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Optimization of Price Strategy with Multi-Level Discount for Demand Management of Perishable Products

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***Abstract*—This paper develops a model to get the price policy for fresh products, and help to determine the optimal initial inventory of a sale period. Use freshness function and a demand function to illustrate the fresh condition and the demand of the product. The customer demand on the other hand, is influenced by the price and the freshness condition. In order to make it more realistic, a random factor is added to the demand function. And we propose a new solving method which integrates the scenario and simulation based fitness calculation method into the conventional GA method to help determine the price policy.**

***Index Terms*—Perishable product, Demand function, Scenario simulation, GA algorithm**

I. Introduction

Deterioration is defined as damage, decay, loss quantity or loss of usefulness compared with the initial condition. The fresh food products, as a special kind of deterioration item, not only deteriorate but also loss freshness during inventory. If we don't consider this special nature of fresh product and don't take measures, the customers may turn to fresher products and leaving much inventory unsold. So the shop manager needs to consider about lowering the price as the production becoming less- fresh and encourage customers to buy them, may increasing the profit and eliminate waste.

The demand of a product is negatively influenced by the price, usually the higher the price the lower the demand will be. Many researchers have formulated a price-dependent demand function in their works. For example, negative relationship between the price and the quantity a product with demand is discussed by Kocabiyikoglu and Popescu [1]. Not only price, there are many other factors which may influence the demand, such as inventory level and customer's preference. Levin [2] believes sales of certain items will increase as inventory on the shelves increases. Tal Avinadav et. [3] try to find optimal pricing and inventory policies while considering the effect of two marketing motivators: price and remaining shelf-life duration.

I. Problem Description

A. Freshness function

We use the value between 0 and 1 to represent the freshness of the product. That is at the very initial time, the product will have a freshness of 1, and the freshness of the product will decrease along with time. So construct the freshness function $\theta(t) = \theta^t$. Figure 1 shows the changing trend of the freshness with time.

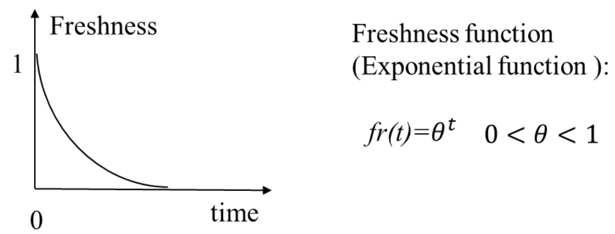

Fig. 1. Freshness function

The freshness changing trend of the product cannot be controlled given the reservation facilities of the store. But we can still control the demand of the product by pricing strategy.

B. Demand function with price and freshness

The optimal pricing problem is similar to the newsboy problem, The word "newsboy" was mentioned by Morse and Kimball's book according to Chen, Cheng, Choi and Wang [4], and was proposed as a problem and the formulation was appeared in the paper by Kenneth Arrow, T. Harris, and Jacob Marshak [5]. The products need to be sold for a specific fixed time and must be discarded at the end of the sale period. However, the freshness problem is much more complicated: not only the entire products loss freshness, but also a fraction of the products deteriorates for the whole sale period. And also the fresh products' prices can be controlled during depending on the freshness condition of the products.

The demand of a product is negatively influenced by the price, usually the higher the price the lower the demand will be. And at the same time the freshness of products will also influence the customer's wiliness of buying. However, the freshness of the products can't be controlled, so the main target of our work is to find an optimal price strategy to stimulate the customers' consumption. And the problem here is to construct a suitable demand function that is influenced by the price and freshness.

The stochastic demand is usually broken down into two parts: 1) the expected value which related to price and freshness. 2) The price and freshness independent stochastic demand disturbance term.

Generally speaking, the expected value of the demand is assumed to be a decreasing function of price and the increasing function of freshness. And it can have different expressions for different products and different distributions at the same time. The two commonly used demand functions

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are additive demand functions and multiplicative demand functions.

In our work, we can construct the demand function related with price and freshness of product.

$$\mathrm{D}(t) = (a - bP(t))\theta^{t} \qquad (1)$$

And use additive demand function to and adding a random fluctuation.

$$\mathrm{D}(t) = (a - bP(t))\theta^{t} + \varepsilon \qquad (2)$$

Here we assume the random fluctuation follows the normal distribution [6]. The expected value of demand is decided by the price and the freshness of product, and is changing along with time. Dave [7] introduced the time-varying demand rate into the inventory management of the perishable products. figure 2. shows a time-vary normal distribution.

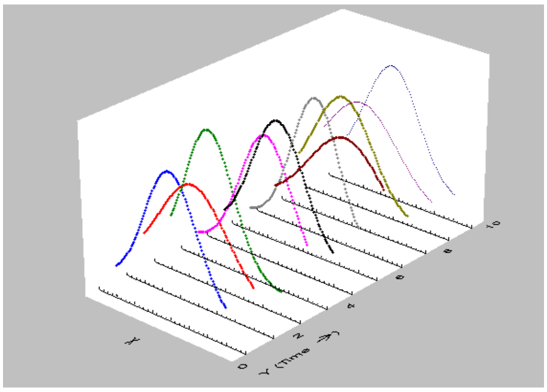

Fig. 2. Time-vary normal distribution

C. Price strategy

Dynamic pricing policy is a most important part for the supply chain management. And there are much more details need to be considered in the sales process of fresh products, which will lose value along with time [8]. So here we propose a price strategy based on the freshness of the product. In my research set the discount time point at 1/2T, 3/4T, 7/8T… (T is the time point when the product is on a certain un-fresh level and will be discarded)

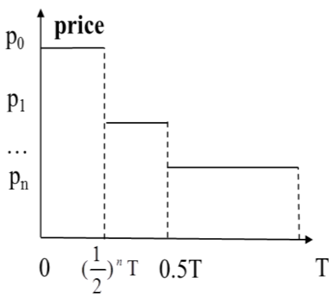

Fig. 3. The basic format of price strategy

Here, the target is to find the most suitable price at different stage for fresh products.

II. 3 PROBLEM FORMULATION

A. Notation

In my research of price strategy for fresh products involves several variables and the meanings are as below：

D(t) The demand at time t

I(t) The inventory at time t

Q The initial inventory

P(t) Selling prices, is the decision variable

P0 The original value of the price

h Inventory cost of unit product

c Purchasing cost per unit product

λ The deterioration rate

θ Freshness changing ratio

d Out of stock cost of unit product

B. Assumption

Below are the assumptions in the problem formulation.

1. The replenishment is instantaneous and shortages are allowed.
2. A constant fraction of the products deteriorate per unit time.
3. The products loss freshness along with time.
4. Set the discount time point based on the freshness level.
5. The demand follows a time-change normal distribution.

C. Mathematical formulations

Below is the formulation of expect profit of the product in a sale period.

$$\max \quad \mathrm{E}(profit) = \sum_{t=0}^{T} P(t)*D(t) - Q*c - \sum_{t=0}^{t_0} h*I(t) - \sum_{t=t_0}^{T} d*|I(t)| \qquad (3)$$

$$\begin{aligned} & I_0(0) = Q \\ & p_{i+1} < p_i \\ & 0 < p_i < p' \qquad (4) \\ & I(t+1) = I(t) - \mathrm{D}(t) - \lambda I(t) \end{aligned}$$

P (t) is the price at time t, and is decision variable. By setting the proper value of the price， we can help to get the maximum profit. I(t) is the inventory level at time t. Q is the initial inventory, c is the purchasing cost of unit product and d is the out of stock cost of unit product.

As equation (3) shows, the average profit is the total revenue minus costs, there include three costs, first is the purchasing cost, and then the inventory cost and out of stock cost.

Equation (4) is the constraint. The inventory at the next time point t+1 equals to the inventory of the time point t minus the demand and the deteriorate part at time t. And the prices are at a descendant order.

III. SOLVING METHOD

A. Stochastic simulation

Because the stochastic demand is influenced by the price and the freshness condition, which is time-vary and will change at discrete time points. That means at every time t, the demand is different. So it's difficult to get the optimization result by mathematical deduction. Therefore, discrete-event system simulation can be used to simulate random inventory system operation. Here we will use GA algorithm to do optimization. Let's say every simulation process of getting the profit for the whole sale period is to simulate a real sale procedure, in order to get the stable value, we need to simulate as many scenes as we can. A GA and Scenario

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Simulation Hybrid Algorithm to solve the stochastic problem are developed in this study.

B. GA algorithm

Genetic algorithm (GA) is an intelligent optimization algorithm by imitating biological evolution mechanism. Goldberg [9] has done much research about GA and we can know more detail about GA from his work. When dealing with the optimal problem, the first method we can think about is to find the absolute optimal value from point to point. However, in some condition, the point to point method is a huge amount of computation and is time consuming. So we adopt GA which can simultaneously search a population of points, and use probabilistic transition rules as a guide to search the solution.

GA uses three genetic operators: selection, crossover, mutation to evaluate the population of solution code. The group performs evolutionary operations to guide the population search to the optimal solution direction. Below are the details of every genetic operator.

Encoding and initial population

The chromosome is composed by a series of prices (p1, p2, p3…pn) which is randomly selected from [0-p0],

Cross over method: Random single point cross

Randomly select the same location of two individual, and exchange the value. As Fig. 4.shows.

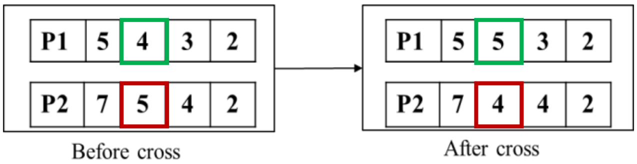

Fig. 4. The crossover operation in chromosomal in genetic algorithm

Mutation

Set the mutation rate of a small value such as 0.01, and randomly select the mutation location and randomly change the value of the selected position.

C. GA + Scenario Simulation Hybrid Algorithm:

Because the demand follows a time-vary stochastic distribution, which means in every realistic scene the profit of each sale time period will be different. So here we simulate the real scene as much as possible to eliminate the effects of the uncertainty when calculating the fitness value [10] (here the fitness value is the profit of each sale time period). Fig. 5. describes how the hybrid GA+ Scenario Simulation Hybrid Algorithm method works.

The procedure mostly includes three steps:

Step1. Initial a set of price strategy according to the Initial inventory, selling cycle length, discount time point and discount number.

Step2. And then for each individual, get the fitness value in step2 by scenario simulation.

Step3. Ranking the price strategies based on their fitness value (the profit value). Update strategies by GA operators, reproduction, crossover and mutation in order to obtain a set of new price strategies.

Step4. Repeat step2 and step3 until the generation value set before and the fitness converge to a certain value.

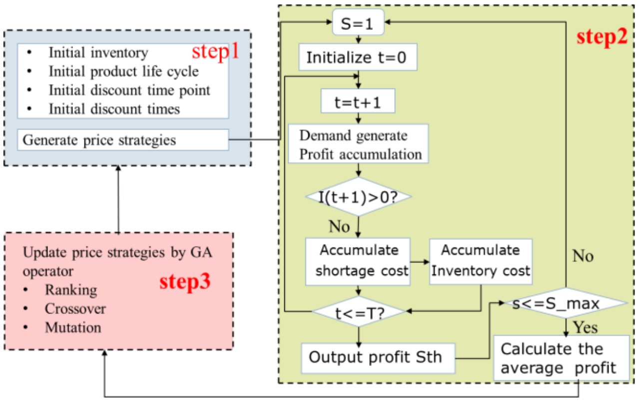

Fig. 5. Flow diagram for v GA + Scenario Simulation Hybrid Algorithm

IV. NUMERICAL ANALYSIS

A. Parameter setting

The price influence parameter b=0.1, demand scale influence parameter a=60, initial price P0=500 Japanese yen. And the purchasing cost is c=200 yen per unit product. Inventory cost h=5 yen, out of stock cost d=5 yen. The freshness changing ratio θ=0.8, demand variance δ=10 and the deterioration rate λ=0.01.

Here we want to set a three level price strategy [P0, P1, P2] in a sale period of the products and to maximize the profit.

B. Show the result of price strategy obtained by our GA, and compares it with other linear and non-linear price policy.

Here we assume the linear price strategy as the price given by a simple linear price function. E.g., $p(t)$=500−60t Non-linear price strategy is the price given by a simple non-linear price function. E.g. $p(t)$= 500∗(3/4)^t

And get a three level price and the value is get from time point of t=0, 4, 7.

TABLE I
COMPARISON WITH OTHER PRICE STRATEGY

Price Policies given by GA		Linear Price Policies		Un-linear Price Policies	
Initial inventory	43 units	Initial inventory	43 units	Initial inventory	43 units
Maximum profit	6590yen	Maximum profit	4901 yen	Maximum profit	4104yen
Price strategy	[500,423,381]	Price Strategy	[500,260,80]	Price Strategy	[500,158,67]
Out of stock cost	27 yen	Out of stock cost	80 yen	Out of stock cost	109 yen

In table 1, we compared the price strategy get from GA with other two kinds of strategy under the fixed initial inventory. According to the assumption that demand is negatively related to the price, we can see that because the other two prices is lower than the GA result, the out of stock cost is higher. But the GA strategy which we proposed can get higher profit than the other two strategies.

C. Evaluate the calculation performance of GA.

Set the population size 100, and generation size 100. The crossover probability is 0.9, mutation probability is 0.1, and Scenario is 3000.

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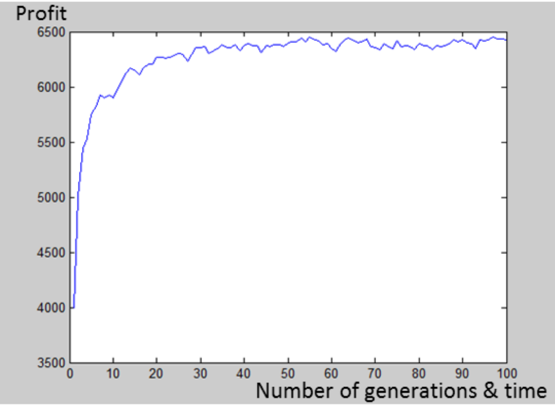

Fig. 6. Converge curve of GA algorithm

Fig. 6.shows the fitness value (profit) in the process of evaluation. From generation0-10, the fitness value rapidly increases, and with the number of the generation increases, the algorithm will finally converge to a certain maximum value 6500 yen.

D. Sensitivity analysis

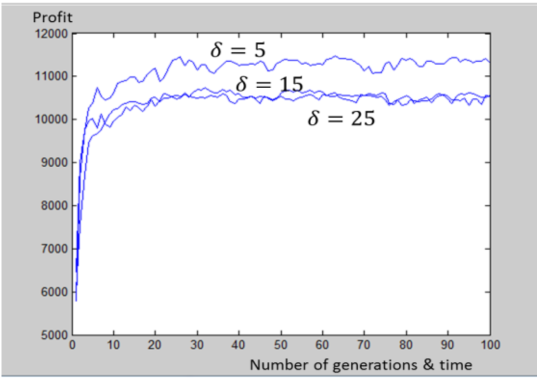

Fig. 7. The evaluation of the effect of the demand variance.

Fig. 7. is the evaluation of the effect of the demand variance δ. The lower the demand variance, the higher the demand, and more likely the out of stock or overage may happen, so under the same initial inventory level, the demand with lower variance may have higher profit.

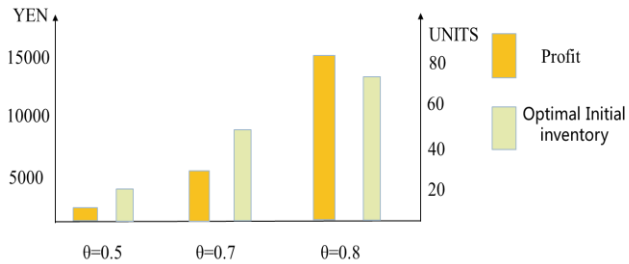

Fig. 8. Sensitivity analysis of the freshness changing ratio

Fig. 8.shows the sensitivity analysis of the freshness changing ratio. Different freshness changing ratio represents different kinds of products, the demand decrease dramatically with high freshness changing ratio, so under the same demand function, the faster the product loss freshness, the lower the maximum profit and the lower the optimal initial inventory.

V. Conclusions and Future Works

Conclusions:

Our work first summarizes the characteristics of perishable fresh products, and analyzes the difference with general merchandise: not only deteriorate but also losing freshness long with time, which means the quality and quantity loss happened at the same time during sales. And also we used the value between 0-1 and the exponential function to represent the freshness condition and change trend of the fresh products.

Based on the fact that the customer demand is decreasing with price and increasing with freshness, we proposed a customer demand model which can properly reflect the connection between the demand with price and freshness, and in order to make the model more realistic, a stochastic influence factor is added into it. And because the freshness of the products, we need to consider lowering the price to stimulate the consumption of the customer, our work proposed multi-level discount price strategy to maximize the profit.

The demand's mean value is determined by the price and the freshness, which are both changing with time, and also because of the stochastic influence factor, they make the demand follows time-vary distribution. It's hard to solve the optimal problem using traditional mathematical deduction, so we proposed a scenario simulation method to get the profit value, and in the process of solving the optimal price, we integrate the GA algorithm for reducing the amount of computation.

Future works:

The model of the optimal price strategy studied in this paper considers only the single-period problem of a single commodity of fresh products, so in the future can consider the problem of multi-period and multi-products.

And also, my research only considered the maximum profit as the criterion to evaluate whether the strategy is optimal strategy, but in the future, satisfaction level and the profit will be combined at the same time as a multi-objective problem

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