous pricing regimes, in which the price trajectory is a continuously decreasing function of time. Smith (1975), Chung et al. (2007), and Roy and Chaudhuri all apply this price differentiation approach in the setting of deteriorating inventory (2007). Because items with a short shelf life can be used for a variety of reasons, differing prices by expiration date might generate extra demand, resulting in increased profitability.

Li et al. (2006a) offer a model for optimizing product flows in a dynamic forwarding process that considers the next step at all times based on current real-time product quality data given by RFID systems. Their model's goal is to reduce costs, and one of the components of that goal is product value loss, which is influenced exponentially by the length of time the product is exposed to the detected temperature. With a 0.99 level of confidence, Herbon et al. (2012) show that a modest price difference in inventory systems boosts profitability, whereas a bigger divergence diminishes earnings.

3. PROBLEM STATEMENT

For a single perishable commodity with periodic replenishments, a multi-period, capacitated finite-horizon inventory system is examined. A shop, for example, refreshes its stock from a supplier on a regular basis and sells the goods to consumers. Perishable items, as said in the introduction, deteriorate in quality over time, yet they can still be sold until their expiration dates. The idea of product freshness (measured in time units as the difference between the expiry date and the present time) is used to quantify quality degradation.

To optimize net profit, the merchant must select when and how much perishable food to purchase, as well as the price at which to sell it throughout each period. Let E signify the perishable product's life-cycle length, or the period between the arrival of a product shipment and the manufacturer's known expiry date. The freshness of item I of the product throughout each period t is determined by its own expiration date Ei, which is provided for each item at the replenishment moments 0, T, 2T, and so on, and (ii) the present time t. Freshness is a deterministic attribute that determines the quality of each item while it is on the shelf. Thus the freshness is linearly related to the current time and the function is defined as

$$\delta_{it} = E_i - t$$

In this problem, there are two actors: (a) the retailer who acquires the goods and sets the selling price, and (b) customers whose consumption is deterministically based on the price and freshness of the commodity. Client consumption is based on the utility function of the customer, which is in turn based on the product's freshness and price. The utility function is a linear function of both parameters in the simplest example, and it should not be less than a specified minimum (utility level) at which a purchase is performed.
The more the product consumption, the higher the profit margin for the store.

Let Pit represent the dynamic price of item I over time t, and let δit represent its freshness. An exponential connection between price and freshness is established in order to describe price differentiation in the production-inventory system. The pricing function's deterministic property allows you to set a price for each degree of freshness and maintain price consistency as freshness changes. The price of item i at time t is defined as:

$$P_{it}/P_{i0} = exp(-\ \beta(E_i\ -\ \delta_{it}))$$

Where,

Pi0 - Initial price of the product i or the MRP of product i

β - Discount Factor

Ei - Expiry of product i

δ_{it} - Freshness of product i at time t

The utility level U(pit, δit) received by the client who purchases the item is used to measure customer happiness. When freshness rises by 1 unit of satisfaction, the utility function increases by α(units of satisfaction) given a current price (one time unit). Customers will avoid acquiring even a new item if the utility acquired by them does not surpass a pre-specified value Umin, according to such a modeling approach.
The utility level is a function that adds up:

$$U(P_{it},\ \delta_{it})\ =\ A\ -\ P_{it}\ -\ \alpha\delta_{it}$$

Where,
$A,\ \alpha$ - Parameters reflecting the utility increase with decrease in p and/or increase in δ

The shipment cost of a lot is decomposed into a fixed cost K that is independent of the lot size and a unit cost c that is incurred for each item delivered in the lot, according to traditional inventory management models. At the conclusion of each month, the inventory cost h of a unit retained in inventory is charged. Resupply or inventory are used to meet a required consumption level at any given time.

4. OBJECTIVES

- The objective of this project is to build a model for deployment in the retail shops tracking their inventory stochastically and suggesting the price changes in form of discounts to increase the sales along with reducing the loss incurred due to lost sales. In turn increasing the expected profit.

- The modeling is to be done considering the real world scenarios like holidays or the days with no sales etc.

- A windows application is also built with the purpose of applying as a plugin to the main inventory management app suggesting the reorder time, reorder quantity and the expected profit or loss with the near-optimal solution.

- The users are also to be provided with the flexibility of selecting the model to be implemented based on the favorability/the characteristics of the data.

5. PROBLEM FORMULATION

Parameters:

E - life-cycle length
Umin - minimal utility gained
c - unit cost
h - inventory cost of a unit per a period
η_t- expected loss incurred from selling a damage item to customers in period t
K - shipment cost of a lot
δit - freshness of item i in period t
α, A- utility parameters
pi0 - initial price set for item i of freshness level E.

Decision Variables:
T - replenishment cycle length
β - intensity of the price discount when freshness decreases by one unit
I - product's replenishment quantity in period 0, T, 2T, …
x_t = 1 if the retailer makes replenishment in period t, and 0 otherwise
Sit - storage of item i at the end of period t; Sit = 1 if item i is stored in period t and 0 otherwise
Cit - Consumption of item i in period t, C it=1 if the item is consumed and 0 otherwise
Ct - product quantity consumed in period t, Ct = ΣiC it, t = 0, 1, 2, …, H,
St - product quantity stored in period t, t = 0, 1, 2, …, H; St = ΣiSit (by definition, 1 0 S = I −)
p_{it} - dynamic price of item i in period t

Objective Function:

maximize:

$$Profit = Rev - (order\ cost + purchase\ cost + holding\ cost + Lost\ sales\ cost)$$

$$= 1/(H + 1)\{\Sigma_{i=1,\ ...,\ I_0} \Sigma_{t=0,\ ...,\ H}\, p_{it} C_{it} - (\Sigma_{t=0,\ ...,\ H}(Kxt + (c(I_0 - S_{t-1})x_t$$

$$+ c^{AD}(I_0 - S_{t-1})xt) + h\Sigma_{i=1,\ ...,\ I_0}\Sigma_{t=0,\ ...,\ H} S_{it}$$

constraints:

$\delta_{it} = E_i - t,\ t \in \{0, 1, \ldots, H\},\ i = 1, \ldots, I_0,$ — (1)

$p_{it}/p_{i0} = \exp(-\beta(E - \delta_{it})),\ t \in \{1, \ldots, H\},\ i = 1, \ldots, I_0,$ — (2)

$U(p_{it}, \delta_{it}) = A - p_{it} + \alpha\, \delta_{it},\ t \in \{0, 1, \ldots, H\},\ i = 1, \ldots, I_0,$ — (3)

$S_{i,t} = 1 - C_{it},\ t \in \{mT, m = 0, 1, \ldots, q\},\ i = 1, \ldots, I_0,$ — (4)

$S_{i,t} = S_{i,t-1} - C_{it},\ t \notin \{mT, m = 0, 1, \ldots, q,\ t \leq H\},\ i = 1, \ldots, I_0,$ — (5)

$p_{it} = p_{i,t+T},\ t \in \{0, 1, ..., H - T\},\ i = 1, ..., I0$ — (6)

$x_t = x_{t+T},\ t \in \{0, 1, ..., H - T\},$ — (7)

$I_0 - S_{t-1} - Mx_t <= 0,\ t \in \{mT,\ m = 0,\ 1,\ ...,\ q\},$ — (8)

$I_0 - S_{t-1} - M(1 - x_t) <= 0,\ t \notin \{mT,\ m = 0,\ 1,\ ...,\ q,\ t \leq H\},$ — (9)

$U_{\min} - U(p_{it}, \delta_{it}) - M(1 - C_{it}) \leq 0,\ i = 1, \ldots, I_0,\ t \in \{0, 1, \ldots, H\}$ — (10)

$-\delta_{it} - M(1 - C_{it}) \leq 0,\ t \in \{0, 1, \ldots, H\},\ i = 1, \ldots, I_0.$ — (11)

The freshness, price, and usefulness of item I in time t are defined by constraints (1) through (3), respectively. Storage is linked to the consumption of item I at the end of period t by constraint (4) and its complimentary constraint (5). Constraints (6)-(7) define the retailer's price's periodicity. If there is a positive buy (of value $I0-St-1$) at the start of period t, then $xt = 1$ (and, hence, the fixed ordering cost K is incurred), and $xt = 0$ otherwise, where M is a suitably high integer. Consumption $Cit = 0$ if utility $U(pit, \delta it)$ is smaller than Umin, according to constraint (10) In the same way, constraint (11) states that $Cit = 0$ if freshness is 0.

6. METHODOLOGY

The problem formulation suggests this problem being a Non-Linear Mixed Integer Programming problem. But even for smaller cases with a planning horizon as 10, the problem extends to thousands of variables which even with good computational machines will take lots of time to calculate, for which heuristic methods are to be used to get a near-optimal solution.

Solution Encoding:
Array of 3 Variables

- Time period of ordering.
- Inventory level during reorder.
- Discount factor

Objective function:
For each of the solution points, a simulation is carried out for t = 0,1,2,...,T,...,2T,..., qT. During each time period, the revenue is calculated considering the dynamic price of the product and the number of sales in the time.

Thus,

F(x) = Profit = Total Revenue - Purchase cost - Lost sales cost - Ordering cost - Inventory holding cost - Expiry cost

The data generated from the probabilistic models is considered. The total cost incurred is subtracted from the total sales for each of the time t. This gives us the total profit for the respective time.
For each time t, the number of sales is calculated by product satisfaction value. The product satisfaction value or the product utility value is calculated using the price and the product freshness. The parameters A and alpha are set to base on the day-to-day scenarios where the customer behavior towards the product is likely to change. Each customer has a minimum utility value and to simulate this closer to the real world scenario, a random number is generated from [0.8,1] which is then multiplied with the minimum utility value which is then used to determine if a certain product is purchased or not.

Initial solution:
The initial population is calculated using the EOQ calculations.
Time period of ordering is varied from [2, Date of Expiry].
Calculate the EOQ values(Inventory Level variable) based on the expected demand values and the time period
Randomly generate N (population size) solution points with T in range [2, Date of Expiry] and I in range [0.8*Q, 1.5*Q].
Take the discount factor variable values randomly from [0,1].

Heuristic 1 used: **Genetic Algorithm**

- The genetic algorithm is a method based on natural selection, the mechanism that drives biological evolution, for addressing both limited and unconstrained optimization problems. Genetic algorithms depend on biologically inspired operators including mutation, crossover, and selection to develop high-quality solutions to optimization and search problems.

- Roulette wheel selection is used to calculate the population for the mating pool.

- Crossover used: Since the problem is real coded, linear arithmetic operator is used to get the child chromosomes. Crossover probability is taken as 0.8.

- Mutation used: A random number is generated for the mutation operation. Mutation probability is taken as 0.05.

- Elitism is used while passing on to the next generation.

Heuristic 2 used: **Particle Swarm Optimization**

- PSO is a computational approach for solving a problem by iteratively trying to improve a potential solution against a set of quality criteria. Several particles (agents) are employed to form a swarm that moves about the search space seeking for the best answer. Each particle in the swarm searches the solution space for its positional coordinates, which are related to the best solution that that particle has found thus far. It's referred to as pbest, or personal best. The PSO keeps track of another best value known as gbest or global best. This is the best possible value obtained by any particle in that particle's vicinity thus far.

- Particle velocity is defined by:

$$V_i^{t+1} = W.V_i^t + c_1 U_1^t \left(P_{b_1}^t - P_i^t\right) + c_2 U_2^t \left(g_b^t - P_i^t\right)$$

- Then the above steps are repeated until the termination conditions are reached.

Heuristic used 3: **Simulated Annealing**

- This is a local search technique for addressing optimization problems that are both unconstrained and bound-constrained. It alters a single solution and explores a very small part of the search space until the local optima is found, similar to the stochastic hill climbing local search algorithm.

- It may accept poorer solutions as the current working solution, unlike the hill climbing algorithm. The probability of accepting inferior solutions increases at the start of the search and lowers as the search progresses, allowing the algorithm to first discover the region for the global optima while avoiding local optima, and then hill climb to the optima itself.

- The temperature decrease is considered to be linear in this case.

7. DATA DESCRIPTION

The data variables are collected through surveys to the local retail stores in the city of Bhubaneswar, Odisha. Survey is conducted for fruits (mostly apples)

Survey details:

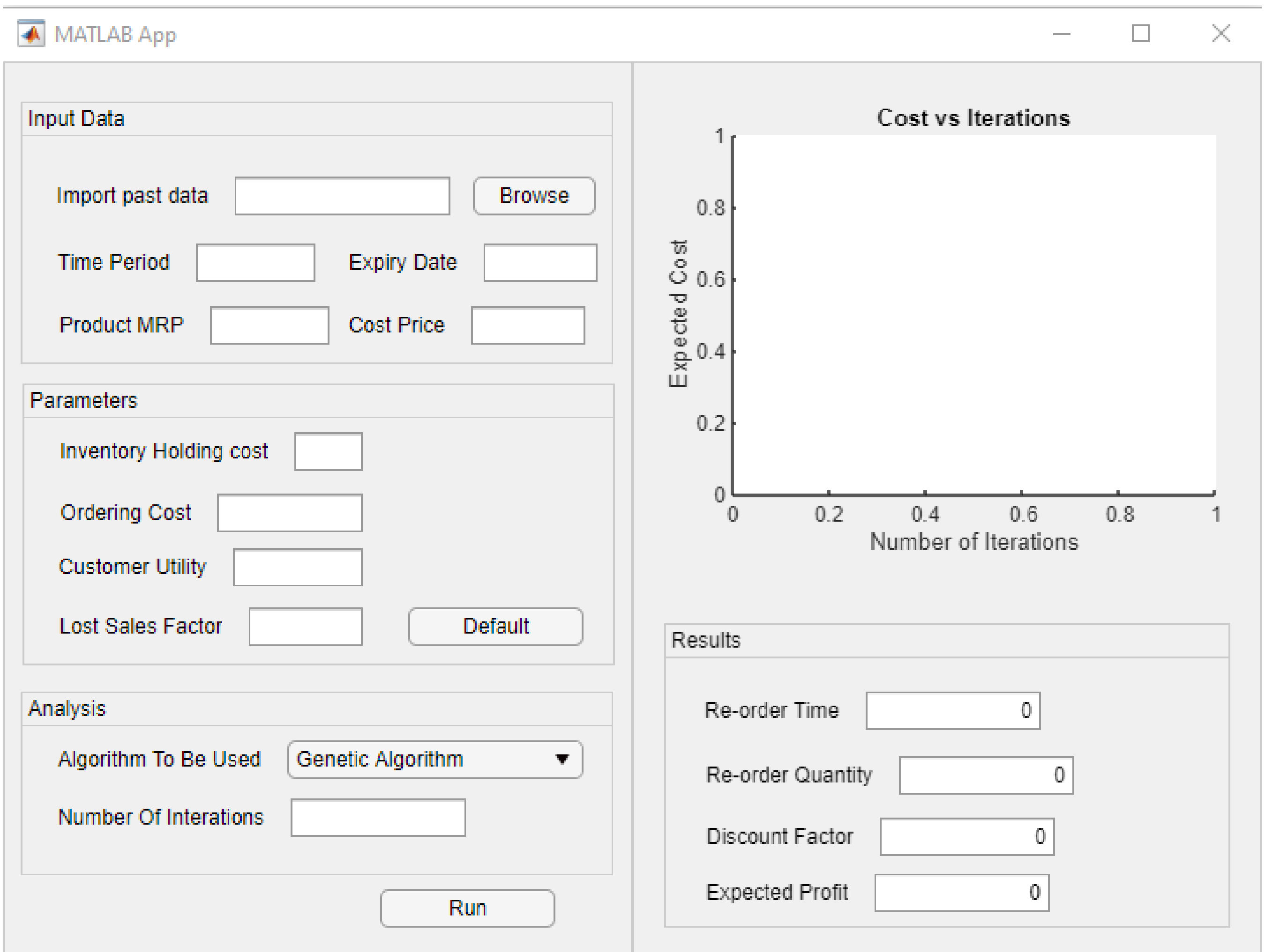
Store Name	No. of customers per day	Buying price of the good	Reorder price	Rent per month	Total Items sold per month
SS Mart	200-250	85	200	40000	5000
Reliance Fresh, Gandamunda	100-150	83	150	35000	4000
Home Shop	100-150	90	100	30000	4000
Reliance Fresh, Jagamara	150-200	83	150	40000	4500

SELLING PRICE - 130
CATEGORIES OF PRODUCTS = 6
Parameter Calculation:
Number of customers per day = Normal distribution (mean - 150, variance - 25)
Cost price of goods = Avg. of Buying price = 85.25
Reorder cost = Avg. of reorder price = 150
Inventory cost = Avg of (Total rent/Total items sold for each store) = (8 + 8.75 + 7.5 + 8.8)/4 = 8.28 = 0.096 i.e 10% approx.

Thus the data is created using random values from a normal distribution of mean = 150 and variance = 25.

8. ALGORITHM IMPLEMENTATION

The algorithm is implemented using the App Designer toolbox from MATLAB. A standalone desktop application is built which can also be applied as a plugin to an inventory management app. Below is the structure of the Application.



In the Input Data section, the functionality of importing past data (in .xlsx format) is supported. Then the user provides the Time Period or the Planning Horizon for the product, after which the expiry date, product selling price, and product cost are entered. Then the model parameters are given as input. If the scenario to be observed is a normal weekday scenario, default button is to be used to set the values. Then the Algorithm to be used is selected along with the number of iterations. Pressing the Run button, will execute the algorithm based on the parameters given. The plot will show the expected profit changes over the number of iterations and then after the termination, the results are published. The results being the decision variables, Re-order Time, Re-order Quantity, Discount factor and the objective value as the Expected Profit.

9. RESULTS

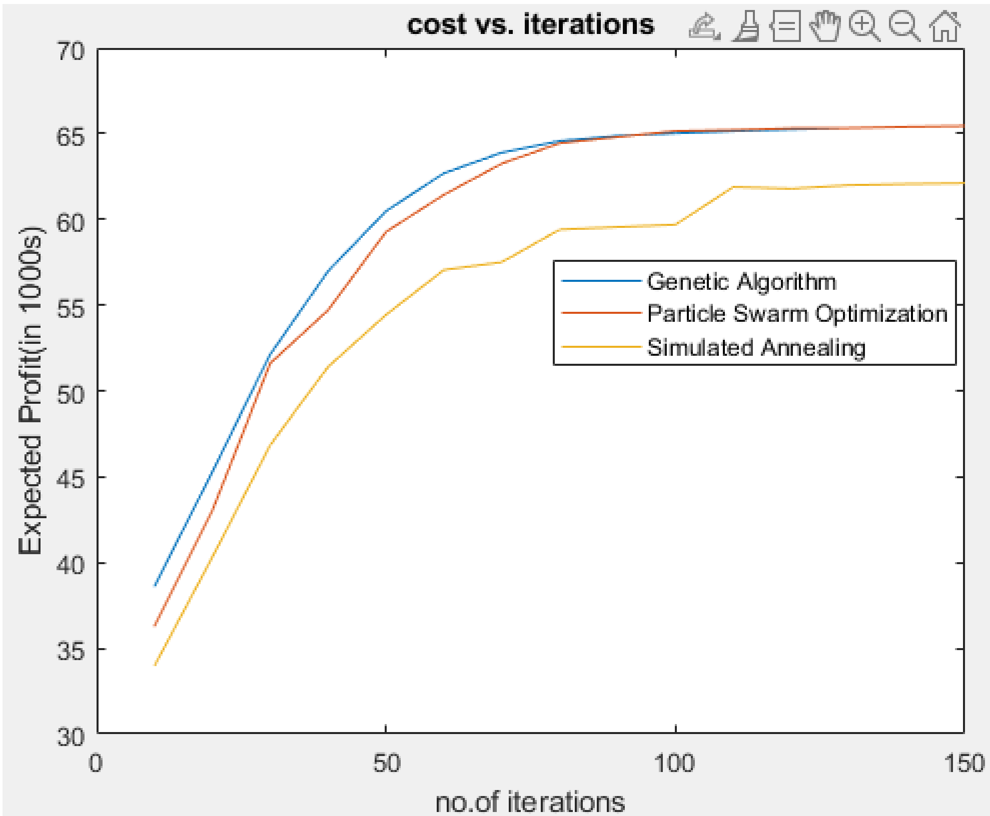


Fig 1: Result of each model is plotted based on the number of iterations

This graph is simulated using MATLAB. The values are stored in an array after each interval of the multiple of 10.As can be seen in the figure, Genetic ALgorithm and Particle Swarm Optimization perform the best among the three algorithms. In Simulated Annealing Steep changes can be seen signifying the sudden changes in the global best solution. These are the small convex peaks that the Simulated Annealing algorithm reaches. In this case it can also be seen how the Genetic Algorithm and the Particle Swarm Optimization algorithm merge after 80 iterations, whereas on the other hand Simulated annealing fails to obtain the optimal solution.

Algorithm	**Iterations**	**Time (secs)**
Simulated Annealing	50	111.6
Simulated Annealing	100	217.62
Genetic Algorithm	50	153.6
Genetic Algorithm	100	285.7
Particle Swarm Optimization	50	142.9
Particle Swarm Optimization	100	271.5

Table 1: Run time for different algorithms for different number of iterations

From table 1, it can be observed that the Simulated Annealing algorithm takes the least computational time and GA and the PSO algorithm are close to each other in the computational time, implying Simulated Annealing gives a fast computed solution.

For Expected profit vs Customer Minimum Utility, alpha = 4, A = 105 is considered.

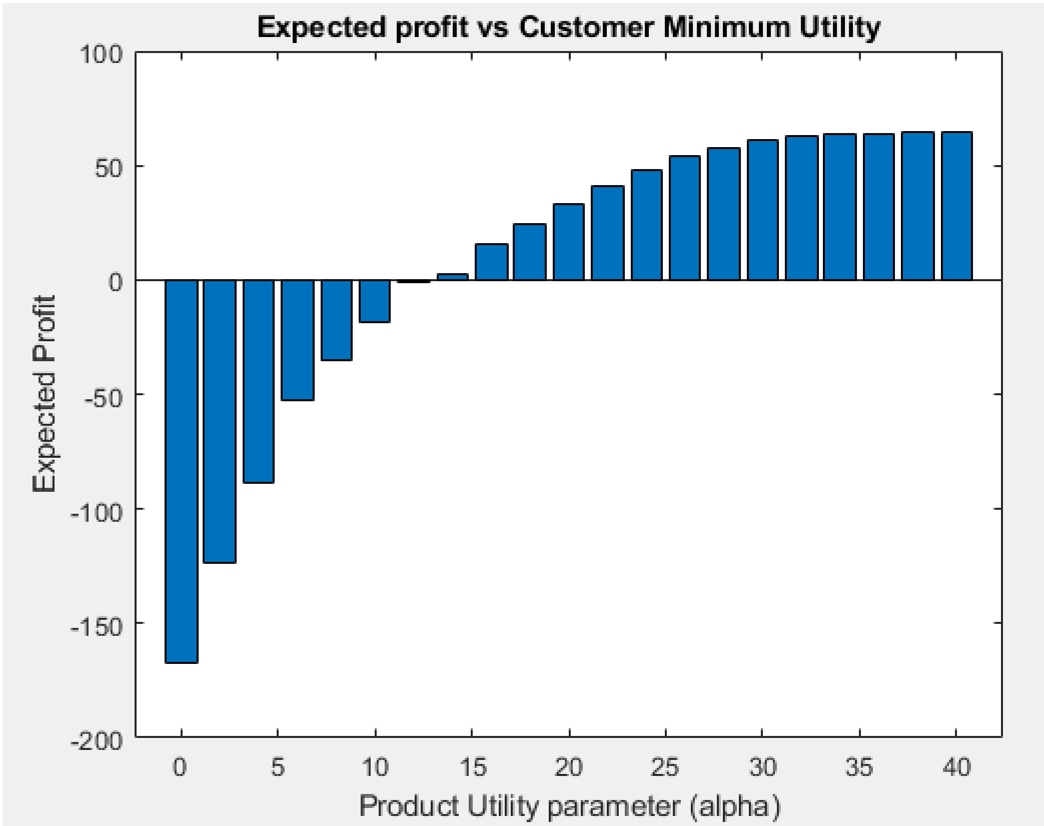


Fig 2: Sensitivity analysis of the Product Utility parameter

This simulation is conducted considering the A value = 50 and the customer utility value value = 20 corresponding to a normal weekday. As can be seen from the figure, the expected profit is minimum when the alpha is 0. This implies that the customer won't buy any product causing all the stock to expire. The customer minimum utility value being 40 is always greater than the product utility value. As the alpha value increases, it can be seen that around the values from 12-14, the expected profit becomes nearly zero. This is the case of no profit no loss. After the alpha value of 30, the expected profit is stable at 64000 Rs. This is because the product utility value is always greater than the customer utility value implying most of the customer buying the product. This case is the case of high demand.

10. CONCLUSION

As can be concluded from the results, the Genetic Algorithm and Particle Swarm Optimization algorithms give good results as compared to the Simulated Annealing. However Simulated Annealing is faster than the other two algorithms. In today's date, with the availability of super computers and cloud services, the computational limitation is diminished implying Genetic Algorithm and Particle Swarm algorithms to be used in the final App. The model tries to replicate the real world scenarios with the parameters tab in the App window.

The App is intended to be used as a plugin with other inventory management apps to provide additional support. In companies like Amazon where complete automation of grocery shopping is enabled, this plugin could prove to be very useful.

11. FUTURE WORK

- Currently the algorithm is built for a single perishable product. This can be improved to multiple products by using a 2 - D array with the rows denoting different products.

- The correlation among the products is out of the scope of this project but is an essential factor in today's world which should be considered for good performance of the model.

- This technique may also be used to several classes of customers, each of which may have different incomes and utility preferences.

- The App developed is still in the testing step. There are multiple error handlings to be set along with multiple assistance like a stop button to stop the results mid-way returning the best of the results from the current iteration.

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