Certificate of Attendance

THIS CERTIFIES THAT

Ivan Gunawan

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ATTENDED THE

2020 IEEE International Conference on Industrial Engineering and Engineering Management

ON

14-17 December, 2020

ORGANIZED BY

IEEE Singapore Section
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AND PRESENTED

IEEM20-P-0068: Modeling the Recall Process of Bulk-Liquid Industry: A Linear Programming Approach

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2020 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)

IEEE IEEM2020 VIRTUAL

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Daily Program: 15 Dec | 16 Dec

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Optimal Planning of a Closed-loop Supply Chain with Recovery Options and Carbon Emission Considerations

Fareeduddin Mohammed *Universiti Teknologi Malaysia, Malaysia*
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Choosing the Right Communication Medium for Knowledge Transfer in Global Production Networks

G. Schuh *RWTH Aachen University, Germany*
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Modeling the Recall Process of Bulk-Liquid Industry: A Linear Programming Approach

Ivan Gunawan *Universitas Katolik Widya Mandala Surabaya, Indonesia*
Iwan Vanany *Institut Teknologi Sepuluh Nopember, Indonesia*
Erwin Widodo *Institut Teknologi Sepuluh Nopember (ITS), Indonesia*

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Niklas Rodemann *RWTH Aachen University, Germany*
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Welcome from the Organizers

It is not an overstatement that 2020 has proven to be one of the most challenging years of our lives. The COVID-19 pandemic situation has led to profound changes in the ways we live, work, and in the ways we exchange information.
IEEM2020 was scheduled to take place from 14 to 17 December 2020 in Singapore at the Marina Bay Sands Convention Centre. However, it was clear by July that it would not be possible to have the in-person conference, and the most appropriate course of action is to conduct the IEEM2020 virtually.
We therefore warmly welcome you to this online conference. From handshakes to headsets, the engagement will be different, but no less valuable. All papers have gone through the same review process as in the past. We are grateful for the many authors who submitted their papers, and the many more reviewers who reviewed the papers at this difficult time. Between presenting and watching the presentations, we hope you will make time to join the quizzes and win prizes that you can use in next IEEM 2021 in Singapore!

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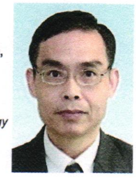

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Modeling the Recall Process of Bulk-Liquid Industry: a Linear Programming Approach

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Abstract – **This article presents a decision-making model in food recall. Four options can be selected for treating recalled products: disposed, redirected for other use, downgraded, and reprocessed. The model will help stakeholders to decide how the recalled products should be allocated for each follow-up action to minimize the recall cost. The model has been tested on a real recall case in the edible oil industry. The model is proven to be able to find the optimal allocation for recalled products to produce a minimum recall cost. The sensitivity analysis shows that the recall cost can also be reduced by a product pricing strategy. Downgrading is the most favorable decision in the real case example.**

Keywords – **Food recall, follow-up action, recall cost, decision-making.**

I. INTRODUCTION

From 2008 to 2018, there were 8,914 reported food recalls from various food categories [1]. Although, every year there are hundreds of food recall announcements released by the government bodies globally, unpublished or unreported food recalls are believed even more. For the food industry, food recall is considered as an undesirable reverse supply chain event because it causes unpredictable losses [2]. Therefore, studies associated with the financial cost of recall decisions are expected to deliver significant implications [3].

Even though a food recall is an essential problem in the field of the food supply chain; to the best of our knowledge, there are still very few studies that discuss decision-making models in food recalls. 'Recall' is generally defined as any action aimed at achieving the return of a hazardous product that has been supplied or provided to consumers by the manufacturer or distributor [4]. Thus, a food recall can be explained as a withdrawal of food products after reaching the customers due to poor quality or unsafe. Based on the definition, the decisions that must be made during a food recall are when to recall, how to recall, and what to do with the recalled products. Regarding the coverage in the supply chain, a food recall can be derived into three levels: consumer recall, trade recall, and stock recovery [5]. A consumer recall occurs when the products have reached the consumers. Then, a trade recall occurs when the products have been beyond the direct control of the company but it is still in the distribution network so that the communication model is business-to-business. Meanwhile, a stock recovery occurs when the products are still in the company's control.

Studies focusing on the recall decisions are needed to provide insight in making tactical or operational decisions during a food recall. The earliest study about recall decision modeling was conducted by [6] which proposed a reverse distribution planning model to minimize distribution cost. Furthermore, reference [7] proposed a recall cost-sharing model. Reference [2] developed a time-to-recall model to decide when to recall. Similar to [2], [8] developed a mathematical model to compute optimal recall time in minimizing recall cost. Reference [9] investigated the recall decisions in a supply chain under product liability. Reference [10] conducted a study to understand the financial impact of a product recall. Then, reference [11] proposed a method to predict the total recall cost by assuming a food recall as a project. All previous studies attempted to answer when to recall and how to recall. Meanwhile, in this study, the research question is what to do with the recalled product. To address the research question, we proposed an optimization modeling approach.

The idea behind the proposed model is that not all food products are disposed after being recalled. We can consider the characteristics of the recalled food and the reason why the food is recalled. Actually, there are four options to treat the recalled food: downgraded, reprocessed, redirected for other use, and disposed [12]. Then, these options will be consistently called as follow-up actions after a recall. The proposed model will produce an optimal decision in allocating the recalled products for each follow-up action. The model is developed based on a linear programming approach. The concept of model development comes from a combination of the transportation model with termination time. The objective function of the model is to minimize recall costs. The hypothesis used in this study is the right decision in determining follow-up action after recall will minimize the total recall cost. Eventually, this model will lead the stakeholders to find out what follow-up actions can significantly reduce the recall cost.

All recall processes follow a standard procedure [13], but the case from a specific food industry will enrich the description, ensure the model applicability, and enhance the managerial implication. Then, a real case of edible oil trade recall will be employed. The case in the edible oil industry involves liquid and bulk products, so the developed model is intended to accommodate continuous objects. The edible oil also allows being downgraded, reprocessed, redirected for other use, and disposed. Therefore, all follow-up actions after recall can be involved. Besides, the term trade recall is used to emphasize that the recall case was business-to-business voluntary recall whose products had not yet reached the consumer or the end-customer.

II. RESULTS

A. The Problem Situation

Due to a certain quality problem, a batch of edible oil that originated from the same storage tank had to be recalled. The oil had been distributed to the 24 customers. Some customers are retailers and the others are food industries that use edible oil as their ingredients.

The recall announcement was triggered by a complaint made by a customer. The complaint was investigated by the quality assurance team and there was a proven production problem. The top management decided to recall the problematic batch which had been delivered to the customers. The customers who received the product from the problematic batch are called the affected customers.

The recall process began by sending a quality control team to conduct on-site inspections. The data obtained from the field inspections was the amount of product left to be recalled and the last quality condition. The recalled products would be stored in the same storage tank where the products were stored before being distributed to customers. In the storage tank, there were products from the same batch that were still left and contaminated too. Furthermore, the management must decide what to do with all of it.

The follow-up actions involved are downgraded, reprocessed, redirected for other use, and disposed. ‘Downgraded’ means resold to the secondary market with new quality information that is lower than the previous quality. ‘Reprocessed’ means processed again into the product of the same quality. ‘Redirected for other use’ means resold as a non-food product such as bioenergy material. ‘Disposed’ means hiring a third party for dispose it as waste. Finally, the industry would send compensation in the form of product exchange according to the amount of product that had been purchased.

The target time to complete all of the recalled product is 2 weeks. After that, the industry will carry out a clean-in-place procedure so that they can make a clear separation between the recalled batch and the new batches.

B. The Process under Investigation

A conceptual model is developed as a guide for the development of the formal model. The conceptual model as seen in Figure 1 comprehensively shows the structure of the process under investigation. The process is explained as follows: when there is a recall announcement, the products are immediately recalled from each affected customer (i) to the factory. The recalled products will be mixed with the remaining products at the factory from the same batch (e). The products, that are already in the factory storage tank, are then decided how much quantity will be allocated for each follow-up action (j). If the quantity of the recalled product and the remaining product at the factory from the same batch (e) are greater than the storage tank capacity, the quantity which cannot be accommodated in the storage tank will be disposed. The factory is also responsible to allocate product for customer compensation.

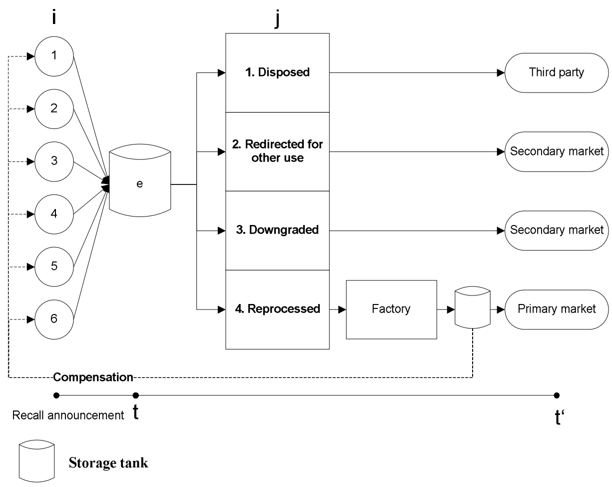

Fig. 1. The conceptual model.

C. The Formal Model

The formal model of the process under investigation can be written as follows

The objective function

$$Min\ RC = \sum_{i=1}^{I} tr_{fi} + \sum_{i=1}^{I} tr_{if} + \sum_{i=1}^{I} in_i + \sum_{t=1}^{T}\sum_{t'\geq t}^{T'} M_{tt'}(P_m + pr) + \sum_{t=1}^{T}\sum_{t'\geq t}^{T'} M_{tt'}(1-t)H_f + {}^{s_{40}}/_{\gamma_{41}}(P_m + pr) + eP_e + s_{4T'}M + \sum_{j=1}^{4} c_j \quad (1)$$

where

$$c_1 = \left(b_{111}\min\left(\sum_{i=1}^{I} a_i p_i + e\,; Cap_{rc}\right) + L\right) dc \quad (2)$$

$$c_2 = \sum_{t'=1}^{T'} b_{21t'}\min\left(\sum_{i=1}^{I} a_i p_i + e\,; Cap_{rc}\right)(t'-1)H_f - \sum_{t'=1}^{T'} D_{2t'}P_{2t'} \quad (3)$$

$$c_3 = \sum_{t'=1}^{T'} b_{31t'}\min\left(\sum_{i=1}^{I} a_i p_i + e\,; Cap_{rc}\right)(t'-1)H_f - \sum_{t'=1}^{T'} D_{3t'}P_{3t'} \quad (4)$$

$$c_4 = \sum_{t=1}^{T}\sum_{t'=1}^{T'} b_{4tt'}\min\left(\sum_{i=1}^{I} a_i p_i + e\,; Cap_{rc}\right)pr + \sum_{t=1}^{T}\sum_{t'=1}^{T'} b_{4tt'}\min\left(\sum_{i=1}^{I} a_i p_i + e\,; Cap_{rc}\right)(t-1)H_f + \left(\sum_{t=1|t<t'}^{T}\sum_{t'\geq t}^{T'} b_{4tt'}\min\left(\sum_{i=1}^{I} a_i p_i + e\,; Cap_{rc}\right)\gamma_{4t} + \sum_{t=1|t<t'}^{T}\sum_{t'\geq t}^{T'} M_{tt'}\gamma_{41}\right)(t'-t)H_f + \sum_{t'=1}^{T'} s_{4t'}H_f - D_{4t'}P_{4t'} \quad (5)$$

The constraints

1. Production capacity constraint

$$\sum_{t'=1}^{T'} b_{4tt'} \min\left(\sum_{i=1}^{I} a_i p_i + e\,; Cap_{rc}\right) + \sum_{t'=1}^{T'} M_{tt'} \leq Cap_t^{pr}\ \forall t = 1, \ldots, T \quad (6)$$

2. Material availability constraint

$$\sum_{t'=1}^{T} M_{tt'} \leq Cap_t^m\ \forall t = 1, \ldots, T \quad (7)$$

3. Storage capacity constraint

$$\sum_{t=1|t<t'}^{T} b_{4tt'} \min\left(\sum_{i=1}^{I} a_i p_i + e\,; Cap_{rc}\right)\gamma_{4t} + \sum_{t=1|t<t'}^{T} M_{tt}\gamma_{4t} + s_{4t'} \leq Cap_4^I\ \forall t' = 2, \ldots, T' \quad (8)$$

4. Compensation and demand for reprocessed product in period 1.

$$b_{411} \min\left(\sum_{i=1}^{I} a_i p_i + e\,; Cap_{rc}\right)\gamma_{41} + M_{11}\gamma_{41} + s_{40} \geq \sum_{i=1}^{I} a_i + D_{41} \quad (9)$$

5. Demand for reprocessed product in period t'>1

$$\sum_{t=1|t\leq t'}^{T} b_{4tt'} \min\left(\sum_{i=1}^{I} a_i p_i + e\,; Cap_{rc}\right)\gamma_{4t} + \sum_{t=1|t\leq t'}^{T} M_{tt'}\gamma_{41} + s_{4,t'-1} \geq D_{4t'}\forall t' = 2, \ldots, T'. \quad (10)$$

6. Demand for redirected-for-other-use product

$$b_{21t'} \min\left(\sum_{i=1}^{I} a_i p_i + e\,; Cap_{rc}\right) = D_{2t'}\forall t' = 1, \ldots, T' \quad (11)$$

7. Demand for downgraded product

$$b_{31t'} \min\left(\sum_{i=1}^{I} a_i p_i + e\,; Cap_{rc}\right) = D_{3t'}\forall t' = 1, \ldots, T' \quad (12)$$

8. Quantity disposed

$$\sum_{i=1}^{I} a_i p_i + e - Cap_{rc} = L \quad (13)$$

9. Reprocessed product stock in period 1

$$b_{411}\min\left(\sum_{i=1}^{I} a_i p_i + e\,; Cap_{rc}\right)\gamma_{41} + M_{11}\gamma_{41} + s_{40} - \left(\sum_{i=1}^{I} a_i + D_{41}\right) = s_{41} \quad (14)$$

10. Reprocessed product stock t'>1

$$\sum_{t=2|t\leq t'}^{T} b_{4tt'} \min\left(\sum_{i=1}^{I} a_i p_i + e\,; Cap_{rc}\right)\gamma_{4t} + \sum_{t=1|t\leq t'}^{T} M_{tt'}\gamma_{41} + s_{4,t'-1} - D_{4t'} = s_{4t'}\forall t' = 2, \ldots, T' \quad (15)$$

11.Constrain to guarantee the allocation of proportions

$$\sum_{j=1}^{4}\sum_{t=1}^{T}\sum_{t'=1}^{T'} b_{jtt'} = 1 \quad (16)$$

Indices

i = customer index
j = follow-up action index
j' = follow-up action product index
t = follow-up action period index
t' = customer demand period index

Parameters

a_i = quantity purchased by customer i (kg)
P_i = product price for customer i (IDR/kg)
$P_{j't'}$ = product j' price in period t' (IDR /kg)
P_m = material price (IDR /kg)
tr_{if} = transportation cost charged for transporting a_ip_i from customer i to factory (f) (IDR)
tr_{fi} = transportation cost charged for transporting a_i from factory (f) to customer i (IDR)
pr = processing cost (IDR /kg)
in_i = inspection cost in the customer i (IDR /customer)
p_i = percentage product left in the customer i
H_f = factory holding cost (IDR /kg/period)
γ_{4t} = reprocessed yield in period t
t = follow-up action period
t' = customer demand period
e = quantity product still left in the factory from the same *batch* (kg)
P_e = expected price of product left in the factory from the same batch (IDR /kg)
dc = disposal cost (IDR /kg)
$D_{j't}$ = demand for product j' in period t (kg)
s_{40} = stock left in the storage tank before recall announcement (kg)
c_j = follow-up action cost (IDR)
Cap_t^m = material capacity in period t (kg)
$Cap_{j'}^I$ = storage tank capacity for product j' (kg)
Cap_t^{pr} = production capacity in period t (kg)
Cap_{rc} = storage tank capacity for recalled product (kg)
M = very high value

Variables

$b_{jtt'}$ = proportion of product to be decided for follow-up action j in period t to meet demand in period t'
$M_{tt'}$ = the amount of material needed to be processed in period t to meet demand in period t' (kg)
L = the difference between storage capacity and the amount of recalled product (kg)
$s_{j't}$ = stock in the storage tank for product j' in period t

Additional equations related to the industry characteristics

Yield for reprocessed product

$$\delta - \varepsilon \cdot t = \gamma_{4t} \quad (17)$$

where

γ_{4t} = yield when reprocessed is conducted in period t
δ = constant which can be gotten from regression analysis or yield in period t=1
ε = ratio of yield decrease to time
t = time

Demand equation for reprocessed product and redirected for other use product

$$\alpha - \beta_{j'} \cdot P_{j't'} = D_{j't'} \quad (18)$$

where

$D_{j't'}$ = demand for product j' in period t' (kg)
α = constant which can be gotten from regression analysis or $D_{j't'}^{max}$
$\beta_{j'}$ = conversion factor from price to product j' demand
$P_{j't'}$ = product price in period t' (IDR/kg)

Demand equation for downgraded product

$$\frac{\beta_3 \cdot (\rho \cdot P_{4t'} - P_{3t'})}{\rho \cdot (1-\rho)} = D_{3t'} \quad (19)$$

where

$D_{3t'}$ = demand for the downgraded product in period t'
$P_{3t'}$ = downgraded product price in period t' (IDR/kg)
β_3 = conversion factor from price to the demand of the downgraded product
ρ = customer acceptance ratio of the downgraded product.
$P_{4t'}$ = reprocessed product price in period t' (IDR/kg)

The objective function as in (1) to (5) shows that the components to calculate recall cost are transportation cost for shipping compensation product to the customer, transportation cost for bringing back recalled product to the factory, material cost, material processing cost, material storing cost, the material cost in the initial stock, the processing cost of the initial stock, potential income from selling the remaining products from the same batch with recalled batch, the penalty for remaining stock at the end of the recall period, and follow-up action cost. The objective function is then followed by 11 constraints as in (6) to (16) which accommodate the industry characteristics.

Equation (17) represents the yield that will be obtained from the reprocessed. The longer the processing time is determined the lower the yield obtained. This condition accommodates the characteristics of food products that will experience a decrease in quality over time. For running the sensitivity analysis, two demand functions are added. The demand for the reprocessed product and redirected-for-other-use product is generated using a linear price-response function as in (18) and the demand for the downgraded product is generated using a dual sales channel model as in (19) which was introduced by [14]. The dual sales channel model is adapted in this system because there is an interplay between the market of the downgraded product and the market of the reprocessed product. If the price difference between the reprocessed product and the downgraded product is relatively small, the demand for the downgraded product also decreases.

Besides, all of the fundamental assumptions of linear programming, the other assumptions used in the developed model are

a. Compensation is always done in period-1 (t'= 1) and the amount of compensation is equal to the amount of product purchased by the customer.
b. The recalled products from the customers have the same quality as the reprocessed product (j'= 4).
c. The yield and the cost of processing new material are the same as the yield and the cost of reprocessing the recalled product.
d. There is no backlog.

III. NUMERICAL EXAMPLE

A numerical example is employed to test the model. The hypothetical data generated from reduced real case data is presented in Table I to Table IV.

TABLE I
HYPOTHETICAL DATA RELATED TO CUSTOMER

i	a_i	$tr_{fi/if}$	p_i	in_i
1	27,000	8,235,000.00	0.85	3,500,000.00
2	18,000	3,510,000.00	0.75	2,000,000.00
3	25,000	6,000,000.00	0.9	2,500,000.00
4	25,000	7,500,000.00	0.8	2,500,000.00
5	27,000	4,185,000.00	0.9	1,500,000.00
6	16,000	6,300,000.00	0.9	3,500,000.00
7	4,000	5,625,000.00	0.8	3,500,000.00
8	27,000	8,235,000.00	0.75	3,500,000.00

TABLE II
HYPOTHETICAL DATA RELATED TO COST AND PRICE

Cost					Price		
pr	P_m	H_f	dc	P_e	P_{21}/P_{22}	P_{31}/P_{32}	P_{41}/P_{42}
500	7,000	50	1,000	10,000	5,000	7,000	10,000

TABLE III
HYPOTHETICAL DATA RELATED TO DEMAND

Period 1			Period 2		
D_2	D_3	D_4	D_2	D_3	D_4
2,000	20,000	100,000	2,000	20,000	100,000

TABLE IV
HYPOTHETICAL DATA RELATED TO STOCK AND CAPACITY

e	s_{40}	Cap_t^m	Cap_t^{pr}	$Cap_{j'}^I$
5,000	40,000	200,000	400,000	150,000

TABLE V
THE OPTIMAL ALLOCATION OF RECALLED PRODUCT

Demand for					
Redirected for other use		Downgraded		Reprocessed	
Period 1	Period 2	Period 1	Period 2	Period 1	Period 2
1,369%	1,369%	13,69%	13,69%	69,88%	New batch

IV. REAL CASE EXAMPLE

After the model was tested, the data from a real case was used to solve the model. The real case data was from a trade recall which involved 24 customers in 2014. The recall was set to be completed in two periods. A period is a week or seven days.

The demand function for the reprocessed product, the downgraded product, and the redirected-for-other-use product is shown in (20) to (22) and the yield function is shown in (23).

$$D_{4t'} = 350{,}000 - 25P_{4t'} \tag{20}$$

$$D_{3t'} = \frac{25 \cdot (0.93P_{4t'} - P_{3t'})}{0.93(1 - 0.93)} \tag{21}$$

$$D_{2t'} = 75{,}000 - 25P_{2t'} \tag{22}$$

$$\gamma_{4t} = 0.943 - 0.003 \cdot t \tag{23}$$

Then, the minimum recall cost of the real case condition is IDR1,831,932,000. However, the recall cost still can be reduced by product pricing strategy. In this case, a product pricing strategy is a possible strategy to adopt because edible oil is a commodity product.

Sensitivity analyzes were performed to see the influence of the product pricing on the recall cost. The sensitivity analyzes were conducted by changing the price of each follow-up action product for every multiple IDR100. Increase the price of the reprocessed product will lower the demand of the reprocessed product, but it actually reduces the recall cost. This suggests that reprocessing the recalled product, with a cost structure like the case observed, cannot generate a profit to reduce the recall cost. On the other hand, lower the price of the downgraded product will escalate the demand and has an impact on reducing the recall cost. Finally, the sensitivity analysis for the redirected for other use product shows the same pattern as the sensitivity analysis for the reprocessed product. Therefore, if the company is forced to make a single decision, the downgrade decision should be made because downgrading is more favorable for the company than a decision to reprocess or to redirect-for-other use in this recall situation. Sensitivity analysis provides an insight that the sale of the downgraded product still generates a profit that can reduce the recall cost.

V. CONCLUSION

The linear programming approach has succeeded in modeling the recall process. The model can minimize the recall cost by optimally allocating the recalled products at each follow-up action. An interesting finding from this model is that not only the product allocation strategy but also the product pricing strategy can affect the recall cost. The sensitivity analysis shows the influence of product pricing on the recall cost. Changes in the prices of the reprocessed product and the redirected for other use product have the same effect on the recall cost. Increase the price of the reprocessed product or the redirected-for-other use product so that the demand drops will reduce the recall cost. Conversely, lowering the price of the downgraded product so that the demand increase will reduce the recall cost. Thus, the best decision in the situation as in the case observed is downgraded the recalled products. The redirected-for-other-use option can be effectively reduced the recall cost if the amount of product from the same batch remaining in the storage tank (e) exceeds the demand of the downgraded and the reprocessed product

The model produced by this study makes a theoretical contribution to the food supply chain area. The results obtained from this study have managerial implications for the food industry which has the same cost structure. When the stakeholders have to make a single decision on a recall case, they can consider downgrading the recalled products. Moreover, the selling price of the downgraded product can still be lowered to increase the demand so that it can more effectively reduce the recall cost. A further sensitivity analysis using the model can help the stakeholders found what is the lowest price for the downgraded product. The model can also generate new optimal decisions if there is a change in the cost structure.

The linear programming approach will produce a deterministic model. Therefore, the future work direction is to provide a model that can accommodate uncertain demand. A heuristic approach in the solution search process needs to be developed to facilitate practical use. Sensitivity analysis also needs to be carried out not only on product pricing but also on other relevant parameters such as yield for reprocessing, recall time, or a combination of parameter changes.

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