Food Waste Reduction Using Simulation Modeling: A Case Study of Bakery Products in a Downstream Supply Chain

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ABSTRACT

In response to Sustainable Development Goals 12.3, this study investigated potential interventions to reduce the total food waste within a downstream supply chain of bakery products. Data collected from the supply chain's players, including the wholesaler, the two retailers, and the consumers, were analyzed and used as inputs for a simulation model. First, the experiment was focused on the inventory management of the wholesaler and the retailer. The result suggested that an appropriate inventory replenishment policy could potentially cut 46% of the downstream food wastage. In addition, this study resolved the debate about the influence of the price discount made by the stores on household food waste. The result suggested that the price discount might increase household bakery wastage by 27%, but the total downstream food waste could actually reduce by half. Finally, this study also explored the consumer contribution to this problem and found that 40% of the total downstream food waste could be reduced if the consumers always check their food stock before making any new purchase. These quantified results could support the policy maker and the operator's decisions for a sustainable solution and encourage the consumers to act on the food waste problem.

1. INTRODUCTION

The Agriculture Organization of the United Nations (FAO) reported that 1.3 billion metric tons of food was being lost and wasted each year [1]. Since then we have become more concerned about the effects of this waste crisis on food production and supply chains, economics and the environment. The food supply chain comprises the various activities necessary from primary production to final consumption that is agricultural activities of growing, harvesting, packaging, transportation, storage, distribution, retailing and retail packaging, purchasing for consumption, and disposal for whatever reason. Especially important is the supply chain of foodstuffs with a short “shelf life”, the perishables, such as fruits, vegetables, and bakery products.

The food supply chain consumes natural resources, particularly water, and requires significant inputs of fertilizers and chemicals for pest and weed control that may actually have a negative impact on the environment. So, any food waste must be seen as a waste of resources and a waste of the effort put in to produce it, as well as the obvious waste of the product (in a world where hunger is still a significant problem) [2].

The downstream supply chain produces about 931 million tonnes of food waste annually [3]. The United Nations has announced the Sustainable Development Goals (SDGs) that direct the reduction of food waste at the retail and household levels by half by 2030, specifically SDG 12.3 [4]. Policymakers worldwide responded to the statement by implementing regulations and laws in line with the directive goals [5]-[7]. This agreement will let all stakeholders act for sustainable outcomes.

Fresh bakery has been a significant food product for food waste reduction. The figure for bakery waste in the UK household was 500,000 tonnes in 2012, valued at £870 million, which was 11% of the total food waste [8]. It was reported to be 20% in retail [9]. A study of food waste figures of a store in Italy also found that the bakery department produced 31% of food waste volume and contributed to 13% of the store’s food wastage cost [10]. Some waste reduction strategies for fresh bakery included improving demand forecasts, redistribution, introducing in-store production during the sales period, and reducing the price of the products near the best-before date [11]. This latter strategy is, however, open a current debate on whether the price discount is good for the supply chain as a whole as the food can just be pushed to the lower supply chain’s players, such as consumers, and the problem is not truly solved [12]-[14]. This study emphasizes this question and uses a quantitative method to achieve a quantified measure.

Consumers generate demand signals that are passed up to all players in the supply chain. Therefore, the consumer plays a significant role in food waste reduction, especially in

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purchasing behaviors such as not checking home food stock before buying new food [15]-[17]. This study intended to provide a quantified result for applying this practice so that the consumer could realize the importance of this practice and encourage them to take part in food waste reduction.

To demonstrate a well-defined impact of a unique food waste solution, the researcher should obtain quantified results via a comprehensive and comprehensible research method [18, 19]. Quantitative techniques applied in previous work were aimed to reduce food waste in the retail context including mathematical and simulation modeling, as shown in Table 1. Most studies focused on reducing food wastage only at the retailer level. Therefore, the interaction between players of the downstream supply chain was missing. When the retailer achieves the optimal solution to reduce its food waste, the total food wastage of all players in that supply chain may still be high. This situation needs to be thoroughly investigated especially when include price discounting at the retail store. Some models were applied to a numerical data set of a specified product, differentiated mainly by its shelf life, and the store sells the product as pre-weighed and prepacked, or the customer selects and weighs the product themselves. These retail tactics, therefore, provide unique assumptions about each product type that vary from store to store. Furthermore, most studies acknowledged the inventory of food products with different remaining shelf lives as this is important to capture the reality of the retail inventory system and to produce a practical application.

There is the urgency of the SDG's target 12.3, to be achieved by 2030, and the theoretical gaps which require a quantitative tool to solve the food waste problem of the downstream supply chain as a whole. To fill these theoretical gaps, this study applies simulation modeling to evaluate food waste reduction in a 3-level supply chain which includes the wholesale, retail, and consumer levels. The data used in the model were from the stores that applied age-based inventory systems and sold prepacked bakery products.

The objectives of our study were to provide an option for food waste prevention and reduction, providing answers to these three research questions:

1. How much can a suitable inventory replenishment policy reduce the downstream supply chain's total food waste quantity?
2. How much can a price discount scenario reduce the downstream supply chain's total food waste quantity?
3. How much can consumers reduce the total food waste quantity of the downstream supply chain by routinely checking their food stocks?

Section 2 of this paper describes the case study and the research methodology, including data collection, statistical analysis of the model inputs, simulation modeling, and numerical experiments. Section 3 presents and discusses the results from the model from several scenarios. Finally, Section 4 concludes the discussion and suggests future potential studies.

Table 1. Quantitative techniques applied to food waste problems

Quantitative techniques	Level of supply chains	Total food waste of that supply chain prevention/reduction	Specified food products	Consider/ Investigate the quantified impact of: Aged-based inventory	Price discount	Consumer behavior – checking home-stock	Articles
ORM/ NPVM	S, R		Fresh bakery, fruit and vegetables	✓	✓		[11]
SM	R		Multiple product categories	✓			[20]
SBOM / DSL	R		Meat	✓	✓		[21]
SBOM / IRP	R		Not specified	✓			[22]
SBOM / IRP	R		Prepacked fresh fruit and ready meals	✓			[23]
SBOM / IRP	R		Prepared fresh meals	✓			[24]
MDP	R		Not specified	✓	✓		[14]
MSM	R, C	✓	Prepacked				[25]
MSM	R, C	✓	Prepacked	✓			[13]
DP/ LT	R		Perishable /festival	✓			[26]
SPM	W, R, C	✓	Fresh bakery and other prepacked	✓	✓	✓	This study

Note: ORM/NPVM–Operational Research Modeling/Net Present Value Model; SM–Simulation Modeling; SBOM/DSL–Simulation Based Optimization Model/Dynamic Shelf Life; SBOM/IRP–Simulation Based Optimization Model/Inventory Replenishment Policy; MDP–Multi-stage Dynamic Programming; MSM–Mathematical and Spreadsheet Modeling; DP/LT–Dynamic Programming/Lateral Transshipment; SPM–Spreadsheet

Modeling; S–Supplier; W–Wholesaler, R–Retailer; C–Consumer

2. METHODS

Our research methodology consisted of 4 main steps: (1) data collection, (2) statistical analysis, (3) model construction, and (4) numerical experimentation.

In the first step, we collected information from the participants in the downstream supply chain, to define and set the model's scope. For the wholesaler and retailers, the essential data included inventory replenishment policies, logistics, type of products, the volume of each product, the shelf life of each product, packaging sizes, sale promotion and price discounts, and wastage. We interviewed the wholesaler functionaries who responded to obtain information about inventory management and sales policies at the wholesale level. For the retailer level, the store owners were interviewed and they also allowed us to collect their sales figures and wastage of the products for 30 days, which was the primary data used in our model.

Data required for the consumer level included reasons for bakery goods wastage and the customers' buying and consuming behaviors. We first interviewed 30 customers of the two participating retailers as a preliminary survey to design a questionnaire. The principal questionnaire was then distributed randomly at the two stores and through social media platforms. Responses from 400 people were collected. This first research step is presented in Section 2.1.

In the second step, discussed in Section 2.2, the consumers' responses to the questionnaires were statistically analyzed to be used as the model inputs.

The third step was to build the simulation model based on the information collected in the first step and the statistical inputs from the second step. The model assumptions, the sequence of activities, and the equations of the inventory replenishment policy are presented in detail in Section 2.3.

The last step, Section 2.4, explains the numerical experiments that were conducted based on the three research questions.

2.1. The case study and data collection

We studied a downstream supply chain that distributed bakery products from a factory to the end customers through a wholesaler and several local retailers. We found that every day a lorry freighted 200 to 300 baskets of bakery products to the wholesaler. Each basket held 30-45 packages. About 15-20% of the wholesaler's inventory had been found to have 1-2 days before its expiry date; later, they mostly became food waste.

In this study, we considered only two retailers that received the product from the wholesaler, as depicted in Fig.1. Retailer 1 had a more effective order rate of 300-400 packages daily. In addition, this store usually discarded 3% of its expired products. On the other hand, retailer 2 ordered 20-30 packages daily and had 6% wastage of its products. Both retailers used their experiences to determine each product's order amount.

We selected five products from almost 100 SKUs handled by the stores for our simulation model. These products included bread, pie, cake, Dorayaki, and Daifuku. The selection was made based on an adapted ABC analysis. While the typical ABC analysis ranks products by their total value calculated from their volumes and unit prices, our adapted ABC analysis ranks products by their total wastage values, and the top five were selected.

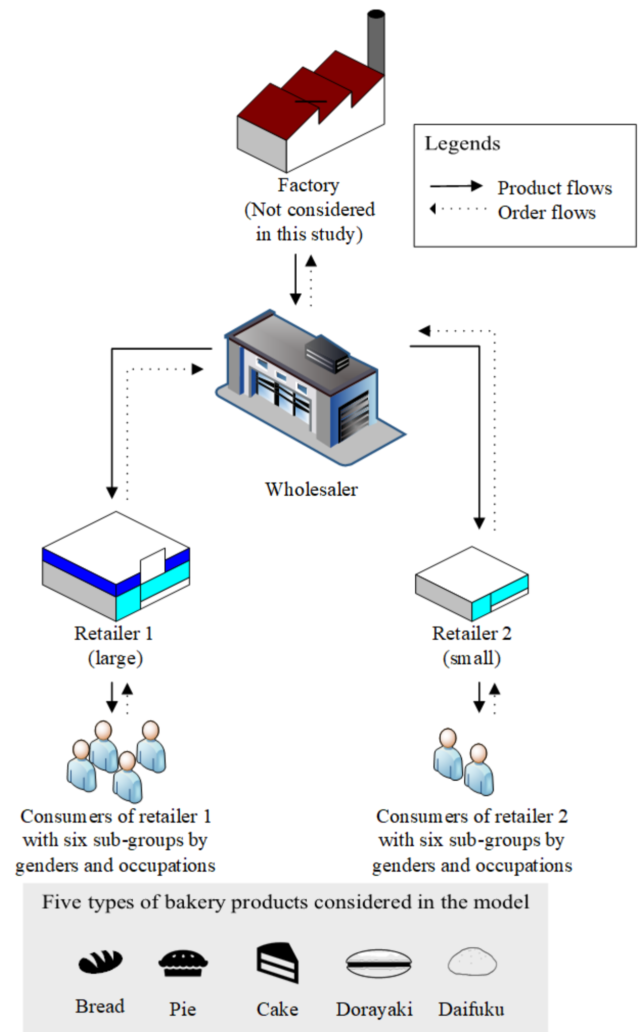

Fig. 1. The supply chain structure of the case study as presented in the simulation model.

The bread was sold in a package size of 150 grams that contained 5-6 pieces. The pie's package size was 110 grams, including 5-6 pieces. Cake, Dorayaki, and Daifuku were a packaged as single pieces in package sizes 130, 55, and 40 grams, respectively. All products had a 5-day shelf life. The monthly food waste of only these five products at the two retailers mounted to 176 packages, which weighed 14,905 grams and costed 2,550 Baht.

The survey showed that the customers generally visited the stores 1-2 times a week on average and bought 1-2 bakery products each time. The consumer most discarded cake, bread, and Daifuku. The most frequent answer for a reason for discarding the bakery products was "passed expiry date," followed by "buy too much/ cannot finish in time," "do not like the taste," and "food deteriorated." Finally, when asked how the consumer deal with food that would become food waste soon, the answers included "feed animals," "bin it," "give it to other people," and "keep it for the following consumption."

Table 2. Items for evaluating the consumers' purchasing and consuming behaviors

Item	Description	Meaning of a 5-mark response towards food waste reduction
Purchasing behavior		
1	You always buy a lot of bakery products to avoid frequent buying.	Negative
2	You like to buy reduced-price bakery products.	Negative
3	You are often affected by advertisements or friends' suggestions to buy a bakery product.	Negative
4	You choose a bakery product that has appealing packaging.	Negative
5	You buy a bakery product that you can consume before its expiry date and can appropriately store.	Positive
6	You buy a bakery product that you can consume the whole portion of it.	Positive
Consuming behavior		
1	You only eat a bakery product that is 100% fresh.	Negative
2	You do not keep a leftover bakery product for subsequent consumption.	Negative
3	You understand the label; "Best before date" versus "Expire date."	Positive
4	You know how to keep a bakery product properly.	Positive

2.2. Statistical analysis of the data for the model inputs

In the questionnaire, the consumers rated their purchasing and consuming behaviors on a 5-point Likert scale ranging from "Highly agree," 5 mark; "Agree," 4; "Neutral," 3; "Disagree," 2; and "Highly disagree," 1. The list of items in Table 2 was designed according to food waste factors frequently mentioned in previous literature, [15]-[17], [27, 28].

As literature suggested that gender and occupation (reflecting income) influenced the rate of food waste generation, [1, 12, 27, 28], six groups of consumers were defined in this study, as shown in Table 3.

Table 3. The parameters of the probability distribution of purchasing and consuming multipliers for the consumer groups

Group	Gender	Occupation	Count	Purchasing multiplier		Consuming multiplier	
				Normal distribution		Normal distribution	
				Mean	Std. dev.	Mean	Std. dev.
1	1	1	81	1.103	0.141	1.077	0.175
2		2	68	1.114	0.136	1.196	0.117
3		3	48	1.073	0.137	1.081	0.212
4	2	1	115	1.108	0.156	1.152	0.200
5		2	54	1.091	0.159	1.219	0.153
6		3	30	1.119	0.132	1.119	0.156
Missing Data			4	Note: Gender: 1 = male; 2 = female Occupation: 1 = student; 2 = official; 3 = businessperson			

The purchasing behavior from the questionnaire responses of each group was calculated according to Somkun (2020) [13] to obtain the purchasing multiplier of the group, as shown in Table 3. This process starts by reverting some scores to the same direction (as in Table 2) towards the "Negative" direction to make the sum score from all items make sense. Therefore, the scores of items 5 and 6 are reverting. For example, if the score is 4, it is reverted to 2. Or, if the score is 1, it is reverted to 5. The sum score is then adjusted by dividing it by 15 to get a purchasing multiplier of that particular questionnaire's response. We suggest readers read Somkun (2017) [25] and Somkun (2020) [13] for the details of this process. Finally, the purchasing multipliers of all people in each group are tested for the probability distribution using Kolmogorov-Smirnov Nonparametric Test. The test result found that the purchasing multiplier of the consumer groups had a Normal Distribution at a 0.10 confidence level. The consuming multiplier was calculated in the same procedure and was tested at the same confidence level. The parameters for the Normal Distribution of the purchasing multipliers are presented in Table 3. The purchasing multiplier distribution function will be used to generate the demand for purchasing of the consumer, which is the first stochastic input.

The consuming multiplier distribution function will determine the consumer's need for consumption, the second stochastic input for the simulation model. Obtaining the consuming multiplier requires a similar procedure to gaining the purchasing multiplier. The Normal probability distribution function with the parameters shown in Table 3 was found to be suitable for representing the consuming multiplier of all consumer groups at a 0.10 significant level.

2.3. The simulation modeling

2.3.1. Model assumptions

- Our simulation model represented a 3-level supply chain of specific bakery products with product and order flows between the players, as depicted in Fig. 1.
- The five bakery products had the same maximum shelf life of 5 days, counting from the date the wholesaler received the product.
- The bakery products deteriorated at a constant rate.
- Food waste is the bakery product that reaches the expiry date. If it has not been sold at the wholesaler, it becomes the wholesaler's food waste. If it has not been sold at the retailers, it is counted as the retailer's food waste. But if the consumer has purchased it, it becomes consumer food waste. In the latter case, food waste may be the whole or remaining portion.
- The study period for the model is 30 days (1 month).
- The wholesaler and the retailers replenish their inventory every day.
- The customer always buys bakery products based on lower prices and then longer life (Last-Come-First-Served, LCFS).
- The customers always eat the bakery product with less remaining life first (First-Come-First-Served, FCFS) and also choose to eat the product that has been kept in stock at home before the bakery product they have just purchased.
- The average daily requirement of the bakery product is calculated from the protein and carbohydrates each gender and age group required for one meal [29].
- The wholesaler always receives a complete order from the factory, and all products delivered have the maximum shelf life.

2.3.2. The simulation model

A simulation model based on spreadsheet software is applied in this study. The model application is not limited to bakery products' supply chain; the usage can be with any prepacked products. Table 4 provides the nomenclature of the parameters and variables used in this study. A set of activities was repeated on each simulated day. Flow charts illustrating this protocol are shown in Fig. 2 (for the consumer), Fig. 3 (for the consumer purchasing decision), Fig. 4 (for the retailer), and Fig. 5 (for the wholesaler).

Table 4. Parameters and variables employed in the model

Symbol	Description
Indices	
t	Time period (day), $t = 0, 1, 2, \dots, T$
l	Remaining life (day), $l = 1, 2, \dots, L$
r	Retailer, $r = 1, 2$
g	Consumer group, $g = 1, 2, \dots, G$
Parameters	
φ	Package size (weight unit)
ρ^g	The average requirement for group g (weight unit/person/day)
n^g	Group size of group g (persons)
β_t^g	Purchasing multiplier for group g at time t
γ_t^g	Consuming multiplier for group g at time t
Variables (All in weight unit)	
FW^{SC}	Total food waste of the supply chain
FW^{C1}	Food waste of the consumer of Retailer 1
FW^{C2}	Food waste of the consumer of Retailer 2
FW^{R1}	Food waste at Retailer 1
FW^{R2}	Food waste at Retailer 2
FW^{W}	Food waste at the wholesaler
D_t^g	The demand of consumer group g at time t
$B_{(l,t)}^g$	Food with a remaining life of l period purchased by consumer group g at time t
E_t^g	Consuming needs of consumer group g at time t
$C_{(l,t)}^g$	Food with a remaining life of l period consumed by consumer group g at time t
$K_{(l,t)}^g$	Food with a remaining life of l period stored by consumer group g at time t
O_t^{Rr}	Orders received by Retailer r at time t
D_t^{Rr}	Orders placed by Retailer r at time t
$I_{(l,t)}^{Rr}$	Inventory level of the food with a remaining life of l period at Retailer r at time t
O_t^{W}	Orders received by the wholesaler at time t
$I_{(l,t)}^{W}$	Inventory level of the food with a remaining life of l period at the wholesaler at time t

Starting from Fig. 2, for a consumer group g at time t, the demand (D_t^g) is generated using the purchasing multiplier (β_t^g), the average requirement (ρ^g), and the group size (n^g). Then, the demand is sent to the purchasing decision module (Fig. 3), where the consumers prioritize the lower price first and then the longer life of the product (LCFS). For example, if there are three packages of a particular product available;

(1) four days before the expiry date at the original price, (2) two days at half price, and (3) one day at half price, in this case, the consumer will purchase (2), (3), and (1), respectively. The retailer provides information on the availability of its age-based inventory. The decision module is repeated until the consumer group's demand is satisfied or the stock is finished, resulting in the amount of food with the remaining life of l period purchased by consumer group g at time t ($B^g_{(l,t)}$).

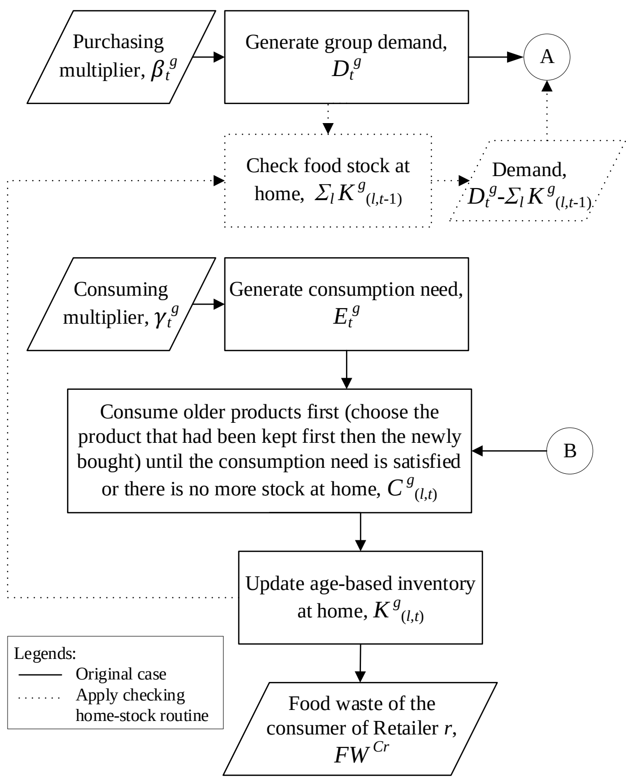

Fig. 2. Flow chart for the consumer activities for consumer group *g* of Retailer *r*.

Resuming Fig. 2, the consuming need (E^g_t) is generated using the consuming multiplier (γ^g_t), the average requirement (ρ^g), and the group size (n^g). The consumer eats the bakery product that is older first (FCFS). When there are particular bakery products with the same remaining life, the consumer will eat the product that has been kept in the household first and then the product that has just been purchased. This consumption activity ($C^g_{(l,t)}$) is repeated until either the consuming need is satisfied or there is no more stock at home. If the inventory and the amount bought are more than the consuming need, the leftover is kept for future consumption ($K^g_{(l,t)}$). And if any bakery product at home has one-day remaining life and has not been eaten in the period, it becomes the consumer's food waste.

As we aimed to test the influence of routine checking of their own stock by the consumers, Fig. 2 also presents this case as shown in the dotted lines. In this case, the consumer will buy the bakery product only the lacking amount between the demand (D^g_t) and the stock at home ($\sum_{l=1}^{L} K^g_{(l,t)}$). After that, other activities proceed as usual.

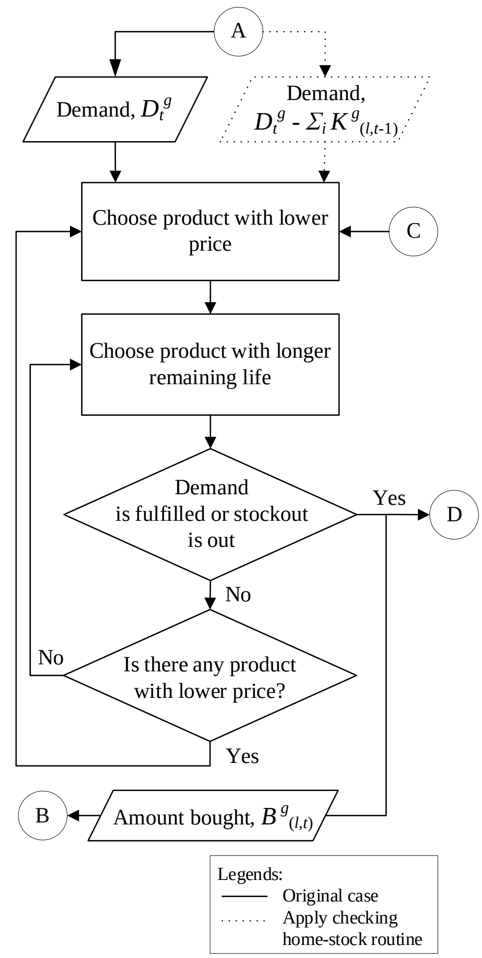

Fig. 3. Flow chart for the consumer purchasing decision module.

Fig. 4 presents the activities for Retailer r, each period starts with the arrival of delivery (O^{Rr}_t) at the amount available at the wholesaler. The receiving delivery can be of different remaining life. Thus, the inventory is updated according to the remaining life of the products ($I^{Rr}_{(l,t)}$). The customer demands occur, and the age-based is updated after each purchase. The bakery product that has one-day remaining life and has not been purchased within that day becomes the retailer's food waste. At the end of each period, an order is placed according to the inventory replenishment policy in Table 5.

Lastly, Fig. 5 explains the wholesaler's events that occur in each period—beginning by receiving a delivery (O^W_t) that the wholesaler placed to the factory from the previous period. The exact number of products ordered is delivered, and all products have the maximum shelf life (L). Then, the age-based inventory of the wholesaler is updated ($I^W_{(l,t)}$). When the retailer's order arrives, the request is checked on the availability of the stock. The available products are immediately sent off to the retailer, and the inventory is updated. Again, the product that has one-day life and has not been purchased will count as the wholesaler's food waste (FW^W). Finally, the wholesaler places an order with the factory (O_t^W) according to the inventory replenishment policy in Table 5.

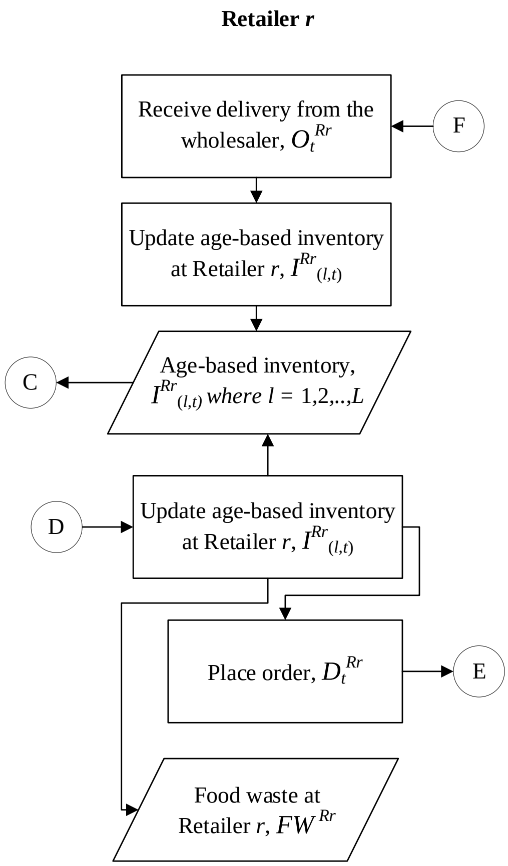

Fig. 4. Flow chart for the retailer activities.

After the simulation time span (T) is completed, the total food waste for this downstream supply chain is calculated as

$$FW^{SC} = FW^{C1} + FW^{C2} + FW^{R1} + FW^{R2} + FW^{W} \quad (1)$$

2.4. Numerical experiments

The simulation model was employed to investigate three food waste intervention options. The first experiment compared the influence of the two inventory replenishment policies presented in Table 5; (ROP, Q) and OUT. The CSL was set to 0.9, which meant the on-hand inventory could satisfy incoming demands for 90% of the total cycles.

The inventory replenishment policy that resulted in lower total food waste in this first experiment was used as a setting in the following experiments.

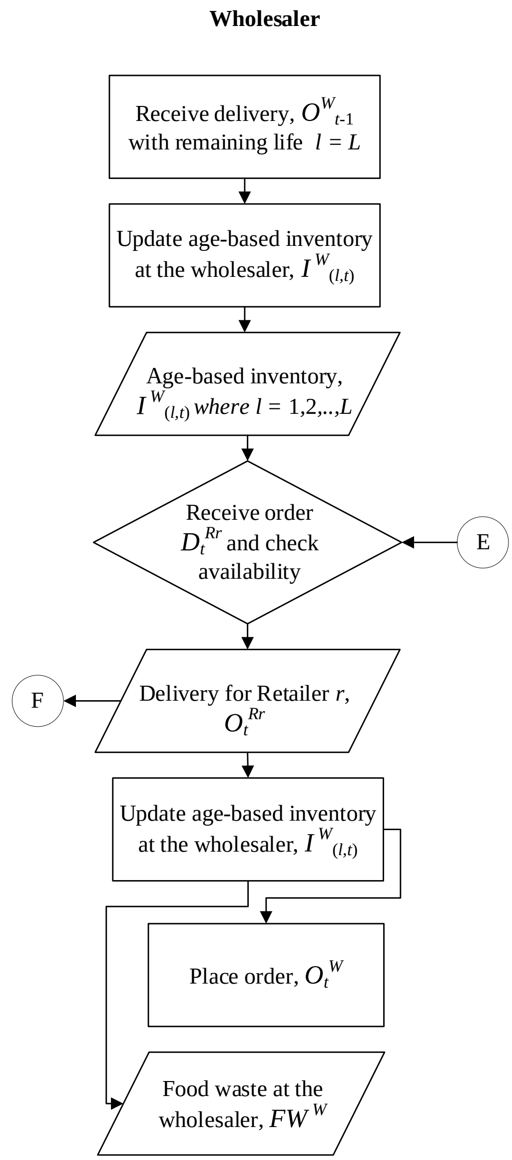

Fig. 5. Flow chart for the wholesaler activities.

The second experiment focused on the influence of price discounts applied to retailers and wholesalers. We explored four scenarios, including:

(S1) No price discounts applied;

(S2) Price discounting applied at the wholesaler;

(S3) Price discounting applied at the two retailers; and

(S4) Price discounting is applied at the wholesaler and the two retailers.

The price discount applied to the bakery products with two-day and one-day remaining life to reduce the price by half. As acknowledged in the assumption, the consumer buys the bakery product by first looking at a lower price, then the longer remaining life.

Table 5. Inventory replenishment policy

Name	**Re-Order Point and Order Quantity (ROP, Q)**
Type	Periodic
Cycle	1 day
Parameters	ROP and Q
Description	At the end of each period, if the total inventory position ($\sum_{l=1}^{L-1} I_{(l,t)}^{Rr}$ or $\sum_{l=1}^{L-1} I_{(l,t)}^{W}$) is lower than or equal to the ROP, the order quantity Q is placed to the higher supply chain player, which is the wholesaler or the factory, depending on which player is under consideration). Else, no order is placed.
Formulas	• $Q = D + F^{-1}(CSL) \times s_D$ $D_L = D \times L$ $s_L = \sqrt{L} \times s_D$ $ss = F^{-1}(CSL) \times s_L$ • $ROP = D_L + ss$
Name	**Order-Up-To (OUT)**
Type	Periodic
Cycle	1 day
Parameters	OUTL
Description	At the end of each period, if the total inventory position ($\sum_{l=1}^{L-1} I_{(l,t)}^{Rr}$ or $\sum_{l=1}^{L-1} I_{(l,t)}^{W}$) has dropped from the Order-Up-To Level, OUTL, the order quantity equal to the difference between OUTL and the current inventory position is placed to the higher supply chain player, which is the wholesaler or the factory, depending on which player is under consideration). Else, no order is placed.
Formulas	• $OUTL = D \times (L + T) + F^{-1}(CSL) \times \sqrt{(L + T)} \times s_D$
Notation	
ROP = Re-Order Point (units) Q = Order Quantity (units) $OUTL$ = Order-Up-To Level (units) D = Average demand per period (units) s_D = Standard deviation of the demand CSL = Cycle Service Level $F^{-1}(CSL) = z =$ Inverse of the cumulative function of the Standard Normal distribution L = lead time (time unit) D_L = Expected demand during lead time s_L = Standard deviation of demand during lead time ss = Safety inventory	

The last experiment examined the consumer practice with their purchasing behavior to see if they always check their home food inventory before buying any new product and how much this would influence food waste reduction.

We collect 100 samples for each experiment to achieve a statistically acceptable result.

The simulation for a particular product was run separately. Then the resulting food waste from all five bakery products was summed up as presented in the graphs.

3. RESULTS AND DISCUSSION

3.1. The influence of the inventory replenishment policy on the supply chain's food waste

At the same service level, the Order Point, Order Quantity (ROP, Q) inventory replenishment policy provides 46% less total food waste than the Order-Up-To policy as displayed in Fig. 6. The total food waste decreased by almost 105 kg per month from 228 to 123 kg per month. The reduction percentage was calculated by

$$\%Reduction1 = \frac{OUTL's\ food\ waste - (ROP,Q)'s\ food\ waste}{OUTL's\ food\ waste} \times 100. \quad (2)$$

Looking into details, the wholesaler produced much less food waste with a 73% reduction when applying the (ROP, Q) policy. The two retailers also owned a high reduction rate of 45% for the large retailer and 24% for the small retailer.

While the stores enjoyed a reduction in food wastage, food waste at the consumer level increased by 1% for the large consumer group and 13% for the small consumer group. This situation showed the connection between the supply chain's players as the parameter setting was based on the consumers' demand. The weight figure showed that the increase was only 200 to 400 grams per month. Therefore, for the overall downstream scope, the (ROP, Q) policy significantly reduced food waste.

Essential components that regulate the values of both OULT and (ROP, Q) as shown in Table 5 (and generally being considered in most inventory replenishment policies) are lead times and CSLs. A longer lead time results in a higher average order rate and stock levels; carrying more perishable foodstuff in stock could lead to a higher chance of food waste generation at the retailer level. A short Food Supply Chain could reduce the delivery lead time by local suppliers [30] and should be further studied. The CSL is also vital for the retail business as product shortages introduce lost sales and, eventually, lost customers. A higher CSL assures better service levels by holding a higher inventory level, and again more food waste is expected. Using this food waste as a resource for renewable energy production [31] is another way for the stores to maintain their customer service level. Although this alternative is not preferable according to the food waste hierarchy, the economic advantage could be studied further.

3.2. The influence of price discount on the supply chain's food waste

The result in Fig. 7 shows that price discounts significantly affect food waste generated in the downstream supply chain. Scenario 2, price discount only at the wholesaler, reduced 16% of the total food waste. The wholesaler obtained the majority of the descent for a 99% reduction compared to its food waste in Scenario 1. At the same time, other players' wastage increased by 7.5% for the retailers and 0.7% for the consumers.

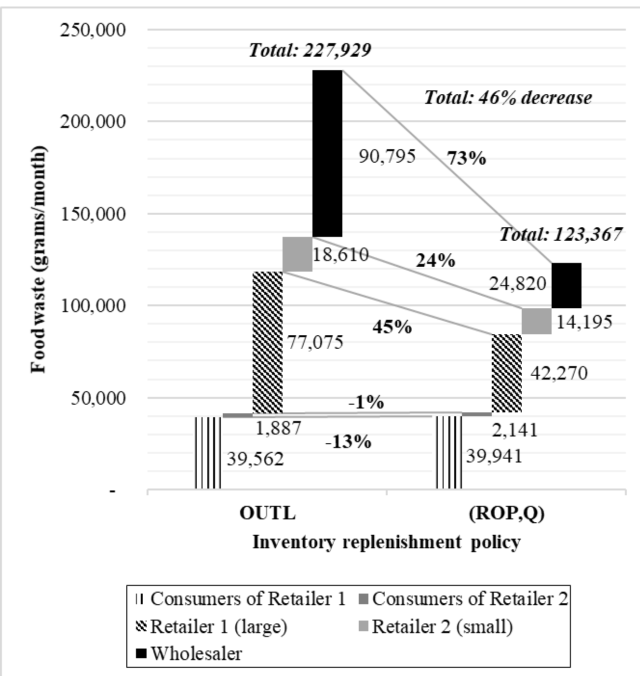

Fig. 6. Compare food waste from the two inventory replenishment policies (at CSL = 0.9).

This reduction percentage was calculated by

$$\%Reduction2 = \frac{S1's\ food\ waste - Scenario's\ food\ waste}{S1's\ food\ waste} \times 100. \qquad (3)$$

When applying Eq. 3 to the retailer, "S1's food waste" and "Scenario's food waste" are the sum of food waste from the two retailers. Likewise, they are the sum of food waste from the consumers of retail 1 and 2 when applied to the consumer level.

Scenario 3, price discount only at the two retailers, gave a 24% reduction of the total food waste compared to Scenario 1. Similarly, the fall came mainly from the retailers, 85% compared to their food waste in Scenario 1. In contrast, food waste increased by 29% for the wholesaler and 27% for the consumers.

Lastly, in Scenario 4, where a price discount was applied for the wholesaler and two retailers, the total wastage significantly dropped when compared to other Scenarios. It was a 50% reduction compared to Scenario 1. All store players had about the same reduction compared to their performance in Scenarios 2 and 3. However, the consumers' food waste notably rose by 27% compared to Scenario 1.

Visibly from the result, price discounts reduced food waste at the particular store that had applied the discount scheme. The bakery product with one- and two-day remaining life are more likely to become food waste at the store, either wholesalers or retailers. When the price of the products is reduced, price-oriented customers will choose to buy these lower-priced items. The suboptimal product then moved to the consumer level of the supply chain. Therefore, the possibility of food waste generation also relocated to the consumer level. Our result validated this situation, and our simulation model provided the quantified expected food waste reduction and increment at all downstream players and the whole downstream supply chain.

The result was, however, entrenched in the assumption that all customers choose lower-price before fresher products. Further study could define this situation more realistically by modeling the customer choices by customer types [12]. Also, the customer was assumed to buy more bakery products without checking that they already had some at home. Section 3.3 explored this latter case further.

3.3. Influence of the consumer's practice on home-stock checking on the supply chain's food waste

This section showed the reduction in total wastage when both the store and the customer were involved in food waste intervention. In Fig.8. When the stores did not apply any discounts (Scenario 1), the consumers checked their bakery stock at home could introduce 40.4% less wastage for this downstream supply chain. This reduction percentage was calculated by

$$\%Reduction = \frac{123{,}367 - 73{,}543}{123{,}367} \times 100 = 40.4\%.$$

Segmenting this reduction, we found that the consumer level reduced 95% of their wastage while the wholesaler had an 18% rise. It is also interesting to see that the retailer level also had a 25% reduction. This finding showed the interrelationship between players in a supply chain. When the consumers always check home stock and buy only an absent amount, this practice reduces the demand volume, and the signal passes to the retailer. Consequently, the retailers adjust their inventory replenishment policy to the lowered demands. This modification resulted in less inventory and less possibility of retail food waste.

The still increase of food waste at the wholesaler could result from the distortion in the demand signal through the retailer's inventory policy. This cause is widely known as the Bullwhip Effect [32, 33]. However, if the retailers share the point-of-sale data with the wholesaler, this Bullwhip Effect could be mitigated. Therefore, a future study could investigate this issue further.

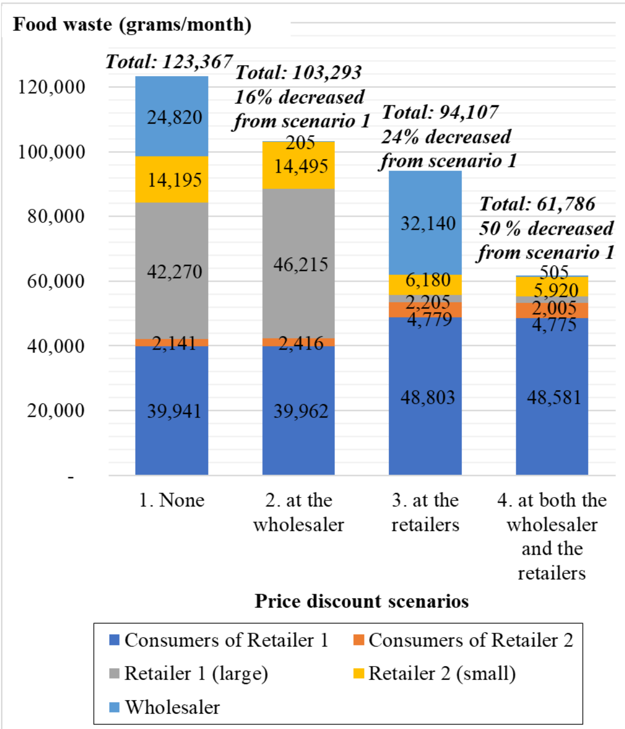

Fig. 7. Food waste from different price discount scenarios (with (ROP, Q) inventory replenishment policy at CSL = 0.9).

4. CONCLUSIONS

A simulation model was employed to investigate the intervention decisions for solving the food waste problem in a downstream supply chain. The model contributes to theoretical implications by adopting the total food waste from all of the players in a supply chain as a critical performance measure whereas most previous studies focused only on wastage reduction at the store level. Our model simulates actual data collected from a supply chain of bakery products, including a wholesaler, two retailers, and consumers.

The results indicate three recommended operational actions to potentially prevent food waste generation. First, the inventory replenishment policy for the bakery products should be to maintain the store's service level while reducing total food wastage. The results also showed that although price discounts could increase consumers' food waste, the strategy could still benefit the overall supply chain. This is an important result rising from considering the entirety of the food chain. Lastly, the consumers are another successive element in the food waste battle. Before consumer buys any new food product, they should make sure that they have checked their home stock first.

The model applies to any prepacked food products. The quantified results could help the store manager decide their inventory replenishment policy and sales promotion that prevent food waste and contribute to the stores' Corporate Social Responsibility and SDG 12.3.

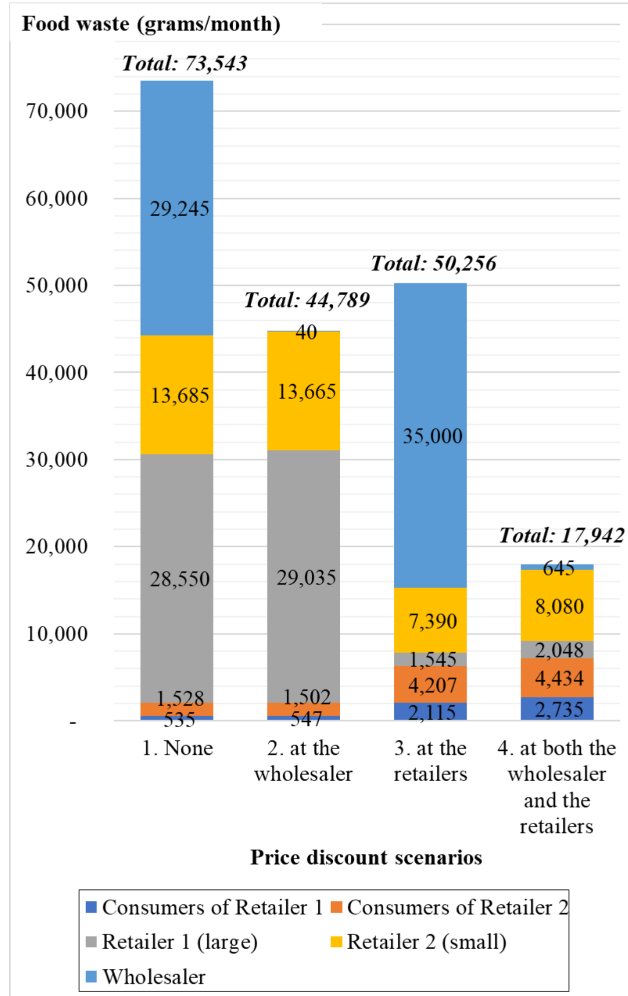

Fig. 8. Compare food waste when consumers always check food-stock at home (with (ROP, Q) inventory replenishment policy at CSL = 0.9).

Further research could consider consumers who make more diverse purchasing decisions and have different consuming behavior. Also, including the original supplier or manufacturer in a supply chain study would make the analysis more comprehensive. As well, the relationship between the Bullwhip Effect and food waste prevention options is an important situation to be investigated.

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