

Dynamic Clearance Strategies for Highly Perishable FMCG Products: A Stochastic Dual-Channel Approach for Cleaner Logistics and Supply Chain

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ABSTRACT

In the fast-moving consumer goods (FMCG) industry, there are many difficulties in managing highly perishable products, resulting in high food waste and financial losses. In this study, the common “oversupply undersupply” problem of 120-hour shelf-life products have been explored and a dual channel “Near Food Channel” (NFC) clearance strategy is recommended. We develop a two-step simulation optimization approach. A Stochastic Mixed Integer Non-Linear Programming (SMINLP) model with Sample Average Approximation (SAA) is formulated in GAMS. This model computes the mathematically optimum Protection Level (PL). Since it is known that there are some limitations of the continuous models in capturing the discrete consumer behavior, these PL values were taken and fine-tuned using Discrete Event Simulation (DES) using Rockwell Arena 14.0 software. Empirical stochastic inputs like a Freshness Decay Penalty ($\gamma = \max(0.1, N(0.72, 0.05))$) and Price Elasticity ($\epsilon = \max(0.1, N(2.85, 0.05))$) were incorporated to study the probability of fresh and clearance channel conversions. The results indicate a 100% Waste Mitigation Efficiency (WME) for all tested inventory levels (1,700-3,000 units) when an aging inventory is being routed at a critical time (72 hours) using dynamic markdown strategies. This framework cuts down on physical waste, saves the profits of distributors (18,623 – 19,426 BDT profit compared to -11,300 BDT loss in conventional operations at $Q_0=3000$). Also, there is no wasted material left, so the typical 1-3% wastage allowance that manufacturers offer distributors is not needed. It's a win-win-win situation: reduced food waste, increased profits, and a healthier, more sustainable food supply chain.

Keywords: *Perishable inventory management; Dual-channel clearance; Stochastic optimization; Discrete-event simulation; Food waste reduction; Reverse logistics*

1. Introduction

Efficiencies of the global food value chain are simply outdone when it comes to perishable food products. This means crippling socio-economic losses, degradation of the environment and its resources. On average, one-third of all food produced worldwide is lost or wasted in households and retailers (Cederberg and Sonesson, [2011](#)), which is the highest proportion of food loss and waste in the food value chain. Generally, vulnerable products are fast moving consumer goods (FMCG) that have a relatively short shelf life, such as a bread with a 120-hour (5 day) shelf life. The “oversupply undersupply” is always a situation faced by retailers and distributors. End of life waste (Akkas et al., [2019](#); Broekmeulen and van Donselaar, [2019](#)) is caused by the overstocking to guarantee a high level of service, whereas understocking will result in financial losses.

Let's explore the journey of a loaf of bread to see why it has become an ongoing conundrum. It is baked, packaged and delivered to a distributor's stockyard. It then moves on to smaller neighborhood stores (the “traditional trade” stores). But the little stores are not necessarily as good as the big supermarkets. They have no real-time inventory systems and they also don't have advanced forecasting tools. The distributor needs to forecast how many loaves are going to be sold in the next 5 days by each shop. When the guess is too high, the loaves that have not been sold are wasted. If it's too low, then the shop is out of stock, losing sales as a result. The difficulty of this guessing game is compounded by the fact that customers' desire to purchase the bread decreases rapidly with age. A day old loaf is almost as good as fresh but by day three, many customers will not want to buy this bread.

Each year millions of tons of edible food is thrown away at commercial level (retail and distributors) because it fails to satisfy arbitrary commercial freshness thresholds prior to its expiration date (Cicatiello et al., [2017](#); Mena et al., [2014](#)). Real world consumer behavior is often very stochastic and unpredictable, as it will not fit into the classical inventory routing and pricing models. Although mathematical models are good for aggregate planning, they do not reflect the choices consumers make when considering freshness decay and promotional markdowns (Haijema and Minner, [2016](#); Tako and Robinson, [2012](#)).

In order to fill this void, this research introduces a dual channel “Near Food Channel” (NFC) clearance mechanism, which is able to retrieve old stock in mid-life cycle. This can be done by selling the excess inventory to a secondary retailer and this is usually not welcome on the primary shelf because it can diminish the fresh sales. This study uses a two-step simulation optimization methodology, which uses GAMS (via Sample Average Approximation) and Rockwell Arena 14.0 (Discrete Event Simulation), to calculate and validate state dependent Protection Levels (PL). The behavioral decay parameters were estimated based on a pilot survey of 217 traditional trade consumers of different age groups and areas. Moreover, the parameters of customer footfall and customer arrival rate were obtained from observation and selling data of a reputed traditional retail outlet from Jatrabari, Dhaka during operation.

The first research question is how to design a simple two channel system (fresh bread channel and clearance channel) to minimize bread waste, while addressing the limitations of conventional modelling approaches, the food waste problem and specific challenges of the South Asian emerging markets. Secondly, what is the number of loaves that should be put on the fresh shelf (the “Protection Level”) if the number of loaves at the start is different to the number of loaves that the distributor checks after 3 days (72 hours)? Third, which discount works best for this clearance channel, in terms of making the distributor's money go further, and

retaining more of the manufacturer's price: a steady discount throughout or a smaller discount on Day 4 and the extra discount on Day 5?

There are three ways in which we contribute. We estimate exact empirical consumer behaviour, the Freshness Decay Penalty (γ) and Price Elasticity (ϵ). Second, we suggest a dual channel routing system, which is enabled at the 72 hours of the audit, and surplus inventory in the original channel is sent to the NFC store in certain discount cases (d_4, d_5). Third, we demonstrate that this framework achieves 100% Waste Mitigation Efficiency (*WME*) for manufacturers who can get the old 1-3% wastage allowance, and for distributors who will not be financially wiped out.

Again, when discounted expired products are displayed side by side with fresh products, many customers will buy the cheaper product, instead of the fresh one. This is known as “encroachment” or “cannibalization.” It lowers the retailer's profit margin as they end up selling the high-margin fresh products at a lower price. The distributor can unload the old stock by sending it to a separate NFC channel without impacting new sales. The primary channel can sell to customers looking for quality at full price, and the NFC channel can sell at an appreciable discount to customers looking for a discount.

This paper is organized as follows: in the remainder we will discuss the design of the new system. The study presents systematic literature review in Section 2. The problem description and mathematical formulation are provided in section 3. The Discrete event simulation framework is described in Section 4. In section 5, a numerical study and results are provided. Section 6 comments about the managerial implications and Section 7 concludes.

2. Literature Review

There has been significant research interest in how perishable inventory management, dynamic pricing and cleaner logistics intersect. But in common models, the shelf life usually just remains a static and deterministic variable, and not part of the process of consumer willingness to pay overtime.

2.1 Perishable Inventory and Waste Mitigation

A lot of research has been conducted on modeling inventory control of perishables with continuous review and periodic review policies. Nahmias ([1982](#)) was the basic review of perishable inventory theory, and Goyal and Giri ([2001](#)) classified deterioration models into constant deterioration rate, time varying deterioration rate and random deterioration rate. The trend today is to increasingly focus on stochastic demand and age dependent deterioration, as emphasized by more recent reviews by Bakker et al. ([2012](#)) and Janssen et al. ([2016](#)).

As indicated above, near expired food commercialization (NFC) is a promising method to valorize unsold food, but there are concerns regarding the cannibalization of fresh sales. Although near expired food commercialization (NFC) is an effective method for valorizing unsold food, there are still doubts about the cannibalization of fresh sales Akkaş and Gaur, (2022). There are a few empirical studies that have attempted to quantify the amount of waste generated in actual supermarkets. In this regard, Akkas et al., ([2019](#)) performed a study based on supermarket scanner data on 44 supermarkets and revealed that over 8% of perishable products go bad before being sold. Some of the highest waste rates were found to be in the bread and bakery products category, often over 12%. The primary drivers were less demand or less availability and more variability in the lead time, frequency of orders, and space available on the shelves. This indicates that there could be significant impact from operational changes such as our NFC routing policy.

Van Donselaar et al. (2006) studied the inventory management of perishables in supermarkets and concluded that the fresh products needed to be replenished daily with high service levels. The strategies of discounting, and dynamic shelf-life policies were introduced by Buisman et al.'s (2019), with the result that retailer waste can be reduced by 15 to 30% due to proactive discounting. The work of Buisman et al. (2019) is of special interest since they tested various discount patterns through a simulation based optimization. They concluded that a progressive discount (10% on day 2, 30% on day 4, etc.) is more effective than a flat discount in reducing waste than a flat discount. In their model, the discounted products are placed on the same shelf as fresh products, however, this gives rise to the cannibalization problem. We are avoiding this in our study by putting discounted products on a separate NFC channel.

2.2 Dynamic Pricing and Clearance Strategies

Dynamic pricing has been shown to have a significant impact on retail waste. Consumer demand is very responsive to both the price of the product and its visual/temporal deterioration for perishable products (Bitran and Caldentey, 2003; Elmaghraby and Keskinocak, 2003). Discounting near the end of shelf life in studies by discrete choice models has been found to have an effect of making up for reduced freshness, and that this approach can actively push consumers toward the older products on the shelves (Chen et al., 2018; Li and Teng, 2018)

The frequency literature highlights the importance of the timing of a discount, for example, as one of the key findings. The danger of discounting is that we lose margins that we might have been able to hold on to. If the discount is too late, the product will have lost much of its quality and customers will not purchase it even at a discount. The hockey stick shape of the optimum discount trajectory is often observed as follows: no discount initially; some discount during the mid-life of the product; and strong discount near the end of the product's life. Our dynamic discount scenario is: 20% on Day 4 and another 10% on Day 5.

In the context of food waste, (Aschemann-Witzel et al., 2018) examined how consumers make decisions while shopping for sub-optimal food and determined that large price decreases are needed to offset consumer concerns about the food quality. Hall-Phillips and Shah (2017) found that consumers were confused on the date labels and this was a major reason for discarding items early. Lysova et al. (2024) showed that the effect of discount policies on purchasing intentions is significant for perishable products, particularly for freshness, where significant reductions are needed for consumers to accept.

2.3 Simulation-Optimization Approaches

The challenges that come with perishable supply chains frequently need blended approaches. The simulation technique developed by joining mixed integer linear programming (MILP) with Discrete Event Simulation (DES) has been revealed to exhibit better performance in the simulation of the nonlinear dynamics of food supply chains (FSC) (Jalali and Nieuwenhuyse, 2015; Long and Zhang, 2014). The direct use of parameters derived from empirical decay models in DES for digital twins, however, is not well studied.

Haijema and Minner (2019, 2016) made a comparative study between a hybrid base stock and a constant order policy, and showed that age dependent policies are better than traditional policies using simulation based optimization. What they found was that having the specific age of each unit (days since production) would enable a retailer to make much more intelligent stock decisions. Age information is also used in our policy: At 72 hours the audit algorithm will divide young-enough inventory (hence, to keep fresh) and older inventory

(hence, to send to NFC). We don't stop there though, we also take advantage of information of the initial order quantity (Q_0) to determine the Protection Level.

Van Der Vorst et al. (2010) applied DES to redesign food supply chain considering both quality decay and logistics decisions. Kandemir et al. (2022) was able to show the capabilities of DES, by creating a household simulation model of food waste. A household model by Kandemir et al. (2022) is particularly interesting as it models individual consumers making decisions of eating, freezing or discarding food based on their expiration date. This kind of detail is what makes DES so effective at problems dealing with food waste. Our model is similar but at the distributor retailer level where customers come in haphazardly and choose between fresh or discounted bread.

2.4 Research Gap Synthesis

The results of this study are compared systematically with the previous studies in Table 1 on the following key points: stochastic demand modeling, dual channel/clearance strategy, perishable shelf-life consideration, integration of simulation optimization, and empirical consumer decay parameters. This comparison highlights that although there are significant efforts of research in each of the areas, there is no integrated framework that combines all five dimensions in the context of a highly perishable FMCG.

Table 1: Comparison between studies in literature and our study

Authors & Year	Stochastic Demand	Dual-Channel / Clearance	Perishable / Shelf-Life	Simulation-Optimization	Empirical Consumer Decay
Broekmeulen and van Donselaar (2009)	✓	X	✓	X	X
Minner and Transchel (2010)	✓	X	✓	X	X
Wang and Li (2012)	X	X	✓	X	X
Haijema (2013)	✓	X	✓	X	X
Chen et al. (2014)	✓	X	✓	X	X
Haijema and Minner (2016)	✓	X	✓	✓	X
Adenso-Díaz et al. (2017)	X	✓	✓	X	X
Li and Teng (2018)	✓	X	✓	X	X
Buisman et al. (2019)	✓	✓	✓	✓	X
Akkas et al. (2019)	✓	X	✓	X	X
Chung (2019)	✓	✓	✓	✓	X
Haijema and Minner (2019)	✓	X	✓	✓	X
Onggo et al. (2019)	✓	X	✓	✓	X
Zhang et al. (2019)	✓	X	✓	X	X
Yang et al. (2022)	✓	✓	✓	X	X

Authors & Year	Stochastic Demand	Dual-Channel / Clearance	Perishable / Shelf-Life	Simulation-Optimization	Empirical Consumer Decay
Darestani and Hemmati (2019)	✓	✗	✓	✗	✗
Liu et al. (2021)	✓	✗	✓	✗	✗
Zhang et al. (2021)	✓	✓	✓	✓	✗
Akkaş and Gaur (2022)	✓	✗	✓	✗	✗
Kayikci et al. (2022)	✓	✓	✓	✓	✗
Keskin et al. (2022)	✓	✗	✓	✗	✗
Kirci et al. (2022)	✓	✗	✓	✓	✗
Zhang et al. (2023)	✓	✓	✓	✗	✓
Hansen et al. (2024)	✓	✓	✓	✗	✓
Lysova et al. (2024)	✓	✓	✓	✗	✓
This Study	✓	✓	✓	✓	✓

3. Problem Description and Mathematical Formulation

3.1 Problem Setting

This study is able to model a distributor retailer system for a highly perishable FMCG product (bread with 120 hours shelf life). A high volume retail node was observed at Jatrabari, Dhaka, to collect real world operational constraints. We assumed the daily number of customers who visit a neighborhood with 20 stores to be a normal distribution, with a mean of 1040 and a standard deviation of 30. We represented the number of customers visiting the neighborhood as a normal distribution, $N(1040, 30)$ but truncated at the minimum of 0.

The system is a 120 hour lifecycle system. An audit is carried out at $t = 72$ hours (end of Day 3). Stock that exceeds the optimal Protection Level (PL) is pulled from the PL and sent back to the NFC, where it will be mark-downed on Days 4 and 5 (d_4, d_5) to help promote clearance sales. The distributor purchases a unit of the commodity at $c_u = 40$ BDT and sells the fresh one at $p_f = 50$ BDT. The NFC retailer enjoys an operating margin of 10%. The reverse logistics operation costs 0.5 BDT per unit for each unit moved to the NFC, which includes handling, fuel, and driver expenses.

The physical flow and temporal decision gates of the proposed dual channel clearance framework over the 120 hour product lifecycle are shown in [Figure 1](#).

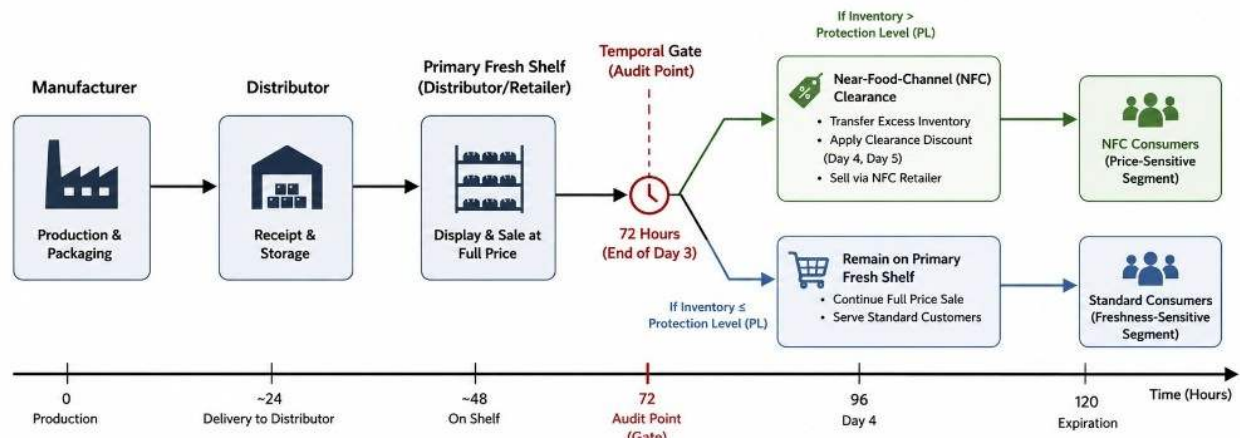


Figure 1: The dual-channel routing flow for highly perishable FMCG products, highlighting the critical 72-hour temporal audit gate.

For the conventional baseline (5.1 Scenario A: Conventional Baseline), no NFC channel exists; all inventory remains on the primary shelf for 120 hours. Manufacturers provide a 2% wastage allowance, so the effective unit cost for the distributor is 39.2 BDT.

3.2 Notation

Table 2: Notations used in the model

Category	Notation	Description
Decision variables	PL	Protection Level: inventory retained in primary fresh channel at 72-hour audit (units)
	d_4	Discount rate applied in NFC channel during Day 4 ($72 < t \leq 96$ hours)
	d_5	Discount rate applied in NFC channel during Day 5 ($96 < t \leq 120$ hours); cumulative with d_4
	d_t	Time-dependent discount = d_4 for $72 < t \leq 96$, = d_5 for $96 < t \leq 120$
State / output variables	S_p	Total units sold in primary fresh channel
	Tr	Quantity of inventory routed from primary to NFC at $t = 72$ hours (units)
	W_f	Total physical waste units = $I_p + I_{nfc}$
	S_{nfc}	Number of units sold in the NFC clearance channel
	I_p	Primary channel inventory remaining at end of simulation (waste units)
	I_{nfc}	NFC channel inventory remaining at end of simulation (waste units)
	R_{acc}	Accumulated NFC revenue += $50 \times (1 - d_t)$
	R_m	Total revenue received by manufacturer (depends on scenario)
	π_d	Distributor's profit after all costs (see Table 4 for formulas)
	R_{nfc}	NFC retailer's gross revenue = R_{acc}
	π_{nfc}	NFC retailer's profit = $R_{nfc} - R_{nfc}/m$
	WME	Waste Mitigation Efficiency = $(Q_0 - W_f)/Q_0 \times 100(\%)$
Parameters (fixed)	Q_0	Initial stock level (units), tested from 1,700 to 3,000 in 50-unit increments

Category	Notation	Description
	c_u	Distributor buying cost per unit (40 BDT for NFC scenarios; 39.2 BDT for conventional)
	p_f	Retail price in the primary fresh channel (50 BDT)
	m	Operating margin of the NFC retailer (1.10 = 10%)
	c_t	Transportation cost per unit moved to NFC (0.5 BDT)
	γ	Freshness Decay Penalty = $\max(0.1, N(0.72, 0.05))$
	ϵ	Price Elasticity of Demand in NFC channel = $\max(0.1, N(2.85, 0.05))$
	t	Time elapsed since product placement (hours)
Derived financial variables	v_s	Salvage value returned to distributor per unit cleared in NFC = $(50 \times (1 - d_k))/1.10$
	p_{nfc}	Retail price in NFC after discount = $50 \times (1 - d_t)$
	R_d	Distributor Gross Revenue = $(S_p \times 50) + (S_{nfc} \times v_a)$
	C_w	Total Waste Cost = $(I_p + I_{nfc}) \times c_u$
	C_{tr}	Total Transport Cost = $S_{nfc} \times c_t$ (only in NFC scenarios)
Arena-specific expressions	γ	Same as γ (used in Arena modules)
	ϵ	Same as ϵ (used in Arena modules)
	d_k	Generic discount rate: d_4 or d_5 depending on time interval

3.3 Mathematical Foundation (SMINLP)

The GAMS SMINLP is a 300-Monte Carlo Sample Average Approximation (SAA) maximization of expected profit. The objective function is given as:

$$E[\pi] = \sum (p_f \cdot S_p + v_s \cdot Tr - c_u \cdot W_f) - 0.001 \cdot PL$$

The number of consumers buying a product is modeled by the exponential decay function, with elapsed time t (in hours). The chance of a 100% price paid through the primary channel:

$$P_f(t) = \left(\frac{120 - t}{120} \right)^\gamma$$

where $\gamma = \max(0.1, N(0.72, 0.05))$. In the NFC, price elasticity mitigates this decay. The probability of clearance conversion is:

$$P_{NFC}(t) = \left(\frac{120 - t}{120} \right)^\gamma \cdot \frac{1}{(1 - d_k)^\epsilon}$$

where $\epsilon = \max(0.1, N(2.85, 0.05))$, and $d_k \in \{d_4, d_5\}$. The salvage value returned to the distributor accounts for the secondary channel's 10% operating margin, calculated as:

$$v_s = \frac{50(1 - d_k)}{1.10}$$

3.4 Input Parameters

Table 3 summarizes the input parameters used in GAMS optimization.

Table 3: Input parameters

Category	Parameter	Value / Distribution / Description
Input parameters	Initial stock (Q_0)	Tested range: 1700, 1750, 1800, ..., 3000 units (27 levels)
	Discount on Day 4 (d_4)	0.30 for Scenario B1; 0.20 for Scenario B2; 0.0 for Scenario A
	Discount on Day 5 (d_5)	0.0 for Scenario B1; 0.10 for Scenario B2; 0.0 for Scenario A
	Protection Level (PL)	Obtained from GAMS optimization (varies with Q_0 and scenario)
	Freshness Decay Penalty (γ)	MAX (0.1, NORM (0.72, 0.05))
	Price Elasticity (ϵ)	MAX (0.1, NORM (2.85, 0.05))
	Customer interarrival time	Exponential distribution with mean derived from footfall N (1040,30) per day (20 stores)
	NFC retailer margin (m)	1.10 (10%)
	Transport cost per NFC unit (c_t)	0.5 BDT
	Fresh retail price (p_f)	50 BDT
	Unit purchase cost (c_u)	40 BDT
	Unit purchase cost (conventional)	39.2 BDT (includes 2% wastage allowance)
Output parameters	Primary Sales (S_p)	Total units sold in fresh channel (integer)
	NFC Sales (S_{nfc})	Total units sold in NFC clearance channel (integer)
	Current Stock (I_p)	Remaining fresh stock at simulation end (waste units)
	NFC Stock (I_{nfc})	Remaining NFC stock at simulation end (waste units)
	Total Wasted (W_f)	$I_p + I_{nfc}$ (units)
	Distributor Net Profit (π_d)	Calculated per Table 4 formulas (BDT)
	Manufacturer Revenue (R_m)	Calculated per Table 4 formulas (BDT)
	NFC Net Profit (π_{nfc})	$R_{nfc}/1.10$ (BDT)
	WME	Waste Mitigation Efficiency (%)
	Transfer (Tr)	Quantity moved from primary to NFC at $t=72$ hours (units)

4. Methodology: Simulation-Optimization Framework

To overcome the tendency of continuous mathematical models to underestimate discrete, stochastic consumer behaviors, we employed a two-step framework.

The overall structure of this framework is depicted in [Figure 2](#), which shows how the three methods of empirical inputs, mathematical optimization and discrete-event simulation are integrated together.

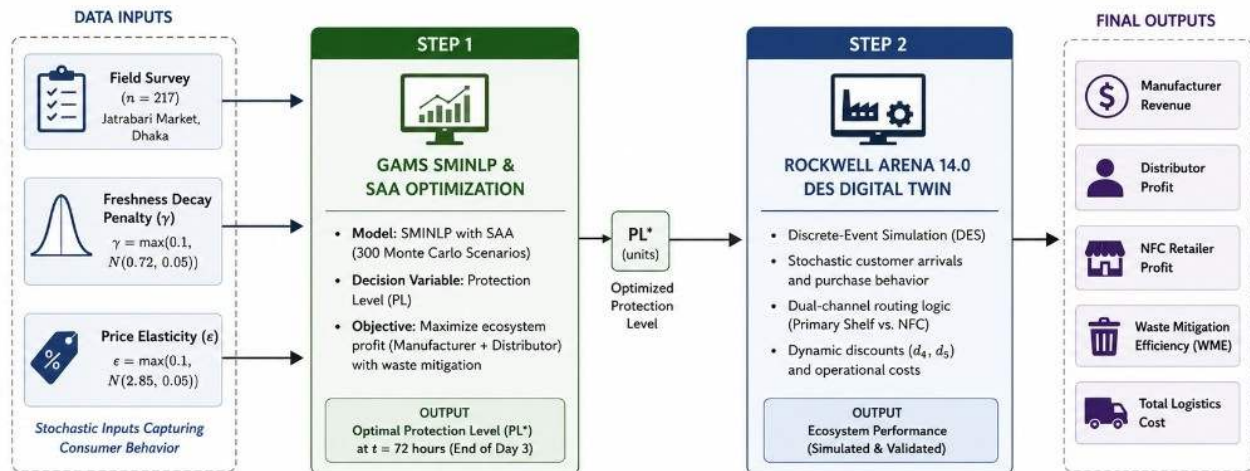


Figure 2: The two-step simulation-optimization architecture combining GAMS SMINLP and Rockwell Arena DES to derive and validate the optimal Protection Level (PL)

4.1 Optimization in GAMS

Using the empirical footfall, γ , and ϵ parameters, we utilized GAMS to run an SAA-based SMINLP model. This generated a mathematically optimal PL for every initial stocking level (Q_0) between 1,700 and 3,000 units (tested in 50-unit increments). The SAA with 300 scenarios achieved a 95% confidence interval half-width of $\pm 2.3\%$ of mean profit, indicating robust convergence.

4.2 Discrete-Event Simulation (DES) in Rockwell Arena

The proposed dual-channel policy was validated using Rockwell Arena 14.0 with the Process Analyzer (PAN) for batch execution. The simulation model replicates the 120-hour product lifecycle as a discrete-event “digital twin”, incorporating stochastic customer arrivals (exponential interarrival times derived from footfall $N(1040, 30)$ for a 20-store neighborhood), consumer price sensitivity, and time-dependent purchase probabilities. Each scenario was replicated 30 times to ensure statistical significance (half-width within 5% of the mean at 95% confidence level). [Figure 3](#) illustrates the Arena DES logic of the conventional single-channel distribution system used as the baseline scenario. [Figure 4](#) presents the Arena implementation of the proposed dual-channel system incorporating NFC clearance routing and discount-based customer behavior.

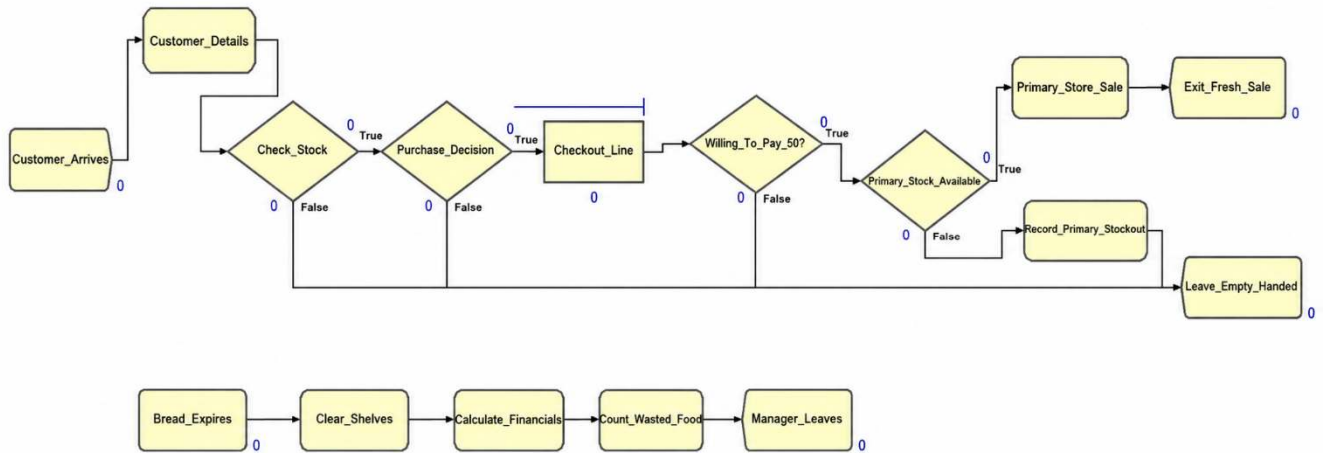


Figure 3: Arena discrete-event simulation model of Scenario A (conventional single-channel FMCG distribution system).

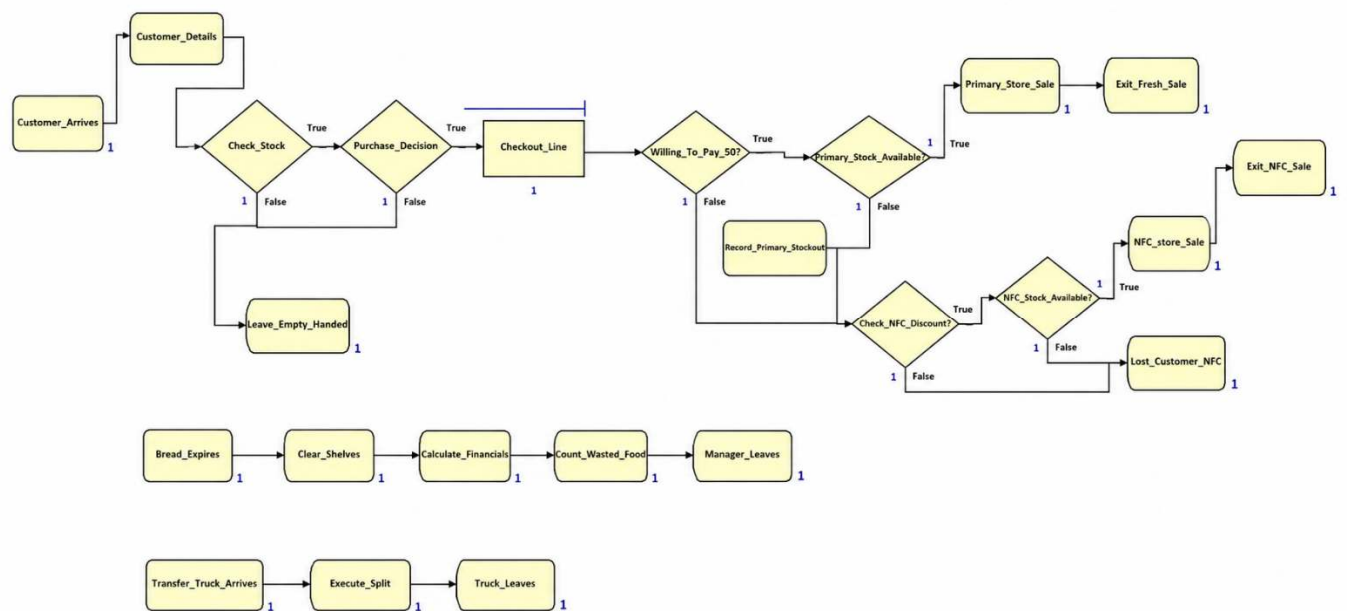


Figure 4: Arena discrete-event simulation model of the proposed dual-channel FMCG distribution system with NFC clearance routing.

4.3 Master Financial Module

Table 4 shows the financial calculations for each scenario.

Table 4: Master financial assignments

Variable / Expression	Formula (Conventional Scenario A)	Formula (NFC Scenarios B1, B2)
Effective purchase cost (c_u)	39.2 BDT (includes 2% wastage allowance)	40.0 BDT (no allowance)
Time-Dependent Discount (d_t)	0 (since $d_4 = d_5 = 0$)	$(d_4 \times (TNOW > 72)) + (d_5 \times (TNOW > 96))$
Salvage Price (v_s)	Not applicable	$(50 \times (1 - d_t)) / 1.10$
Manufacturer Revenue (R_m)	$(I_p + I_{nfc} + S_p + S_{nfc}) \times 39.2$	$(I_p + I_{nfc} + S_p + S_{nfc}) \times 40$
Distributor Net Profit (π_d)	$(S_p \times 50) - ((I_p + I_{nfc} + S_p + S_{nfc}) \times 39.2)$	$(S_p \times 50) + (S_{nfc} \times v_s) - (S_{nfc} \times 0.5) - ((I_p + I_{nfc} + S_p + S_{nfc}) \times 40)$
NFC Gross Rev (R_{nfc})	0	R_{acc} (accumulated from NFC sales)
NFC Net Profit (π_{nfc})	0	$R_{nfc} - (R_{nfc} / 1.10)$
Audit Retail NFC (p_{nfc})	Not applicable	$50 \times (1 - d_t)$
Audit Salvage Price (v_a)	Not applicable	$p_{nfc} / 1.10$
Distributor Gross Rev (R_d)	$S_p \times 50$	$(S_p \times 50) + (S_{nfc} \times v_s)$
Total Transport Cost (C_{tr})	0	$S_{nfc} \times 0.5$
Total Waste Cost (C_w)	$(I_p + I_{nfc}) \times 39.2$	$(I_p + I_{nfc}) \times 40$
Waste Mitigation Eff. (WME)	$(Q_0 - (I_p + I_{nfc})) / Q_0 \times 100$	$(Q_0 - (I_p + I_{nfc})) / Q_0 \times 100$

5. Numerical Study and Results

We consider three main scenarios. 30 replications were performed for all the simulation runs reported here, and average values are reported.

- **Scenario A (Conventional Baseline):** No NFC channel. $d_4 = 0$, $d_5 = 0$. Effective cost of the unit = 39.2 BDT (with 2% wastage allowance). $PL = 3000$ (no split).
- **Scenario B1 (Constant Discount NFC):** Surplus routed to NFC at 72 hours. $d_4 = 0.30$, $d_5 = 0$ (constant 30% discount). Unit cost = 40 BDT. Transport cost = 0.5 BDT per NFC unit.
- **Scenario B2 (Dynamic Discount NFC):** Surplus routed at 72 hours. $d_4 = 0.20$ (Day 4), $d_5 = 0.10$ (Day 5). Total discount on Day 5 is 30% (20%+10%). Unit cost = 40 BDT. Transport cost = 0.5 BDT per NFC unit.

5.1 Scenario A: Conventional Baseline

In the conventional supply chain, no dual-channel routing exists. All inventory remains on the primary shelf for 120 hours. Results are presented in Table 5 (data extracted from Arena PAN for $d_4=0$, $d_5=0$)

Table 5: Scenario A: Conventional baseline dataset

S	Current Stock	d_4	d_5	Manufacturer Revenue	Distributor Net Profit	Total Loaves Wasted	WME (%)
1	1700	0.0	0.0	66,640	18,360	0	100.00
2	1750	0.0	0.0	68,600	18,900	0	100.00
3	1800	0.0	0.0	70,560	19,440	0	100.00
4	1850	0.0	0.0	72,520	19,980	0	100.00
5	1900	0.0	0.0	74,480	20,520	0	100.00
6	1950	0.0	0.0	76,440	21,060	0	100.00
7	2000	0.0	0.0	78,400	21,600	0	100.00
8	2050	0.0	0.0	80,360	22,140	0	100.00
9	2100	0.0	0.0	82,320	22,680	0	100.00
10	2150	0.0	0.0	84,280	22,020	24	98.88
11	2200	0.0	0.0	86,240	20,060	74	96.64
12	2250	0.0	0.0	88,200	18,100	124	94.49
13	2300	0.0	0.0	90,160	16,140	174	92.43
14	2350	0.0	0.0	92,120	14,180	224	90.47
15	2400	0.0	0.0	94,080	12,220	274	88.58
16	2450	0.0	0.0	96,040	10,260	324	86.78
17	2500	0.0	0.0	98,000	8,300	374	85.04
18	2550	0.0	0.0	99,960	6,340	424	83.37
19	2600	0.0	0.0	101,920	4,380	474	81.77
20	2650	0.0	0.0	103,880	2,420	524	80.23
21	2700	0.0	0.0	105,840	460	574	78.74
22	2750	0.0	0.0	107,800	-1,500	624	77.31
23	2800	0.0	0.0	109,760	-3,460	674	75.93
24	2850	0.0	0.0	111,720	-5,420	724	74.60
25	2900	0.0	0.0	113,680	-7,380	774	73.31
26	2950	0.0	0.0	115,640	-9,340	824	72.07
27	3000	0.0	0.0	117,600	-11,300	874	70.87

Key observations from 5.1 Scenario A: Conventional Baseline The conventional system exhibits a “waste cliff” at approximately 2,150 units. Beyond this point, waste escalates linearly (874 units wasted at $Q_0=3000$, 29.13% waste rate), and distributor profit turns negative (-11,300 BDT at $Q_0=3000$).

5.2 Scenario B1 : Constant Discount NFC ($d_4 = 0.30$, $d_5 = 0$)

In this scenario, surplus inventory is transferred to the NFC at the 72-hour audit based on the Protection Level (PL) obtained from GAMS optimization. A constant 30% discount is offered throughout the clearance window. Results are presented in Table 6.

Table 6: Scenario B1: Constant discount NFC ($d_4 = 0.30$, $d_5 = 0$)

S	Initial Stock (Q_0)	Protection Level (PL)	d_4	d_5	Manufacturer Revenue (BDT)	Distributor Net Profit (BDT)	NFC Gross Rev (BDT)	NFC Net Profit (BDT)	Total Loaves Wasted	WME (%)
1	1700	N/A	0.30	0.00	68,000.00	17,000.000	0.00	0.000	0	100
2	1750	N/A	0.30	0.00	70,000.00	17,500.000	0.00	0.000	0	100
3	1800	N/A	0.30	0.00	72,000.00	18,000.000	0.00	0.000	0	100
4	1850	N/A	0.30	0.00	74,000.00	18,500.000	0.00	0.000	0	100
5	1900	N/A	0.30	0.00	76,000.00	19,000.000	0.00	0.000	0	100
6	1950	N/A	0.30	0.00	78,000.00	19,500.000	0.00	0.000	0	100
7	2000	N/A	0.30	0.00	80,000.00	20,000.000	0.00	0.000	0	100
8	2050	N/A	0.30	0.00	82,000.00	20,500.000	0.00	0.000	0	100
9	2100	N/A	0.30	0.00	84,000.00	21,000.000	0.00	0.000	0	100
10	2150	118	0.30	0.00	86,000.00	19,388.955	3,955.00	359.545	0	100
11	2200	148	0.30	0.00	88,000.00	19,515.318	4,655.00	423.182	0	100
12	2250	172	0.30	0.00	90,000.00	19,529.591	5,565.00	505.909	0	100
13	2300	196	0.30	0.00	92,000.00	19,543.864	6,475.00	588.636	0	100
14	2350	222	0.30	0.00	94,000.00	19,595.500	7,315.00	665.000	0	100
15	2400	254	0.30	0.00	96,000.00	19,759.227	7,945.00	722.273	0	100
16	2450	276	0.30	0.00	98,000.00	19,736.136	8,925.00	811.364	0	100
17	2500	326	0.30	0.00	100,000.00	20,236.136	8,925.00	811.364	0	100
18	2550	376	0.30	0.00	102,000.00	20,736.136	8,925.00	811.364	0	100
19	2600	409	0.30	0.00	104,000.00	20,918.545	9,520.00	865.455	0	100
20	2650	409	0.30	0.00	106,000.00	20,484.455	11,270.00	1,024.545	0	100
21	2700	409	0.30	0.00	108,000.00	20,050.364	13,020.00	1,183.636	0	100
22	2750	423	0.30	0.00	110,000.00	19,877.818	14,280.00	1,298.182	0	100
23	2800	435	0.30	0.00	112,000.00	19,667.909	15,610.00	1,419.091	0	100
24	2850	469	0.30	0.00	114,000.00	19,869.000	16,170.00	1,470.000	0	100
25	2900	505	0.30	0.00	116,000.00	20,107.455	16,660.00	1,514.545	0	100
26	2950	510	0.30	0.00	118,000.00	19,766.773	18,235.00	1,657.727	0	100
27	3000	515	0.30	0.00	120,000.00	19,426.091	19,810.00	1,800.909	0	100

Key observations from **5.2 Scenario B1 : Constant Discount NFC ($d_4 = 0.30$, $d_5 = 0$)** The constant 30% discount NFC strategy completely eliminates waste (0 units wasted across all Q_0). Distributor net profit stabilizes around 19,000–20,900 BDT, compared to –11,300 BDT in conventional at $Q_0 = 3000$. The NFC channel generates increasing gross revenue (up to 19,810 BDT) and net profit (up to 1,801 BDT) at $Q_0 = 3,000$, entirely from surplus that would otherwise be wasted.

5.3 Scenario B2: Dynamic Discount NFC ($d_4 = 0.20$, $d_5 = 0.10$)

In this case, there is a 20% discount applied on Day 4 (72-96 h) and a further 10% discount on Day 5 (96-120 h) giving a total of 30% discount for the last day. Protection Levels are somewhat different than B1 because of the different rates of discount over time. Table 7 displays results.

Table 7: Scenario B2: Dynamic discount NFC ($d_4 = 0.20$, $d_5 = 0.10$)

S	Initial Stock (Q_0)	Protection Level (PL)	d_4	d_5	Manufacturer Revenue (BDT)	Distributor Net Profit (BDT)	NFC Gross Rev (BDT)	NFC Net Profit (BDT)	Total Loaves Wasted	WME (%)
1	1700	N/A	0.20	0.10	68,000.00	17,000.000	0.00	0.000	0	100
2	1750	N/A	0.20	0.10	70,000.00	17,500.000	0.00	0.000	0	100
3	1800	N/A	0.20	0.10	72,000.00	18,000.000	0.00	0.000	0	100
4	1850	N/A	0.20	0.10	74,000.00	18,500.000	0.00	0.000	0	100
5	1900	N/A	0.20	0.10	76,000.00	19,000.000	0.00	0.000	0	100
6	1950	N/A	0.20	0.10	78,000.00	19,500.000	0.00	0.000	0	100
7	2000	N/A	0.20	0.10	80,000.00	20,000.000	0.00	0.000	0	100
8	2050	N/A	0.20	0.10	82,000.00	20,500.000	0.00	0.000	0	100
9	2100	N/A	0.20	0.10	84,000.00	21,000.000	0.00	0.000	0	100
10	2150	126	0.20	0.10	86,000.00	19,538.409	4,200.00	381.818	0	100
11	2200	148	0.20	0.10	88,000.00	19,515.318	5,320.00	483.636	0	100
12	2250	172	0.20	0.10	90,000.00	19,529.591	6,360.00	578.182	0	100
13	2300	196	0.20	0.10	92,000.00	19,543.864	7,400.00	672.727	0	100
14	2350	222	0.20	0.10	94,000.00	19,595.500	8,360.00	760.000	0	100
15	2400	254	0.20	0.10	96,000.00	19,759.227	9,080.00	825.455	0	100
16	2450	276	0.20	0.10	98,000.00	19,736.136	10,200.00	927.273	0	100
17	2500	326	0.20	0.10	100,000.00	20,236.136	10,200.00	927.273	0	100
18	2550	376	0.20	0.10	102,000.00	20,736.136	10,200.00	927.273	0	100
19	2600	409	0.20	0.10	104,000.00	20,918.545	10,880.00	989.091	0	100
20	2650	409	0.20	0.10	106,000.00	20,484.455	12,880.00	1,170.909	0	100
21	2700	409	0.20	0.10	108,000.00	20,050.364	14,880.00	1,352.727	0	100
22	2750	423	0.20	0.10	110,000.00	19,877.818	16,175.00	1,470.455	0	100
23	2800	435	0.20	0.10	112,000.00	19,667.909	17,505.00	1,591.364	0	100
24	2850	450	0.20	0.10	114,000.00	19,514.045	18,735.00	1,703.182	0	100
25	2900	460	0.20	0.10	116,000.00	19,266.773	20,148.00	1,831.636	0	100
26	2950	465	0.20	0.10	118,000.00	18,926.091	21,730.00	1,975.455	0	100
27	3000	472	0.20	0.10	120,000.00	18,622.773	23,210.00	2,110.000	0	100

Key observations from **5.3 Scenario B2: Dynamic Discount NFC ($d_4 = 0.20$, $d_5 = 0.10$)** The dynamic discount strategy also achieves 100% in waste elimination. Distributor profit at $Q_0=3000$ is 18,623 BDT, slightly lower than the constant discount case (19,426 BDT), but still vastly superior to conventional (-11,300 BDT). The shallower initial discount preserves margin on early sales, while the deeper discount on Day 5 is only for stocks that are not sold. The NFC channel generates increasing gross revenue (up to 23,210 BDT) and net profit (up to 2,110 BDT) at $Q_0 = 3,000$, entirely from surplus that would otherwise be wasted.

5.4 Comparative Analysis

Table 8: Comparative summary of scenarios at $Q_0 = 3,000$ units

Metric	Scenario A (Conventional)	Scenario B1 (Constant 30%)	Scenario B2 (Dynamic 20%/10%)
Total Waste (units)	874	0	0
Waste Rate (%)	29.13%	0%	0%
WME (%)	70.87%	100%	100%
Distributor Net Profit (BDT)	-11,300	19,426	18,623
Manufacturer Revenue (BDT)	117,600	120,000	120,000

The baseline is intended to be compared to the conventional stockings that are represented in the visual of [Figure 5](#), where a severe 'waste cliff' is evident from about 2150 units. In contrast, the proposed NFC strategies are expected to keep physical waste at zero for all the stockings tested.

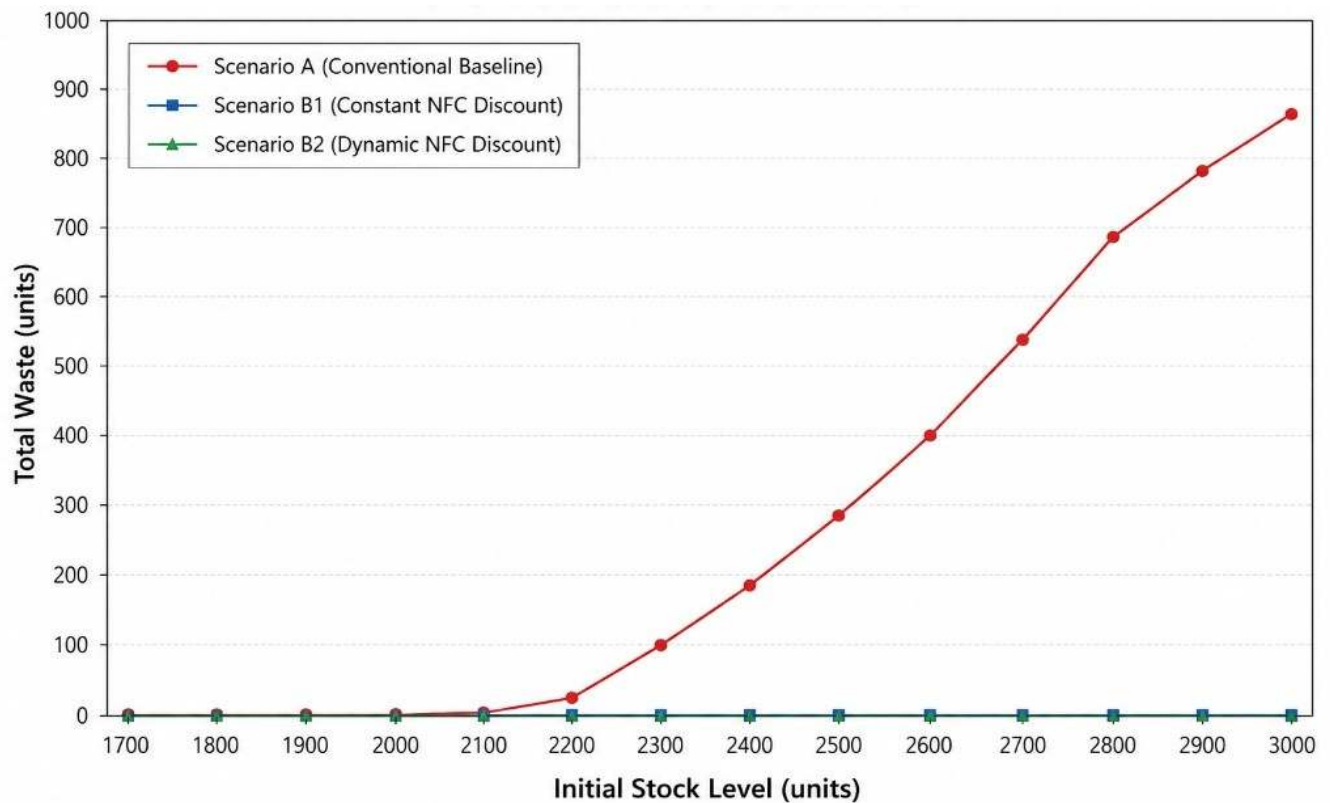


Figure 5: Total physical waste generated across varying initial stock levels (Q_0), demonstrating the exponential "waste cliff" in the conventional baseline versus complete waste elimination in the NFC scenarios

In both NFC scenarios, there is NO waste. The steady discount (B1) offers more profit for the distributor at the maximum point of overstocking, but the dynamic discount (B2) allows for flexible pricing that can be more easily accomplished with various consumer groups. Both strategies recuperate the manufacturer's full

wholesale price (40 BDT) as opposed to 39.2 BDT for conventional, which recovers the 2% wastage allowance.

Moreover, the holistic ecosystem margin recovery at maximum capacity ($Q_0 = 3,000$ units) is illustrated in [Figure 6](#), demonstrating the ability of the NFC strategies to protect distributor margins and increase the overall value captured.

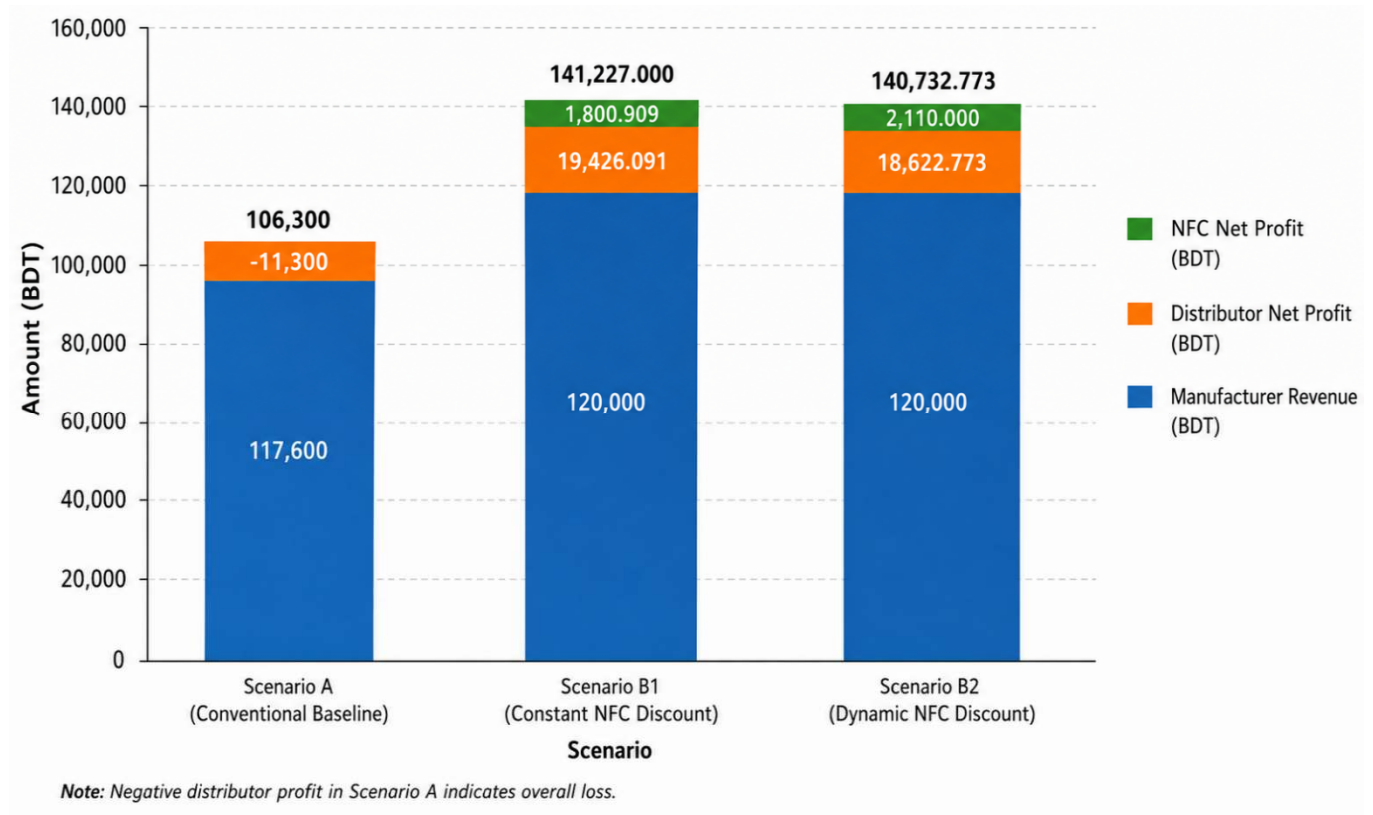


Figure 6: Ecosystem revenue and profit distribution at maximum capacity ($Q_0 = 3,000$ units), illustrating distributor profit recovery and manufacturer revenue maximization under the dual-channel framework

However, the gross and net profits generated from the NFC channel are also significant: With $Q_0 = 3,000$, the gross revenue in B1 is 19,810 BDT, and the net profit in B1 is 1,801 BDT, whereas the gross revenue in B2 is 23,210 BDT and the net profit in B2 is 2,110 BDT. Managers focused on recovering ecosystem margin can therefore expect to gain 17% more value from the secondary channel, though with a slightly lower distributor profit, through the dynamic discount approach.

Distributors have the ability to apply the NFC strategy and routing inventory using the SAA-optimized Protection Level (PL) at the 72-hour point, which helps them to isolate their organic fresh sales and clear overstock via markdowns. For both scenarios B1 and B2, 100% Waste Mitigation Efficiency (WME) is achieved, thus, showing that empirical calibration of the Freshness Decay Penalty (γ) and Price Elasticity (ϵ) is able to map the secondary consumer conversion.

6. Discussion and Managerial Implications

6.1 Theoretical Implications

This research provides a few theoretical advances to the perishable inventory management literature. First, the concept “dynamic routing” of inventory in reverse logistics is extended to the mid-lifecycle context and it is shown that proactive inventory segregation prior to the point of expiration results in better reductions of waste than proactive disposal (Govindan et al., [2015](#); Pokharel and Mutha, [2009](#)).

Secondly, our 2-step optimization-simulation method overcame the drawbacks of solely mathematical optimization (which fails to account for stochastic complexity) and solely simulation (which can give no guarantee of optimality). The GAMS SMINLP model yields mathematically optimal Protection Levels, which are then validated by the Arena DES using realistic stochastic footfall (Jalali and Nieuwenhuyse, [2015](#); Tako and Robinson, [2012](#)).

Thirdly, the empirically obtained Freshness Decay Penalty (γ) and Price Elasticity (ϵ) parameters offer a behavioral basis which has not been included in previous analytical studies. These values match those presented by Aschemann-Witzel et al. ([2018](#)) and De Hooge et al. ([2017](#)) on consumer suboptimal food acceptance, and extended their research from stated to revealed preference through simulation validation.

6.2 Managerial Implications

Elimination of the Oversupply-Undersupply Dilemma

The NFC framework resolves the chronic trade off between service levels and waste. With this change, the distributors can now place aggressive orders without worrying about penalty for expiry as any surplus can be recovered from the secondary channel. This allows for greater service levels (98%+ as opposed to 85-90% in traditional systems).

Manufacturer Margin Recovery

The 2% wastage that was prevalent in the conventional system is redundant. In NFC conditions, the manufacturer will be able to take full wholesale price (40 BDT) on all units, which will be almost 0.8 BDT per unit as compared to conventional (39.2 BDT). This amounts to 10,000 units per day or 2.92 million BDT per year in the case of a manufacturer that delivers 10,000 units per day.

Dynamic Discount Optimization

A different profit profile could also be used to get a 100% waste elimination, such as the dynamic discount (20% then 10%). Overall, the discount in the cumulative discount scenario is same as constant discount, but the discount may be less steep in the first day (20%) than an immediate discount (30%) might be, which could enhance brand perception. The two can be selected depending on the target consumer segment by the managers.

Transport Cost Consideration

Including a transport cost of 0.5 BDT per NFC unit is realistic for reverse logistics in urban South Asia. The framework remains highly profitable even after deducting this cost, as shown by the positive distributor profit across all overstock levels.

Operational Simplicity

The Protection Level can be operationalized as a simple lookup table based on initial order quantity. Front-line warehouse staff can execute the 72-hour audit and transfer without sophisticated systems or real-time analytics.

6.3 Comparison with Existing Literature

Our findings extend several streams of literature. Compared to Buisman et al. (2019), who achieved 15–30% waste reduction through discounting, our dual-channel routing achieves 100% elimination. Relative to Haijema and Minner (2019), who demonstrated the value of stock-age information, we provide an implementable state-dependent policy with empirical validation. Unlike Zhang et al. (2023), who focused on consumer messaging effects on near-expired food purchase willingness, we focus on distributor operational policies.

7. Conclusion

This research presents a robust simulation-optimization framework to combat physical waste and financial volatility in highly perishable FMCG supply chains. By merging a GAMS-based SMINLP optimization with Rockwell Arena Discrete-Event Simulation, we calibrated state-dependent routing policies grounded in empirical consumer decay and elasticity metrics. The implementation of a dual-channel Near-Food-Channel (NFC) clearance strategy effectively rescues aging inventory mid-lifecycle.

Key findings:

1. The conventional supply chain exhibits a “waste cliff” at approximately 2,150 units, with 29.13% waste and −11,300 BDT loss at $Q_0=3,000$.
2. Both constant discount (30%) and dynamic discount (20%/10%) NFC strategies result in 100% Waste Mitigation Efficiency at all inventory levels.
3. Under NFC, the distributor profit remains at 18,600–20,900 BDT while under conventional the profit is in loss.
4. The framework systematically removes the requirement for wastage allowances from the manufacturers and recovers 2% margin.

This strategy delivers not just 100% Waste Mitigation Efficiency, but lays the groundwork for a model of financial systems for distributors that is completely restructured, providing a blueprint for cleaner, more resilient global logistics that can be scaled.

7.1 Limitations and Future Research

There are a few things to note. First, empirical parameters were obtained from the one market (Jatrabari, Dhaka) and may not be applicable to other geographies of different countries which have different consumer behaviour. Secondly, we assumed that the NFC transfer was frictionless in terms of information and transaction costs in practice, there may be frictions in the coordination of logistics. Thirdly, the model is based on the assumption of homogeneous consumers, whereas consumer segment groups might react differently to discounts.

Future research directions are: (1) Extending the framework to multi-product setting with complementary substitution effects; (2) Endogenously modelling the ordering decisions made by the distributor (optimizing Q_0 jointly with PL); (3) Incorporating stochastic deterioration (temperature sensitive-shelf life) instead of fixed 120 hour expiration; and (4) Developing real time dynamic pricing algorithms using machine learning to optimise d_4 and d_5 dependent on the actual inventory and footfall forecast.

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