Product substitution with customer segmentation under panic buying behavior

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ABSTRACT

Under conditions of consumer panic buying, satisfying demand with the available products is a complex problem. In reality, most retailers accept alternative products during panic situations. This study considers the case of firm-driven substitution of products (differing in weight) based on retailer preferences over two time-periods. In the proposed model, panic behavior emerged in the first time-period and interruption in supply occurred in the second time-period. Under this model, retail stores were segmented into high index (valuable) and low index (less valuable) customers. Before meeting the demand of low-index customers, wholesalers attempt to satiate high-index customer’s panic buying behavior. To generate maximum wholesaler’s total profit, we find the optimal amount of substitution quantity, quantity to order, and leftover units. The model is investigated for both without and with substitution. To gain managerial insights, we also examined the influence of both the degree of interruption in supply and substitution costs on profits and decisions. The results can assist business managers to improve the decision-making process.

Keywords: panic buying, customer satisfaction, customer segmentation, substitution, Mixed Integer Program (MIP)

1. Introduction

Panic purchasing caused by interruption in supply is frequently occurs in today’s market. Higher oil prices and changes in government policies lead to supply chain disruptions. For example, protesting against the government’s taxation policies, when owners of fuel stations and petrol tankers announced an indefinite strike in India [1], the Nepal Oil Corporation provided additional fuel in the Kathmandu Valley to assuage panicked buyers who were queuing in front of petrol stations, driven by the fear of impending shortages [2]. Natural disasters, strikes, and terrorist attacks can also cause interruption in supply (Shou et al. [3], Fang et al. [4], and Kumar et al. [5]). He et al. [6] stated that in the present globalized and highly uncertain business environment, management of interruption in supply is a critical challenge for managers. Panic buying often increases the supply-demand imbalance, negatively affecting high-index customers. Therefore, suppliers should first focus on satisfying high-index customers. Generally, wholesalers hold
excess inventory to avoid shortages, thereby establishing a reliable relationship with retailers. However, this behavior can result in excess inventory in one product and shortages in another. For example, earthquakes in Japan resulted in queues for food and water that eventually depleted supplies in supermarkets (Maclaughlin [7]). However, product substitution can be used to overcome this problem. Mardan et al. [8] stated that product substitution is one of the efficient tools to minimize supply uncertainties. According to Transchel [9], substitution behavior decreases the supply-demand imbalance and provides significant profit implications for firms.

In a single-period multiproduct inventory system, Rao et al. [10] considered downward substitution for stochastic demand by using a two-stage mixed-integer stochastic program to minimize total costs. Netessine and Rudi [11] studied an optimal stocking problem for a single-period multiproduct consumer-driven substitution under both centralized and decentralized inventory management to maximize profits. Hoseininia et al. [12] considered a multi-channel distribution system, where the substitutable product is presented by the manufacturer and retailers, the customer may switch to other channels while stock out happens. In addition, Yucel et al. [13] developed an optimal policy capable of maximizing the total expected profit over a planning horizon. The authors also determined the effects of substitution on profits by varying substitution cost parameters.

Stavrulaki [14] studied the joint effect of demand stimulation and substitution by considering a single period two-way substitution model. Vaagen et al. [15] developed a heuristic system for consumer-directed substitution using multi-way substitution to address multiproduct stochastic demand and single-period inventory management. Bayindir et al. [16] investigated optimal conditions for a single-period profit model under substitution for manufactured and remanufactured products. Kim et al. [17] studied the effect of substitution which was price driven on a company’s productivity. In addition, Pentico [18] provides an overview of a detailed survey conducted on assortment problems with substitution.

When a supplier determines the amount to be substituted, it is referred to as “firm-driven substitution” (Lang and Domschke [19], Yu et al. [20], and Xu et al. [21]). Multilevel demand substitution is the combination of an upward and downward substitution strategy. For example, when 1-liter water bottles are out of stock, two half-liter water bottles can be substituted; 1-liter water bottles can be substituted when half-liter water bottles run out of stock.

Figs. A1 and A2 present an example where the product weights are as follows: P1 = 50 g, P2 = 100 g, P3 = 150 g, and P4 = 200 g. Fig. A1 illustrates the substitution structure in terms of the weight of demand D4 for product P4, where each unit of demand D4 is substituted with one of the following: four units of product P1, two units of product P2, two units of product P3, or one unit of product P4. Fig. A2 presents the substitution structure in terms of weight of demand D1 for product P1, where each unit of demand D4
is substituted with one of the following: four units of product P1, two units of product P2, two units of product P3, or one unit of product P4.

Extreme weather events easily cause supply chain disruptions. For instance, the drought in Ethiopia reduced crop yield by 90% [22]. While investigating the effects of substitution on panic buying, Ervolina et al. [23] considered two different customers: customers likely to accept product substitutions and those unlikely to accept substitutions. In panic situations and under the pressure of scarcity, most customers are willing to accept products of the same brand as substitutes. Satisfying customers’ demand for the majority of overall profits becomes a priority, even at the expense of less-valuable customers. Ju et al. [24] segmented suppliers as regular and expedited. Hsu et al. [25] considered two products, classified as low index and high index. Tsao et al. [26] segregates the customers as high indexed stores (HIS) and low index stores (LIS). Shou et al. [3] considered single products when examining panic buying under interruption in supply without substitutions. In this study, we modeled the problem of product segmentation by categorizing retailers (customers) into high index and low index. Our study provides an optimal policy for order quantities during panic buying behavior in first time-period and distributes the available inventory effectively to satisfy high index customers in second time-period.

To the best of our insight, no study has integrated single-brand, multiple weights of product, multilevel substitution of product, customer segmentation and panic buying in a single model. This study considered firm-driven, customer-segmented substitution for single-brand multi-weighted products under panic buying in a two-period model. Our goal is to increase the total profit derived from the retail-price, cost of substitution, purchasing cost, lost demand cost, and stock holding cost. To generate wholesaler’s maximum profit, we explore the optimality of units to be substitutable, ordered, unsatisfied demand and number of remaining units. The developed MIP model is solved within a few seconds by using CPLEX. Here, we discuss the extent to which variability in interruption in supply influences profits, customer satisfaction provided to high-index customers, and overall customer satisfactions and inventory. We also discuss the effect of substitution cost on profits.

The rest of the paper is sorted out as follows. In Section 2 we characterize the problem definition and mathematical model for firm-determined segmented customer substitution considering panic purchasing in. Section 3 illustrates an example and made performance analysis of the model under various situations. The experimental analysis is explained in detail in the Section 4. The expansion of the model is dissected in Section 5. Section 6 compares the results obtained by CPLEX and the proposed genetic algorithm (GA). Section 7 makes the conclusions and provides recommendations for further research.

2. Problem definition and mathematical model
Wholesaler supplies “w” weights of a single product to “n” retail stores over two time-periods. Fig. A3 presents the flow network for first time-period. In the first time-period the amount of products to order is the total of the demand in first time-period and the product of rate of panic \( \alpha_k \) of demand in Second time-period. The remaining products toward the finish of first time-period incurs an inventory cost. These remaining products toward the finish of first time-period are provided to retailers amid Second time-period. Furthermore, the entire retail stores are viewed as high indexed in first time-period.

Fig. A4 presents the flow network for Second time-period. The wholesaler receives \( (1 - \beta_k) \) of his/her order quantity because supply from the supplier is disrupted. During this time-period, the lost demand cost discriminates if the stores are high index or low index, and high-index stores are satisfied before low-index stores. The wholesaler retains the inventory required, and the retailer’s demand is known for all the stores. Transshipment is not allowed between retailers. Lost demand costs, cost of substitution, unsatisfied demand, retail-prices, rate of panic, and purchasing costs are known. This study assumes that prices are constant in both the periods.

**Model:**

**Assumption:**

This model assumes that in both periods the retail-price “\( V_{i,k} \)” is constant, which is reasonable in various situations. For instance, during Hurricane Sandy in 2012, the attorney general of New Jersey issued a warning of the danger of arraignment during a declared state of emergency to merchants and businesses engaging in price gouging over the top costs for food, fuel, or drugs [27]. What's more, amid the baby’s powdered milk lack in Hong Kong, significant providers declared that retail costs were settled (Shou et al., [2016], Tsao et al. [2018]).

In first time-period, the wholesaler determines the order quantity of the product from suppliers dependent on demand in First period and rate of panic\( \alpha_k \). Also, the wholesaler receives the ordered product in full immediately upon issuance. In Second time period, the wholesaler determines the quantity to order according to the interruption in supply \( \beta_k \), under which the second order cannot be supplied in full, as portrayed by Shou et al. [3] and Tsao et al. [26].

- At the termination of each time-period the wholesaler’s inventory is assumed to be replenished.

Thus, the total stock includes inventory in the current period as well as the leftover from the previous period.
• Downward substitution is based on weight; if one 100-gram pack is out of stock, then two 50-gram packs are substituted to satisfy demand.

• In the case of upward substitution, if one 50-gram pack is out-of-stock, then one 100-gram pack is substituted for that demand.

• In the first time-period, entire retailers are viewed as high index. In second time-period, the lost demand cost for HIS are higher than the LIS.

• The cost of substitution ($TC_{i,j}$) is the cost of maintaining goodwill or loss of revenue when $i$ is substituted for $j$.

**Constants:**

$m$ Total time periods;

$n$ Total stores;

$O$ Total products.

**Indices and sets:**

$i = (1,..., m)$ time-periods;

$j = (1,..., n)$ retailers and $n=a+b$, where “$a$” is a high-index store and “$b$” is a low-index store;

$k = (1,..., o)$ products.

**Parameters:**

$V_{i,k}$ unit price for product $k$ in time-period $i$;

$C_{i,k}$ unit cost of purchasing for product $k$;

$HC_k$ inventory holding cost per unit of product $k$;

$P_{i,j,k}$ lost demand penalty cost per unit of product $k$ in retailer $j$ for time-period $i$;

$A_{k,l}$ quantity substituted per unit of product $k$ substituted per unit of product $l$;

$TC_{i,k,l}$ cost for substituting per unit of product $k$ for product $l$ in retailer $j$ for time-period $i$;

$D_{i,j,k}$ product $k^{th}$ demand in retailer $j$ in time-period $i$;

$TD_{i,k}$ product $k^{th}$ total demand for in time-period $i$;

$Z_{i,k}$ $k^{th}$ product initial inventory in time 1;

$\alpha_k$ rate of panic for $k^{th}$ product;

$\beta_k$ rate of interruption in supply for $k^{th}$ product.

**Decision variables:**

$O_{i,k}$ quantity of $k^{th}$ product in time-period $i$ to be ordered;

$T_{i,j,k,l}$ amount of $k^{th}$ product satisfying $l^{th}$ product demand in store $j$ during time-period $i$;

$R_{i,j,k}$ amount of $k^{th}$ product received by store $j$ during time-period $i;$ 

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$S_{i, j, k}$ amount of $k^{th}$ product sent to store $j$ during time-period $i$;

$U_{i, j, k}$ amount of unsatisfied demand for $k^{th}$ product in store $j$ during time-period $i$;

$E_{i, k}$ amount of $k^{th}$ product leftover from time-period $i$;

$H_{i, k}$ total amount of unit’s available satisfying $k^{th}$ product demands during time-period $i$.

The Mathematical model

$$\text{Max TP} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{o} \left[ (V_{i, k} \times R_{i, j, k}) - (C_{i, k} \times S_{i, j, k}) - \left( \sum_{l=1}^{o} T_{C_{i, k, l}} \times T_{i, j, k, l} \right) - (P_{i, j, k} \times U_{i, j, k}) \right]$$

$$- \sum_{i=1}^{m} \sum_{k=1}^{o} (E_{i, k} \times H_{C_{k}})$$

(1)

Eq. (1) exhibits the objective function which maximizes the total profit, which is the difference between sales revenue and the sum of all costs including purchasing cost, cost of substitution, lost demand penalty and holding expense.

Distribution constraints

The amount of product $k$ received in stores $j$ and those subsequently distributed by wholesaler are expressed as Eqs. (2) and (3), respectively. The quantity received is less than or equal to quantity send ($R_{i, j, k} \leq S_{i, j, k}$) in view of substitution.

$$R_{i, j, k} = \sum_{l=1}^{o} T_{i, j, k, l} / A_{l, k}, \quad \forall \ i = 1, 2; \ j = 1, 2, \ldots n; \ k = 1, 2, \ldots o$$

(2)

Property 1:

We define $R_{i, j, k}$ as fractional. Hence the $A_{l, k}$ cannot attain the value zero. In our case it is always an integer and greater than or equal to one.

$$S_{i, j, k} = \sum_{l=1}^{o} T_{i, j, k, l}, \quad \forall \ i = 1, 2; \ j = 1, 2, \ldots n; \ k = 1, 2, \ldots o$$

(3)

Property 2:

If the retail-price is fixed in both time-periods, then in the first time-period there is no shortage. Hence, the quantity received, quantity send and demand in the first time-period are equal ($R_{1, j, k} = S_{1, j, k} = D_{1, j, k}$). It is not applicable when the retail-price is not constant.

The number of units distributed is less than or equivalent to the amount of products available and the amount of received quantity is less than or equivalent to the number of units demanded, as denoted by Eqs. (4) and (5).
\[ \sum_{j=1}^{o} \sum_{l=1}^{o} T_{i,j,k,l} \leq H_{i,k}, \quad \forall \ i = 1,2,...,m; \ k = 1,2,...,o \quad (4) \]

\[ \sum_{l=1}^{o} \left[ T_{i,j,k,l} / A_{i,k} \right] \leq D_{i,j,k}, \quad \forall \ i = 1,2,...,m; \forall \ j = 1,2,...,n; \ k = 1,2,...,o \quad (5) \]

Unsatisfied and inventory constraints

The unsatisfied demand is denoted by Eq. (6), which calculates by deducting the quantity received to the retailers from the demand. The inventory is determined utilizing Eq. (7).

\[ U_{i,j,k} = D_{i,j,k} - \sum_{l=1}^{o} \left[ T_{i,j,l,k} / A_{i,k} \right], \quad \forall \ i = 1,2; \ j = 1,2,...,n; \ k = 1,2,...,o \quad (6) \]

\[ E_{i,k} = H_{i,k} - \sum_{j=1}^{n} \sum_{l=1}^{o} T_{i,j,k,l}, \quad \forall \ i = 1; \ k = 1,2,...,o \quad (7) \]

Total units available

The quantity available is the whole of the inventory left from time-period i-1 and the amount ordered during time-period i is expressed in Eq. (8). Equation (9) denotes the number of available units as the aggregate of the underlying stock and the amount ordered during first time-period.

\[ H_{i,k} = O_{i,k} + E_{i-1,k}, \quad \forall \ i > 1; \ k = 1,2,...,o \quad (8) \]

\[ H_{1,k} = O_{1,k} + Z_{1,k}, \quad \forall \ k = 1,2,...,o \quad (9) \]

Total demand

Equations (10) and (11) represent the sum of the total demands of all the stores in first time-period and Second time-period, respectively.

\[ TD_{1,k} = \sum_{j=1}^{n} D_{1,j,k} \quad \forall \ i = 1, \ k = 1,2,...,o \quad (10) \]

\[ TD_{2,k} = \sum_{j=1}^{n} D_{2,j,k} \quad \forall \ i = 2, \ k = 1,2,...,o \quad (11) \]

Order to period assignment constraint

Equation (12) denotes the quantity ordered during first time-period, which is the sum of the aggregate demand in the first time-period and multiply the rate of panic \( \alpha_k \) and whole demand during Second time-period. Equation (13) denotes the amount ordered during second time-period, which is the multiplication of the total of the rate of interruption in supply \( 1 - \beta_k \) and rate of panic \( 1 - \alpha_k \) and the total demand during second time-period.
\[ O_{1,k} = TD_{1,k} + \alpha_k TD_{2,k}, \quad \forall \ 0 < \alpha < 1; \ j = 1,2,\ldots n; \ k = 1,2,\ldots o \] (12)

\[ O_{2,k} \leq (1 - \beta_k)(1 - \alpha_k) TD_{2,k}, \quad \forall \ 0 < \alpha < 1; \ j = 1,2,\ldots n; k = 1,2,\ldots 0 \] (13)

Non-negativity constraint

\[ T_{i,j,k,l} \geq 0, \text{integer}, \quad \forall \ i = 1,2,\ldots m; \ j = 1,2,\ldots n; \ k = 1,2,\ldots o; \ l = 1,2,\ldots o \] (14)

\[ U_{i,j,k} \geq 0, \text{integer}, \quad \forall \ i = 1,2,\ldots m; \ j = 1,2,\ldots n; \ k = 1,2,\ldots o \] (15)

\[ O_{i,k} \geq 0, \text{integer}, \quad \forall \ i = 1,2,\ldots m; \ k = 1,2,\ldots o \] (16)

The developed MIP model is solved in CPLEX and which provides optimal solutions for the proposed model under all the tested instances.

Penalty cost

The lost demand cost segregates the customers as LIS and HIS. The lost demand cost for low-index stores (LIS) is expressed as \( P_{i,b,k} = \eta \times \text{the retail-price of k}^{\text{th}} \text{product} \) (\( 0 < \eta < 1 \)) and that for high-index customers is expressed as \( P_{i,a,k} = \eta \times \text{the retail-price of k}^{\text{th}} \text{product} + \max (P_{i,b,k}) \).

Property 3:

The penalty cost of HIS is always greater than the LIS \( (P_{i,a,k} > P_{i,b,k}) \). If the penalty costs of all the customers are equal, then there is no segregation of customers \( (P_{i,a,k} = P_{i,b,k}) \).

3. Numerical example

We provide the numerical example from Tsao et al. [26] and also refer the data for demand. We consider a scenario of involving four products (P1, P2, P3 and P4), four stores and two periods. The products were from the same brand but in different quantities (weights). The weights of the products from P1 to P4 are 50g, 100g, 150g, 200g. Table B1 shows the parameter of retail-price and cost components of each product. Where the table B2 shows the cost of substitution products for retailers in both time-period. The ratio of substitution products in both time-period depends on weights of the product (Table B3). In addition, the rate of panic, interruption in supply and initial inventory are given as \( \alpha_k = \{0.3, 0.3, 0.3, 0.3\} \), \( \beta_k = \{0, 0, 0.7, 0.8\} \) and \( Z_{l,k} = \{3500, 2700, 1370, 1770\} \) respectively. In the first time-period all retailers are considered as high indexed and in the second time-period retailer 1 and 2 are considered as high indexed, hence the lost demand cost for HIS are \( P_{i,k} = \{24, 28.8, 33.6, 38.4\} \). In second time-period the retailer 3 and 4 are considered as LIS, hence the lost demand cost for the LIS are \( P_{2,k=2,4} = \{4.8, 9.6, 14.4, 19.2\} \). No interruption in supply occurred for Product 1 and Product 2; however, the interruption in supply rates for 3\(^{\text{rd}}\) and 4\(^{\text{th}}\) product were 0.7 and 0.8, respectively.

Table B4 presents the optimal solution for each product that should be distributed to the retail stores. Where there is no substitutable product in the first time-period; this period was associated only
with the onset of panic. As a result of the interruption in the supply on second time-period, the substitution is executed in second time-period to maximize the aggregate profit and encourage the customer satisfaction in high-indexed retailer. The substitution units are provided from the overabundance stock and the low-index customers order quantity. The profits obtained without customer segmentation substitution (WOCSS) model and with customer segmentation substitution (WCSS) model are Rs. 1127636 and Rs. 1168943. As indicated by the highlighted values in Table B4, nearly 10670 units are used for substitution by the wholesaler and stores, based on the weight ratio, received 4752 units. X, Y, Z denotes the substitution of the products in table B4.

4. Experimental analysis
For experimental reproductions, we generated cases involving four products and four stores over two periods. To demonstrate our experimental analysis we provide the parameter of brand G from Tsao et al. [2018] and the same is used for both section 5 and section 6.

4.1 Impact of variation in substitution costs on profits
Fig. A5 demonstrates that increasing the substitution cost as a percentage of product cost led to a decrease in total profits: \( TC_{i,k,l} = \theta \times \text{purchasing cost} + \text{loss in purchasing cost} \) \((0 < \theta < 1)\). Fig. A5 illustrates the effects of variation in substitution cost on the profit on WOCSS and WCSS model. As demonstrated, profit increased with decreasing \( \theta \) and the profit continually increased under customer-segmented substitution.

4.2 Impact of variation in interruption in supply
The rate at which supply disrupted is varied to examine the performance of WOCSS and WCSS model. In reality, the interruption in the supply isn’t really equivalent for entire products. The simulation considered no interruption in supply \((\beta_{1,2} = \{0,0\})\) for Product 1 and Product 2 and varies the rates of interruption in supply \((\beta_{3,4})\) for 3rd and 4th product. Table B5 presents the correlation of the impact on the WOCSS and WCSS model while increasing \(\beta_{3,4}\). The results are analyzed in the following section.

4.2.1 Impact on total profit
The rate of interruption in supply for 3rd and 4th product changes from 0 to 1 and their effects on total profit is analyzed in cases both WOCSS and WCSS model. Fig. A6 exhibits, increased interruption in supply had a pronounced effect on profits when customer-segmented substitution is conducted. The profits increased by as much as 17% when excess products and the order quantity of the low index customer are substituted for items that were out of stock, giving preference to high-index customers.

4.2.2 Impact on percent of customer satisfaction obtained in HIS
We examined the percent of customer satisfaction received by high-indexed retailer in the WOCSS and WCSS model when the rates of supply is interrupted between 0 and 1 for 3rd and 4th product. Fig. A7 illustrates the influence of customer-segmented substitution on customer satisfaction. The customer satisfaction of high-index stores increased under customer-segmented substitution. To satisfy the demand from high-index stores, excess inventory is substituted in the first substitution phase, whereas both the excess inventory was substituted and orders were deallocated from low-index stores in the second phase.

4.2.3 Impact on percentage of overall customer satisfaction obtained in retailers

We analyzed the percent of overall customer satisfaction in the retailers for the WOCSS and WCSS model when the rates of supply is interrupted between 0 and 1 for 3rd and 4th product. Fig. A8 illustrates that in the first substitution phase, the overall customer satisfaction percentage was higher under the customer-segmented substitution model. However, in the second substitution phase, the deallocation of the orders of low-index customers caused the overall customer satisfaction in WCSS to be lower than that in cases without customer-segmented substitution.

4.2.4 Impact on inventory

The influence of varying interruption in supply rates for 3rd and 4th product on the inventory held by the wholesaler is analyzed. The inventory was constant during first time-period since substitution is not yet actualized. In Second time-period, the abundance inventory in the wholesaler is utilized for the substitution of products, thereby decreasing the available units leftover to zero. In our case the rate of interruption in supply rate is 0.1, the inventory available during Second time-period was higher than zero, regardless of whether substitution implemented. Whenever the rate of interruption in supply is 0.2, the inventory available during Second time-period was zero in cases involving substitution. Fig. A9 clearly illustrates that the units leftover remained consistent when the interruption in supply rate is above 0.2. Because the rate of panic is constant, the maximum allowable order quantity to order in first time-period attained whenever the interruption in supply rate is 0.2. The inventory relies on substitutable product rate, rate of panic and the initial units leftover.

4.3 Impact in constant interruption in supply for all products

Suppose that the interruption in supply is even for entire products. Even if it is rarely possible, Table B6 compares the WOCSS and WCSS model. Following the same data in numerical example, we correlate the profits WOCSS and WCSS under different interruption in supply rate (from 0.1 to 1). Overall, the customer segmented substitution model performs better (higher profit) than the model without substitution.

4.4 Impact of variation in Rate of panic
The rate of panic is varied to analyze the performance of the WOCSS and WCSS model. We consider that there is no panic ($\alpha_{1,2}=\{0,0\}$) for Product 1 and Product 2 and rate of panic($\alpha_{3,4}$) varies for 3rd and 4th product. Table B7 presents the correlation of WOCSS and WCSS model while increasing $\alpha_{3,4}$, where the interruption in supply rates for products are kept as constant as $\beta_k=\{0,0.5,0.6\}$. The results are analyzed in the following section.

### 4.4.1 Impact on total profit

The rate of panic for 3rd and 4th product changes from 0 to 1 and their effects on total profit is analyzed in cases both WOCSS and WCSS model. The Fig. A10 illustrates, whenever the rate of panic increases which increase the profits when WCSS model conducted. In the WCSS model, the profit increased unto rate of panic is 0.8 and decreases afterwards. The increase in the rate of panic will increase the inventory within the first time-period and reduces the interruption in supply in 2nd time-period. In WCC model unto the rate of panic is 0.7, some amount of product 1 and 2 are stored as inventory to fulfil the demand of products 3 and 4. So above 0.7 the need to stock excess quantity from products 1 and 2 decreases and hence the inventory reduces. Anyhow, the growth in the rate of panic elevates the unit’s leftover in the first time-period and reduces aggregate profit.

### 4.4.2 Impact on percent of customer satisfaction obtained in high-index retailers

We examine the percent of customer satisfaction received by HIS in WOCSS and WCSS when the rate of panic for 3rd and 4th product varied between 0 and 1. Fig. A11 illustrates the influence of WCSS model on customer satisfaction level. While the WCSS, in the low rate of panic at the initial stages reduces the inventory in the first time-period hence the customer satisfaction level for the HIS get reduced. In general, the WCSS display better performs than the WOCSS.

### 4.4.3 Impact on percentage of overall customer satisfaction obtained in retailers

We analyze the overall customer satisfaction in the retailers under various rate of panic (0–1) for 3rd and 4th product for both WOCSS and WCSS. Fig. A12 illustrates, first and the second substitution phase which happens in the beginning because of the deallocation of the orders of low-index customers. Hence the overall customer satisfaction in WCSS to be lower than that in cases WOCSS in the beginning. When the inventory in the first time-period get increased, it leads to first phase substitution (rate of panic 0.2 to 0.7) and when the inventory increases further, there may be no substitution (rate of panic 0.8 to 1).

### 4.4.4 Impact on inventory

The influence of varying rate of panic for Product 3 and Product 4 on the inventory held by the wholesaler is analyzed. Fig. A13 clearly illustrates, units leftover increased gradually when the rate of panic increases. The increase in the rate of panic increases the inventory in the first time-period and decreases the amount of interruption in supply in the second time-period. As discussed in section 4.4.1, in
the WCSS the unit’s leftover increases unto the rate of panic is 0.7 and decreases above 0.7. Finally, due to the increase in the rate of panic the unit’s leftover increases above 0.8.

5 Impact of price change

All of the periods the retail-price \((V_{i,k})\) is constant in the previous sections. In this section, the retail-price in second time-period rises when the rate of interruption in supply increases. Dixit et al. [28] provided the model as a function of price for both increasing as well as decreasing in the retail-price. Later Li et al. [29] considered the model as a function of price for both increasing as well as decreasing in the retail-price and furthermore considered constant demand and which was not depend on retail-price. Tsao et al. [26], the rise in retail-price on the second time-period \(V_{2,k} = V_{1,k} + \beta(P_{\text{max},K} - V_{1,k})\) and assumed that \(V_{1,k}\) is a retail-price in first time-period, where \(P_{\text{max},K}\) denotes the permitted increased retail-price, which is unchanging. The interruption in supply decides the rise in retail-price.

In this case we considered that there is no interruption in supply \((\beta_{1,2} = \{0,0\})\) for 1st and 2nd Product and varies the interruption of supply rates \((\beta_{3,4})\) for 3rd and 4th Product, and in our experimental analysis we set \(P_{\text{max},K} = 1.5* V_{1,k}\). Table B8 shows the impact of the WOCSS and WCSS models, with respect to rise in \(\beta_{3,4}\). The outcomes are investigated.

5.1 Impact on total profit

The rate of interruption in supply for 3rd and 4th product are varies between 0 and 1 and their effects on total profit is investigated. Fig. A14 shows that in this case, the increase in the price and interruption in supply had a pronounced effect on profits when customer-segmented substitution conducted. Another critical problem to emerge is stocking/hoarding behavior. Because of the rise in the retail-price in second time-period, which exceeds more than the sum of lost demand and units leftover cost, stocking/hoarding behavior elevated. The increase in interruption in supply and retail-price leads to hoard the quantity of the demand on first time-period to fulfill the demand in second time-period.

5.2 Impact on percent of customer satisfaction obtained in high-index retailers

We examine the impact on percent of customer satisfaction obtained in high and low index retailers while increasing \(\beta_{3,4}\) in the WCSS and WCSS model. Fig. A15 illustrates the influence of customer-segmented substitution on customer satisfaction. The interesting fact to notice here is that the hoarding behavior arises because of the increase in retail-price. As mentioned in section 4.2.2, to satisfy the demand from high-index stores, excess inventory is substituted in the first substitution phase, whereas both the excess inventory and the orders deallocated from low-index stores are used in the second phase of substitution. A third phase of substitution arise here is that the demand of stores in the first time-period is hoard to satisfy the demand of HIS in second time-period. Because of the rise in the retail-price in
second time-period, which exceeds more than the sum of lost demand and units leftover cost, stocking/hoarding behavior elevated.

5.3 Impact on percentage of overall customer satisfaction obtained in retailers

By varying the rate of interruption in supply for 3rd and 4th product ranging from 0 to 1, and its impact on percentage of overall customer satisfaction obtained to retailers is investigated. Fig. A16 shows that as discussed in the section 4.2.3, unto interruption in supply is 0.5 the first phase of substitution takes place and above 0.5 the second and third phase substitutions take place, which lead to reduction in the overall satisfaction level of retailers in WCSS model.

5.4 Impact on inventory

By varying the rate of interruption in supply for 3rd and 4th product ranging from 0 to 1, and its impact on inventory is investigated. Fig. A17 shows that there are three stages: 1) Initial stage (interruption in supply 0.1) where substitution does not takes place and using initial inventory, the demand is satisfied cent percent. 2) In the second stage (interruption in supply rate from 0.2 to 0.6 for WCSS model and 0.2 to 0.4 for WOCSS model) where the unit’s leftover are same because the rate of panic is consistent so the maximum allowable order quantity to order in first time-period is attained where the rate of interruption in supply is 0.2. 3) In the third stage (interruption in supply above 0.6 for WCSS model and 0.4 for WOCSS model), the increase in retail-price and interruption in supply increase the hoarding behavior. The demand of the stores in the first time-period is utilized to fulfill the demand in second time-period which increase the inventory.

6 Comparison of Genetic Algorithm (GA)

Table B9 and table B10 show the performance of the mathematical model by comparing the profit, decision variables and CPU run time. The parameters of brand G from Tsao et al. [26] are used to solve the problem in the proposed GA. The population size is set to be 75 and the elite preserving operation is set to be 14% of population size. The probability for crossover and mutation are 0.3 and 0.8 respectively. Table B9 shows total expected profit and CPU time (seconds) of the CPLEX model and the proposed GA. The GA terminates when the iteration reached 1000. Table B10 shows the comparison of the decision variable from the CPLEX and GA. P\textsubscript{k} in HIS represents the sum of product k (P\textsubscript{k}) received in HIS. P\textsubscript{k} in LIS represents the sum of product k (P\textsubscript{k}) received in LIS. Similarly, TSQ denotes the sum of substitution quantity received in all the stores. In the first time-period, there is no shortage and all the retailers are viewed as HIS. Hence, send quantity and the quantity received is equal to the demand. Hence, the Table B10 shows the decision on second time-period.

7. Conclusion
In this paper, we frame a WCSS model for single-brand multi-weighted products in two periods of panic buying. To generate a model to increase the wholesaler’s aggregate profit, we investigate the optimum amount of product substituted, order quantity, unsatisfied and demand number of leftover units. We varied substitution cost as a percentage of the product cost and examined the effects on wholesaler profits WOCSS and WCSS models. The decision maker’s objective is to maximize the total expected profit of the wholesaler. From a managerial point of view, our findings show that substitution and customer segmentation will increase profit significantly. The importance of segregating customers as high index and low index is studied. Moreover, experimental analysis of the WCSS model shows that the HIS customer satisfaction is always perform better than the WOCSS model. Higher retail-prices in the second time-period provide an interesting finding that hoarding behavior increases in the first time-period. A comparison of the WCSS and WOCSS models clearly indicates that the WCSS model reduces inventory efficiently. In addition, we varied the interruption in supply and rate of panic to determine the influence of substitution and customer segmentation on wholesaler profit and customer satisfaction. The increase in interruption in supply decreases the profit and customer satisfaction. While the increase in rate of panic expands the inventory and improves profit and customer satisfaction, if interruption in supply’s occur. Finally, the numerical example for the WCSS model is solved by GA and the solution is compared with the obtained CPLEX solution. The proposed model can be extended by employing multi-product and multi-weight product substitution for further research.

**References**


Appendix A

Fig. A1. Substitution structure in terms of weight of demand D4 for product P4

Fig. A2. Substitution structure in terms of weight of demand D1 for product P1

Fig. A3. Flow network for First time-period
Fig. A4. Flow network for Second time-period

Fig. A5. Impact of increasing $\theta$ on profit in the WOCSS and WCSS model

Fig. A6. Impact on total profit while increasing $\beta_{3,4}$ in the WOCSS and WCSS model
Fig. A7. Impact on percent of customer satisfaction obtained in high and low index retailers while increasing $\beta_{3,4}$ in the WOCSS and WCSS model.

Fig. A8. Impact on the overall percentage customer satisfaction while increasing $\beta_{3,4}$ in the WOCSS and WCSS model.
Fig. A9. Impact on inventory while increasing $\beta_{3,4}$ in the WOCSS and WCSS model.

Fig. A10. Impact on total profit while increasing $\alpha_{3,4}$ in the WOCSS and WCSS model.
Fig. A11. Impact on percent of customer satisfaction obtained in high and low index retailers while increasing $\alpha_{3,4}$ in the WOCSS and WCSS model.

Fig. A12. Impact on the overall percentage customer satisfaction while increasing $\alpha_{3,4}$ in the WOCSS and WCSS model.
Fig. A13. impact on inventory while increasing $\alpha_{3,4}$ in the WOCSS and WCSS model

Fig. A14. impact on total profit while increasing $\beta_{3,4}$ in the WOCSS and WCSS model
Fig. A15. impact on percent of customer satisfaction obtained in high and low index retailers while increasing $\beta_{3,4}$ in the WOCS and WCSS model.

Fig. A16. impact on the overall percentage customer satisfaction while increasing $\beta_{3,4}$ in the WOCS and WCSS model.
Fig. A17. Impact on inventory while increasing $\beta_{3,4}$ in the WCSS and WCSS model.

Appendix B

Table B1: Parameter of retail-price and cost components of each product.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$V_{i,k}$ in both time-periods (Rs)</th>
<th>$C_{i,k}$ in both time-periods (Rs)</th>
<th>$HC_{i}$ in both time-periods (Rs)</th>
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<td>Product</td>
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<td></td>
</tr>
<tr>
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<td>48</td>
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Table B2: Cost of substitution products for retailers in both time-period

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<th>P4</th>
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<td>8</td>
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<td>-</td>
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Table B3: Ratio of substitution products in both time-period
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**Table B4:** Distribution of quantity obtained from CPLEX (units)

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<th>P4</th>
<th>Profit (in Rs)</th>
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<td>P2 7515</td>
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Table B5: Correlation of WOCSS and WCSS model while increasing β_{3,4}
Table B6: Impact on the WOCSS and WCSS model while $\beta$ (constant for all products) and $\alpha = 0.3$

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<tr>
<th>Rate of Interruption in supply</th>
<th>Total profit (WCSS)</th>
<th>Total profit (WOCSS)</th>
<th>Percentage of increase in total Profit (%)</th>
<th>Percentage of HIS customer satisfaction (WCSS)</th>
<th>Percentage of HIS customer satisfaction (WOCSS)</th>
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Table B7: Correlation of WOCSS and WCSS model while increasing $\alpha_{3,4}$

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<th>Rate of panic (WCSS)</th>
<th>Profit (WCSS)</th>
<th>Profit (WOCSS)</th>
<th>Increase in Profit %</th>
<th>% of customer satisfaction (WCSS)</th>
<th>% of customer satisfaction (WOCSS)</th>
<th>% of overall customer satisfaction (WCSS)</th>
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<th>Inventory (WCSS)</th>
<th>Inventory (WOCSS)</th>
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Table B8: Correlation of WOCSS and WCSS model while increasing $\beta_{3,4}$
Table B9: GA and CPLEX results for example problem

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<th>GA</th>
<th>CPLEX</th>
<th>GAP=(CPLEX-GA)/CPLEX*100</th>
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<th>Run time(s)(CPLEX)</th>
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</thead>
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Table B10: Comparison of decisions in GA and CPLEX results for example problem

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<th>CPLEX</th>
<th>GAP=(CPLEX-GA)/CPLEX*100</th>
</tr>
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<td>P2 in HIS</td>
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Biographies

Yu-Chung Tsao is a Professor in the Department of Industrial Management at National Taiwan University of Science and Technology, Taipei, Taiwan. He was a visiting scholar in the School of Industrial and Systems Engineering at Georgia Institute of Technology. He received a PhD in Industrial Management from National Central University. He has published more than 100 research papers. His current research interests include: Supply chain and Logistics Management, Production and operation
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**Praveen Vijaya Raj Pushpa Raj** is currently PhD student in the Department of Industrial Management at National Taiwan University of Science and Technology, Taipei, Taiwan. His current interests in research are applied operations research and supply chain management.