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Bulk food recall decisions: Postponement and preponement to sustain food business

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ABSTRACT

Without packaging, bulk food is prone to contamination which may lead to external quality failure that demands food recall. Companies need to employ effective recall decisions to prevent major loss and minimize the costs associated with recall. This study aims to determine the most effective disposition timing to reduce such recall costs and to ensure that business remains sustainable. Two disposition timing models that accommodate postponement and preponement decisions are developed: the former through Dynamic Linear Programming and the latter through Dynamic Mix Integer Linear Programming. These models aim to minimize recall costs by optimizing product allocation for each possible disposition alternative. The models were used in a real case scenario in the edible oil industry in Indonesia. The results show that recall costs in the preponement model are lower than in the postponement model when the transportation cost is high to recall back all the products to the factory.

1. Introduction

Fulfilling food demand is not only a matter of quantity but also quality (Cao et al., 2011). Unsafe food products can be categorized as a quality failure (Aung and Chang, 2014). An external quality failure is a quality problem detected after food products have been shipped. This may lead to a food recall which is the effort to remove food products with quality problems from circulation. Food recall aims to eliminate problems or to prevent negative impacts (Li et al., 2017). However, this will burden a business with recall costs that can lead to financial loss and bankruptcy (Lu and Zhang, 2010). Effective recall processes will help a company to maintain its business continuity after a recall.

External quality failures can pose a risk to business continuity so it is essential to develop and implement effective recall decisions in order to increase resilience. Resilience and business sustainability are interconnected (Jabbarzadeh et al., 2018). There are three important pillars of business sustainability: financial, social, and environmental performance (Gao and Bansal, 2013). Financial disruption due to recall does not only mean costs that are associated with the recall process but also the company's share value on the stock market (Pozo and Schroeder, 2016). Food recall can also be considered a form of corporate social responsibility (Cheah et al., 2007). Being socially responsible can be an effective way for a business to reduce negative reactions from the public which in turn can protect stakeholder interests and sustain the business (Kong et al., 2019). Food recall activities will also increase the need for and use of energy which can negatively impact the environmental performance of a food production system. Therefore, effective decisions in the food recall process will help food companies to maintain food business sustainability.

Strategies in product recall can be broadly generalized as responsive and less-responsive. We considered three-time horizons in categorizing recall stages: pre-recall, during recall and post-recall (Berman, 1999), before a recall is announced, after a recall is announced and after remedial actions are completed respectively. Chen et al. (2009) and Souiden and Pons (2009) categorized strategies in the pre-recall stage as either proactive or reactive. With a proactive strategy a company will make a voluntary recall when a product is found to have a defect that potentially requires a recall. With a reactive strategy a company will try to delay a recall process or try to shift the responsibility to other entities. Chen et al. (2009) found that a proactive strategy has a more negative impact on a company's financial performance compared to a reactive strategy. In contrast, Souiden and Pons (2009) stated that a proactive strategy has a positive effect on a company's image, consumer loyalty and purchase intention. Zhao et al. (2013) also found that a proactive strategy has a positive impact on company performance in the stock market.

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In the post-recall stage, Berman (1999) suggested a total differentiation to assure that the product has been significantly improved so that it can restore consumer confidence. For a branded product, Cleeren et al. (2013) proposed pricing promotion and non-pricing promotion as post-recall strategies and based the strategic recommendations on the types of crisis caused by harmful products. Byun et al. (2020) proved that price promotions are more effective than non-price promotions at retaining loyal consumers after a product recall.

In the during-recall stage, Liu et al. (2016) suggested full and partial remedial strategies. A full remedy means a consumer will get a full refund or total replacement, whereas a partial remedy offers a free repair or a discount. Subject to the company's financial condition it may be willing to provide full remedies if the potential harm of a product is severe. Unlike the pre- and post-recall categories, research has not fully explored the possible initiatives to tackle negative effects in the during-recall phase. There are many approaches to reduce the impacts of a recall such as safety analysis, cost estimation, information gathering and recalled product recovery (Diallo et al., 2016). Therefore, further development of initiatives during recall is a promising research area.

In this study we aim to fill the research gap in the during-recall phase by proposing two disposition timing models. Postponement and preponement are decisions made in determining the right time to differentiate products in a reversed supply chain (Blackburn et al., 2004). These decisions emerge as an effort to tackle the trade-off dilemma between maintaining product value and reducing costs. A recall process also follows a reversed supply chain process (Hora et al., 2011). Rather than simply being destroyed or disposed during recall, product differentiation may be applied to the affected products. Affected products could be redirected for other use, regraded or downgraded, and reprocessed. The International Organization for Standardization (2005) recognizes this as disposition of nonconforming products. Therefore, we believe that the idea of postponement and preponement can also be adapted in a recall.

Disposition timing models can make a significant difference in terms of direct costs during a recall. We defined postponement as the decision to delay disposition of an affected product until all of the affected products are collected at a central location, while preponement is to decide the disposition alternatives as early as possible. Decisions about when affected products should be disposed, redirected for other use, downgraded, and reprocessed during a recall will impact the recall costs. Therefore, this study aims to create an optimization model for a recall process to assess the influence of postponement and preponement decisions on direct recall costs. At a practical level this study will provide suggestions to reduce recall costs based on the empirical evidence. We hypothesize that optimal disposition timing will reduce recall costs.

Diallo et al. (2016) stated that a product recall scenario depends on the product type, the supply chain type, the supply chain scope and the regulations involved. Inability to provide clear identification of the final product is a threat to bulk food product management. When an external quality failure occurs many products will be affected leading to an extensive, costly and impactful recall (Comba et al., 2013). Therefore, we consider a case-based model that is designed for the bulk edible oil industry which is prone to quality problems as a result of contamination and temperature changes during storage and transport from the factory to customers (Gunstone and Martini, 2010). As a bulk commodity it will be a challenge to build models for edible oil products that are distributed overseas. In this study two proposed models are applied to a case in the Indonesian edible oil industry because it often experiences food recalls for various reasons (Gunawan et al., 2017, 2019). In this case all of the alternatives of disposition are applicable. The postponement decision follows Dynamic Linear Programming (DLP) and the preponement decision follows Dynamic Mix Integer Linear Programming (DMILP). The dynamic element in the linear programming accommodates the concept of targeted recall time. Technically, the models aim to minimize recall costs by determining the optimal product allocation for each possible disposition alternative. The results of the two disposition timing models are compared to determine which decision is better in terms of recall costs for each recall situation.

2. Literature review

We classified studies on product recall based on their contribution in the recall time horizons: pre-recall, during recall, and post-recall. Table 1 summarizes recall studies from 2010 to 2020 that focus on analytical solutions and simulations of mathematical models following the methods in system studies presented by Law and Kelton (2000).

As shown in Table 1, most studies propose approaches to reduce recall costs from the pre-recall phase. For example, Velthuis et al. (2010) conducted a simulation study to investigate the interaction of time-to-recall on the direct recall costs of custard. The results show that the longer it took for the custard to be recalled, the greater the direct recall costs were. Therefore, the study suggests that a responsive strategy would be more promising in the case of custard recalls. A study by Memon et al. (2015) concerned the quantity of the recalled product. The study proposes an optimization model to reduce batch dispersion in order to minimize the quantity of recalled products. The results show that the size of the production batch is directly proportional to the recall costs. The larger the production batch size is, the greater the number of the affected customers and the higher the losses. However, in continuous production such as edible oil reducing the recall size with a batch dispersion is only possible if the defect is in the final product. If the problems exist throughout the production process, the recall may not be optimal (Diallo et al., 2016).

In terms of the post-recall phase, mathematical modeling does not seem to be the preferred approach. Most studies in the post-recall phase use an empirical approach, such as: the financial impact of recall announcements on retailers (Ni et al., 2014); the effect of recall on the subsequent demand (Bakhtavoryan et al., 2014) and on consumer behavior (Charlebois et al., 2015); the influence of social media on shareholder value (Hsu et al., 2016); and the effect of egg recall on customer willingness-to-pay after a recall (Li et al., 2017). A study by Richards and Nganje (2014) which does use mathematical modeling discusses the effect of recall on demand after a recall. The findings show that food safety recalls affect both a shift and a rotation in demand. However, the preference for the type of food being recalled also affects the recall costs. The absence of a clear formula for calculating the indirect costs of recall may explain why there are not many experimental studies with mathematical models in this area (Velthuis et al., 2010).

There are two experimental studies using a mathematical model to solve problems during a recall. Ginantaka et al. (2015) aimed to minimize transportation costs by determining the shortest route when recalling the affected products. They highlighted that transportation was a critical component of recall costs. Watanabe et al. (2018) conducted an agent-based simulation to observe the influence of price on a product recall system. They maintained that minimizing costs in a large-scale recall is imperative and that the company executives need to align their perspectives when making recall decisions. The key points of both studies were considered as the capstone for this study. Companies have to determine the optimal disposition timing in a recall as this could have a significant impact on transportation costs which are a major contributor to direct recall costs. Therefore, we developed a mathematical model to investigate the impact of disposition timing on the direct recall costs and to predict the total recall cost.

3. Postponement and preponement decisions in a recall process

Postponement, a concept initially put forward by Alderson (1950), is a cost reduction initiative by delaying product differentiation until the products are ready to be released into the market. This concept has evolved dramatically in supply chain management. Postponement is defined as delaying activities in the supply chain (form, place and time) until real information about the market is available (Yang and Burns, 2003). In this context the opposite of postponement is speculation which is a traditional way to start moving products along the supply chain on a forecasting basis or what is also known as a push system. Products are

Table 1
Summary of the literature on product recalls using mathematical model.

No.	Authors	Years	Research Purposes	Mathematical Model		Time perspective			Product
				Analytical	Simulation	Pre-recall	During recall	Post-recall	
1	Velthuis et al. (2010)	2010	To investigate the interactions of final testing time, product recall time, and direct recall costs.		*	*			Custard
2	Saltini & Akkerman (2012)	2012	To investigate the relationship between batch size and potential recall size		*	*			Chocolate
3	Sezer & Haksöz (2012)	2012	To find an effective system in detecting manufacturing faults that lead to recalls	*		*			Not specific
4	Schoder et al. (2013)	2013	To measure the performance of the internal monitoring system in uncovering contamination scenarios that lead to recall.		*	*			Cheese
5	Piramuthu et al. (2013)	2013	To study the effects of traceability level and technology utilization in a perishable food supply network.	*		*			Food
6	Richards & Nganje (2014)	2014	To study the influence of food recalls on a change in the dispersion of demand.	*				*	Fresh produce
7	Diallo et al. (2014)	2014	To develop a product recall approach following the detection of a critical fault	*		*			Not specific
8	Fan et al. (2015)	2015	To investigate the manufacturer's product recall decisions in supply chain under product liability	*		*			Not specific
9	Ginantaka et al. (2015)	2015	To optimize the direct recall costs on frozen milkfish recall	*			*		Fish
10	Memon et al. (2015)	2015	To develop a model to minimize the direct cost of recall using batch dispersion methodology.	*		*			Not specific
11	Xin et al. (2015)	2015	To minimize the quantity of recalls by while facing food safety crisis	*		*			Food
12	Dai et al. (2015)	2015	To quantify the reallocation of the reduced liability due to traceability improvement by proposing an explicit pricing strategy	*		*			Not specific
13	Watanabe et al. (2018)	2018	To study product recall systems in a setting with price competition		*		*		Not specific
14	Yao & Parlar (2019)	2019	To discover the structure of optimal policy for the product recall timing problem	*		*			Not specific
15	Dai et al. (2020)	2020	To study the interactions of supply chain traceability and product reliability in a competitive supply chain with product recall.	*		*			Not specific
16	This study	2021	To optimize the direct recall costs on bulk edible oil recall through disposition strategies.	*			*		Bulk edible oil

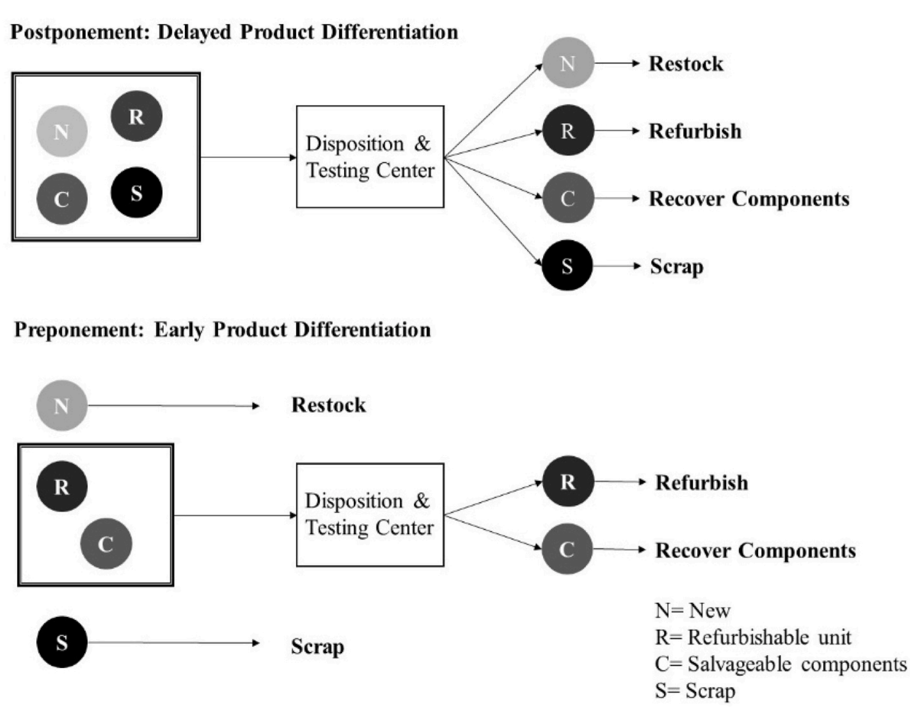

Fig. 1. Postponement versus preponement (Blackburn et al., 2004).

then kept close to customers through a decentralized distribution system (Pagh and Cooper, 1998).

Postponement was reintroduced by Blackburn et al. (2004) as an initiative in designing an efficient reversed supply chain. In this case the opposite of postponement is preponement which aims to create a responsive reversed supply chain. Postponement adopts a centralized model that requires all products to be returned to the factory for disposition, whereas preponement requires a decentralized model so that disposition can be carried out as early as possible. Fig. 1 represents the idea of postponement and preponement in a reversed supply chain.

Postponement and preponement have been translated as analytical mathematical models by Guide et al. (2006) to analyze the impact of these models in the reverse supply chain of electronic products. Guide et al. (2006) suggest using a preponement model in the reverse supply chain of printer products to increase responsiveness. Printer products are categorized as innovative products so they need to maintain product value over time. Other electronic products that are not time-sensitive may adopt a 'less responsive' strategy because they are relatively stable in the market. Since postponement is to delay disposition until all affected products are in the factory, there is only a single instruction for logistics, namely to return all affected products back to the factory. After all the affected products are collected, then a decision as to whether they will be disposed, redirected for other use, downgraded, and reprocessed will be made. In contrast, preponement allows for disposition of affected products to be made while they are still with the customers. Therefore, only products that are to be reprocessed are brought back to the factory. Instead of making disposition based on the condition of the products (Blackburn et al., 2004), we make the determination of disposition timing based on the quantity of products held by customers and their location, making the assumption that there are disposition alternatives such as redirected for other use, downgraded and reprocessed. An illustration of the idea of postponement and preponement in this study can be seen in Fig. 2.

4. Recall process modelling

In this research the recall process to be modeled is a proactive recall. The edible oil industry has to do this because of external quality failures. Therefore, the recall in this study is categorized as incidental activity. Because the edible oil is stored only in one storage tank as a large batch size, this recall is considered a partial recall (Kumar, 2014). The modeling of the recall process involves only a dyadic relationship: between the processor and the industrial customer and/or distributor/-wholesaler (business-to-business), taxonomically referred to as trade recall (Bamgboje-Ayodele et al., 2016).

The disposition timing models aim to minimize the recall costs (RC) that a company must bear. These models involve four disposition alternatives: disposed, redirected for other use, downgraded, and reprocessed. There are two disposition timing models compared in this study: postponement and preponement. The conceptual models of the postponement and preponement can be seen in Fig. 3 and Fig. 4.

The basic idea for each optimization model is the transportation model. In postponement all products that have been distributed to customers are brought back to the factory. The disposition alternatives are determined after the product is in the factory. In preponement the disposition alternatives are determined when the products are still with the customers which means that not all products need to be collected.

In postponement when there is a recall announcement the affected products are immediately collected from customers and brought back to the factory. The affected products that reach the factory storage tank are then calculated, i.e. how much will be allocated for each disposition alternative. If the quantity of the affected product is greater than the capacity of the storage tank, the excess will be disposed.

Preponement allows the affected products to be kept by customers after the recall is announced. This means any storage cost is dealt with by each customer until a disposition alternative is determined. Ni et al. (2014) suggested that product exchange or replacement is a better remedy strategy for companies. In line with this, the current study considers product exchange as a form of compensation for the affected customers. However, it should be noted that this kind of compensation will increase the complexity of the product circulation. The technical differences between postponement and preponement models are tabulated in Table 2.

In addition to the fundamental assumptions in linear programming, the following assumptions are also considered in developing the mathematical models.

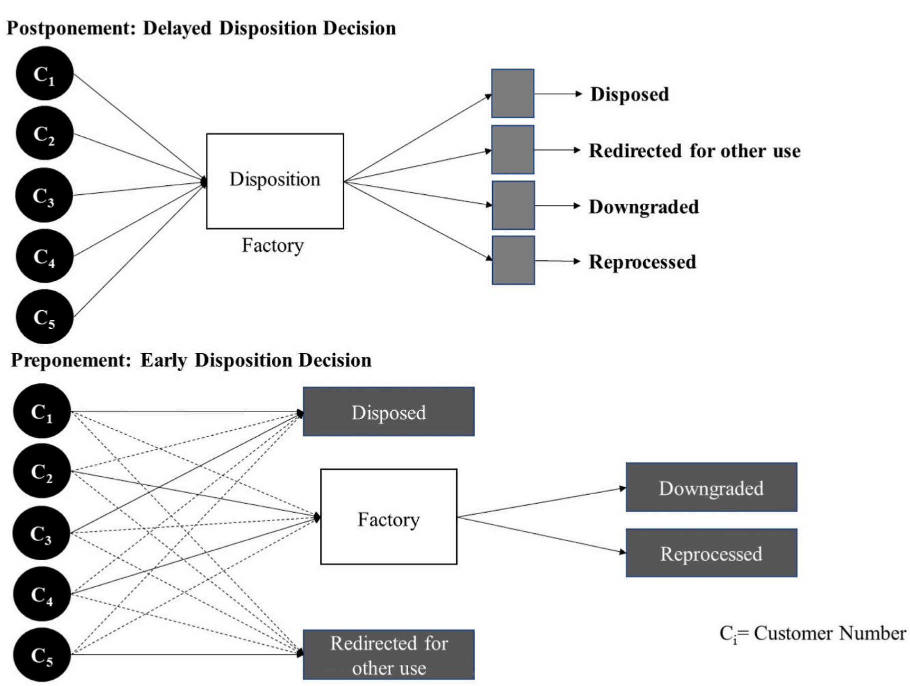

Fig. 2. Postponement and preponement decisions in food recall.

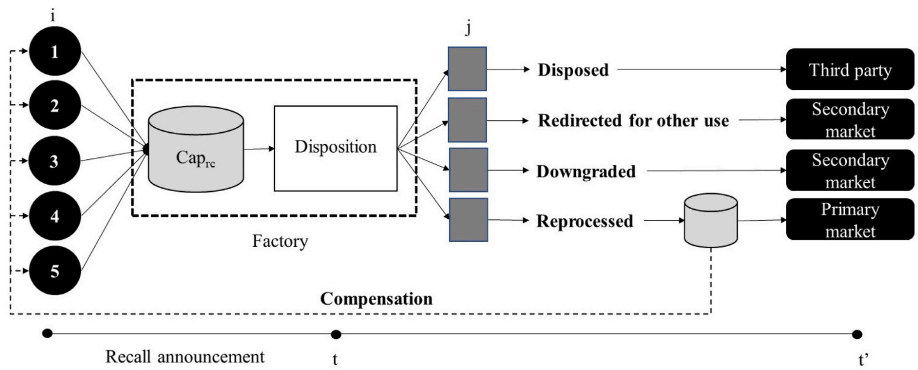

Fig. 3. The conceptual model of postponement in a bulk edible oil recall case.

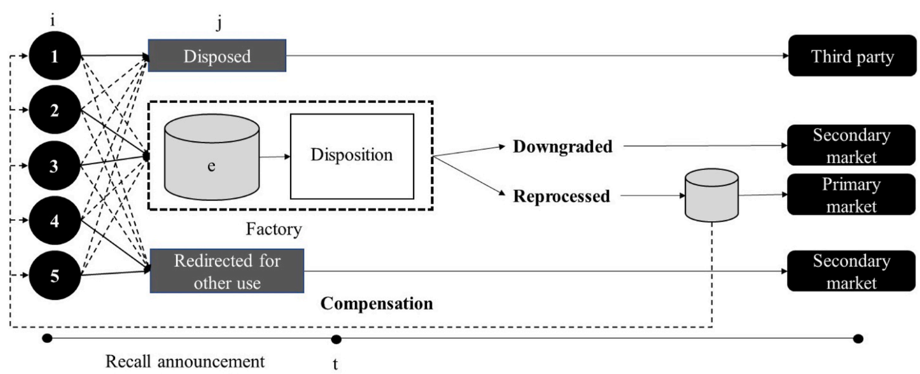

Fig. 4. The conceptual model of preponement in a bulk edible oil recall case.

Table 2
The difference between Postponement and Preponement operationally.

	Postponement	Preponement
When are the disposition alternatives determined?	Disposition alternatives are determined after all affected products have been in the factory.	Disposition alternatives have been determined for each customer before the affected product is brought back to the factory.
How is the treatment of the affected product?	All affected products are sent back to the factory.	Not all affected products from customers are sent back to the factory. Only affected products which are allocated for re-processed, downgraded, and redirected for other use are sent back to the factory.
How to manage the difference between the quantity of affected product and resource capacity or demand?	The difference between the quantity of affected product and the storage tank capacity will be disposed.	The difference between the allocated product for redirected for other use and the demand for redirected for other use products will be disposed.
How is the treatment of the affected product at the customer after the recall announcement?	All demands are sent from the factory so there is no storage at the customer.	The demand of redirected for other use products are sent directly from the affected customers so storage cost may be charged by the affected customer.

- Each disposition alternative (j) will only produce one type of product (j').
- The transportation cost used to deliver the remarketed product is borne by the customer in the selling price.
- The selling price for each type of product during the recall period does not change.
- Compensation is always done in period-1 (t' = 1).
- Product replacement for compensation is given according to the number of products purchased by the customer.
- Transportation costs from customer (i) to factory (f) and from factory (f) to customer (i) are the same.
- The initial quality of the affected product is the same as the reprocessed product (product 4) (j' = 4).
- The storage costs for materials and the finished product are the same.
- The yields of processing new material and reprocessing affected product are the same.
- Process and reprocess costs are the same.
- Processing and reprocessing costs are fixed during the recall period.
- There is no initial stock for the material.
- There is no backlog.
- For preponement there are only two disposition alternatives for the affected products from the same batch remaining in the factory (e): downgraded and reprocessed.
- The products stored by the customers are not mixed with other batches.
- The method of collection from the affected customers is out of consideration.
- All disposition alternatives can be applied to the type of food products under study.

4.1. The proposed model formulation

The mathematical model is written based on the scalar linear programming approach.

4.1.1. Indices

i = customers, i = 1, 2, …, I

j = disposition alternative, j = 1: disposed, 2: redirected for other use, 3: downgraded, 4: reprocessed

j' = products resulting from disposition alternative j, j' = 1, 2, 3, 4

t = disposition alternative period, t = 1, 2, …, T

t' = demand period, t' = 1, 2, …, T'

4.1.2. Parameters

a_i = quantity of product purchased by customer i (kilogram).

P_i = price of the product at the time customer i buys the product (IDR/kilogram).

$P_{j't'}$ = price of product j' in period t' (IDR/kilogram).

P_m = price of material (IDR/kilogram).

tr_{if} = transportation cost for transporting $a_i p_i$ from customer (i) to factory (f) (IDR).

tr_{fi} = transportation cost for transporting a_i from factory (f) to customer (i) (IDR).

pr = production cost (IDR/kilogram).

in_i = inspection cost for customer i (IDR/customer).

p_i = the percentage of product left with customer i (%).

H_f = holding cost at the factory (f) (IDR/kilogram/period).

H_i = holding cost at customer i (IDR/kilogram/period).

γ_{4t} = yield of processing or reprocessing product at period t.

t = disposition alternative period.

t' = demand period.

e = quantity of remaining products from the same batch as the affected batch (kilogram).

P_e = expected price of remaining products from the same batch as the affected batch (IDR/kilogram).

dc = disposal cost (IDR/kilogram).

$D_{j't'}$ = demand for product j' at t' (kilogram).

s_{40} = initial stock of the reprocessed product (product 4) at period 0 (before recall) (kilogram).

c_j = cost incurred by the disposition alternative j (IDR).

Cap_t^m = material capacity in period t (kilogram).

$Cap_{j'}^I$ = storage capacity for product j' (kilogram).

Cap_t^{pr} = production capacity in period t (kilogram).

Cap_{rc} = recall product storage capacity (kilogram).

M = a very large number as a penalty.

4.1.3. Decision variables

$M_{tt'}$ = quantity of material needed to be processed in period t to meet the demand in period t' (kilogram).

$s_{j't}$ = quantity of product stock in the storage tank for product j' in period t (kilogram).

4.1.4. Additional decision variables for postponement

$b_{jtt'}$ = proportion of products to be decided for disposition alternative j in period t to meet the demand in period t'.

L = difference between storage capacity and the quantity of affected product (kilogram).

4.1.5. Additional decision variables for preponement

$$X_{ijtt'} = \begin{cases} 1, & \textit{if the product recalled from customer i is decided to follow disposition alternative j} \\ & \textit{in period t to meet the demand in period } t' \\ 0, & \textit{otherwise} \end{cases}$$

$r_{jtt'}$ = the proportion of product remaining from the same batch that will be decided for follow-up j in period t to meet the demand in period t'.

$L_{t'}$ = difference between the quantity of product allocated for a disposition alternative: redirected for other use and the demand quantity of redirected-for-other-use product (kilogram).

4.2. Postponement model formulation

4.2.1. Objective function

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

with

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

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

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

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

4.2.2. Constraints

a. Production capacity

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

b. Material capacity

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

c. Storage capacity

$$\sum_{t=1|t<t'}^{T} b_{4tt'} \min\left(\sum_{i=1}^{I} a_i p_i + e; Cap_{rc}\right)\gamma_{4t} + \sum_{t=1|t<t'}^{T} M_{tt'}\gamma_{4t} + s_{4t'} \leq Cap^I_4, \forall t' = 2, \ldots, T' \quad (8)$$

d. Compensation and reprocessed product demand in period 1

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

e. Reprocessed product stock in period 1

$$b_{411} \min\left(\sum_{i=1}^{I} a_i p_i + e; Cap_{rc}\right)\gamma_{41} + M_{11}\gamma_{41} + s_{40} - \left(\sum_{i=1}^{I} a_i + D_{41}\right) = s_{41} \quad (10)$$

f. Reprocessed product demand after period 1

$$\sum_{t=1|t\leq t'}^{T} b_{4tt'} \min\left(\sum_{i=1}^{I} a_i p_i + e; Cap_{rc}\right)\gamma_{4t} + \sum_{t=1|t\leq t'}^{T} M_{tt'}\gamma_{41} + s_{4,t'-1} \geq D_{4t'}, \forall t' = 2, \ldots, T' \quad (11)$$

g. Reprocessed product stock after period 1

$$\sum_{t=2|t\leq t'}^{T} b_{4tt'} \min\left(\sum_{i=1}^{I} a_i p_i + e; Cap_{rc}\right)\gamma_{4t} + \sum_{t=1|t\leq t'}^{T} M_{tt'}\gamma_{41} + s_{4,t'-1} - D_{4t'} = s_{4t'}, \forall t' = 2, \ldots, T' \quad (12)$$

h. Downgraded product demand

$$b_{31t'} \min\left(\sum_{i=1}^{I} a_i p_i + e; Cap_{rc}\right) = D_{3t'}, \forall t' = 1, \ldots, T' \quad (13)$$

i. Redirected for other use product demand

$$b_{21t'} \min\left(\sum_{i=1}^{I} a_i p_i + e; Cap_{rc}\right) = D_{2t'}, \forall t' = 1, \ldots, T' \quad (14)$$

j. The quantity of affected product that cannot be accommodated

$$\sum_{i=1}^{I} a_i p_i + e - Cap_{rc} = L \quad (15)$$

k. Constraint to ensure that all affected products are allocated

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

l. Non-negative constraint

$$M_{tt'}, s_{j't}, b_{jtt'}, L \geq 0, \forall t, t', j, j' \quad (17)$$

The objective function of the postponement model consists of two components. The first component represents the costs that do not involve disposition alternatives: transportation costs for shipping compensation products; transportation costs to bring back the affected products to the factory; inspection costs; material costs; material processing costs; material storage costs; material costs of the initial stock; processing costs of the initial stock; potential revenue from selling the remaining products from the same batch as the affected product; storage costs for the remaining product from the same batch as the affected product; reprocessing cost of the remaining product from the same batch with affected batch recall; penalty for remaining stock at the end of the recall period (1). The second component represents the costs due to disposition of the affected products: disposed (2), redirected for other use (3), downgraded (4), and reprocessed (5). Constraint (6) represents the production capacity in each period to process new material and to reprocess the affected products. Constraint (7) represents the material capacity in each period to support the production process during the recall period, which can occur due to the limitation of supplier capacity or the limitation of material storage capacity. Constraint (8) is the storage capacity for the reprocessed product and it requires a new storage tank i.e. not using the same tank as the affected product. This storage tank is limited in capacity.

As stated in the assumptions, compensation should be given in period 1. In addition to compensation the reprocessed product is also used to fulfill demand. Constraint (9) expresses the fulfillment of compensation and demand in period 1. The quantity of remaining products in period 1 that will be stored as stock to be used in the next period is calculated by equation (10). After period 1 there is no compensation responsibility to be paid to the affected customers so constraint (11) is needed. Equation (12) is used to calculate the stock of reprocessed product from the remainder after period 1. Constraint (13) and (14) express the fulfillment of demand for downgraded product and redirected-for-other-use product. The idea of postponement is to bring all of the affected products back to the factory. If the remaining capacity of the storage tank in the factory is smaller than the quantity of the affected product, the excess will be disposed. Equation (15) is used to calculate the excess quantity. Constraint (16) ensures all of the affected products are allocated. Constraint (17) is the last constraint for ensuring the non-negative decision variables.

4.3. Preponement model formulation

4.3.1. Objective function

with

$$Min\ RC = \sum_{i=1}^{I} tr_{fi} + \sum_{i=1}^{I} in_i + \sum_{t=1}^{T}\sum_{t'\geq t}^{T'} M_{tt'}(P_m + pr) + \sum_{t=1}^{T}\sum_{t'\geq t}^{T'} M_{tt'}(t-1)H_f + s_{40}/_{\gamma_{41}}(P_m + pr) + eP_e + \sum_{t'=1}^{T'} r_{31t'}e(t'-1)H_f$$
$$+ \sum_{t=1}^{T}\sum_{t'\geq t}^{T'} r_{4tt'}epr + \sum_{t=1}^{T}\sum_{t'\geq t}^{T'} r_{4tt'}e(1-t)H_f \tag{18}$$
$$+ \sum_{t=1}^{T}\sum_{t'\geq t}^{T'} r_{4tt'}e\gamma_{4t}(t'-t)H_f + s_{3T'}M + s_{4T'}M + \sum_{j=1}^{4} c_j$$

$$c_1 = \left(\sum_{i=1}^{I} X_{i111}\, p_i a_i + \sum_{t'=1}^{T'} L_{t'}\right) dc \tag{19}$$

$$c_2 = \sum_{i=1}^{I}\sum_{t>1}^{T}\sum_{t'=t}^{T'} X_{i2tt'}a_i p_i (t-1)H_i - \sum_{t'=1}^{T'} D_{2t'}P_{2t'} \tag{20}$$

$$c_3 = \sum_{i=1}^{I}\sum_{t=1}^{T}\sum_{t'\geq t}^{T'} X_{i3tt'}tr_{if} + \sum_{i=1}^{I}\sum_{t>1}^{T}\sum_{t'\geq t}^{T'} X_{i3tt'}a_i p_i (t-1)H_i$$
$$+ \sum_{i=1}^{I}\sum_{t=1}^{T}\sum_{t'>t}^{T'} X_{i3tt'}a_i p_i (t'-t)H_f \tag{21}$$
$$+ \sum_{t'=1}^{T'} s_{3t'}H_f - \sum_{t'=1}^{T'} D_{3t'}P_{3t'}$$

$$c_4 = \sum_{i=1}^{I}\sum_{t=1}^{T}\sum_{t'\geq t}^{T'} X_{i4tt'}tr_{if} + \sum_{i=1}^{I}\sum_{t=1}^{T}\sum_{t'\geq t}^{T'} X_{i4tt'}a_i p_i pr + \sum_{i=1}^{I}\sum_{t>1}^{T}$$
$$\times \sum_{t'\geq t}^{T'} X_{i4tt'}a_i p_i (t-1)H_i + \sum_{i=1}^{I}\sum_{t=1}^{T}$$
$$\times \sum_{t'<t}^{T'} (X_{i4tt'}a_i p_i \gamma_{4t} + M_{tt'}\gamma_{41})(t'-t)H_f + \sum_{t'=1}^{T'} s_{4t'}H_f - \sum_{i=1}^{I}\sum_{t=1}^{T}\sum_{t'\geq t}^{T'} D_{4t'}P_{4t'} \tag{22}$$

4.3.2. Constraints

a. Production capacity

$$\sum_{i=1}^{I}\sum_{t'=1}^{T'} X_{i4tt'}a_i p_i + \sum_{t'=1}^{T'} M_{tt'} + \sum_{t'=1}^{T'} r_{4tt'}e \leq Cap_t^{pr},\ \forall t = 1, \ldots, T \tag{23}$$

b. Material capacity

$$\sum_{t'=1}^{T} M_{tt'} \leq Cap^{m}{}_{t}, \forall t = 1,\ \ldots,\ T \tag{24}$$

c. Storage capacity for downgraded product

$$\sum_{t=1|t<t'}^{T} x_{i3tt'}a_i p_i + \sum_{t=1|t<t'}^{T} r_{3tt'}e + s_{3t'-1} \leq Cap_3^I, \forall t' = 2, \ldots T' \tag{25}$$

d. Storage capacity for reprocessed product

$$\sum_{t=1|t<t'}^{T} x_{i4tt'}a_i p_i \gamma_{4t} + \sum_{t=1|t<t'}^{T} r_{4tt'}e\gamma_{4t} + s_{4t'-1} + \sum_{t=1|t<t'}^{T} M_{tt'}\gamma_{41} \leq Cap_4^I, \forall t' = 2, \ldots T' \tag{26}$$

e. Compensation and reprocessed product demand in period 1

$$\sum_{i=1}^{I} X_{i411}a_i p_i \gamma_{41} + M_{11}\gamma_{41} + s_{40} + r_{411}e\gamma_{41} \geq \sum_{i=1}^{I} a_i + D_{41} \tag{27}$$

f. Reprocessed product stock in period 1

$$\sum_{i=1}^{I} X_{i411}a_i p_i \gamma_{41} + M_{11}\gamma_{41} + s_{40} + r_{411}e\gamma_{41} - \left(\sum_{i=1}^{I} a_i + D_{41}\right) = s_{41} \tag{28}$$

g. Reprocessed product demand after period 1

$$\sum_{i=1}^{I}\sum_{t>1|t\leq t'}^{T} X_{i4tt'}a_i p_i \gamma_{4t} + \sum_{t=1|t\leq t'}^{T} M_{tt'}\gamma_{41} + s_{4,t'-1} + \sum_{t=1|t\leq t'}^{T} r_{4tt'}e\gamma_{4t} \geq D_{4t'},\ \forall t' = 2, \ldots, T' \tag{29}$$

h. Reprocessed product stock after period 1

$$\sum_{i=1}^{I}\sum_{t=2|t\leq t'}^{T} X_{i4tt'}a_i p_i \gamma_{4t} + s_{4,t'-1} + \sum_{t=2|t\leq t'}^{T} r_{4tt'}e\gamma_{4t} - D_{4t'} = s_{4t'}, \forall t' = 2,\ \ldots, T' \tag{30}$$

i. Downgraded product demand

$$\sum_{i=1}^{I}\sum_{t=1|t\leq t'}^{T} X_{i3tt'}p_i a_i + r_{31t'}e \geq D_{3t'}, \forall t' = 1, \ldots, T' \tag{31}$$

j. Downgraded product stock

$$\sum_{i=1}^{I}\sum_{t=1|t\leq t'}^{T} X_{i3tt'}a_i p_i + s_{3,t'-1} + r_{31t'}e - D_{3t'} = s_{3t'}, \forall t' = 1, \ldots, T' \tag{32}$$

k. Redirected for other use product demand

$$\sum_{i=1}^{I}\sum_{t=1|t=t'}^{T} X_{i2tt'}p_i a_i \geq D_{2t'}, \forall t' = 1, \ldots, T' \tag{33}$$

l. The quantity of disposed product

$$\sum_{i=1}^{I}\sum_{t=1|t=t'}^{T} X_{i2tt'}a_i p_i - D_{2t'} = L_{t'}, \forall t' = 1, \ldots, T' \quad (34)$$

m. A single disposition alternative for each customer

$$\sum_{j=1}^{4}\sum_{t=1}^{T}\sum_{t'=1}^{T'} X_{ijtt'} = 1, \forall i = 1, \ldots, I \quad (35)$$

n. Constraint to ensure that all product remaining from the same batch is allocated

$$\sum_{j=3}^{4}\sum_{t=1}^{T}\sum_{t'=1}^{T'} r_{jtt'} = 1 \quad (36)$$

o. The binary variable

$$X_{ijtt'} \in \{1, 0\} \quad (37)$$

p. Non-negative constraint

$$M_{tt'}, s_{j't}, r_{jtt'}, L_{t'} \geq 0, \forall t, t', j, j' \quad (38)$$

Similar to the objective function for the postponement model, the objective function for the preponement model also consists of two components: the costs that do not involve disposition alternatives (18) and the costs that are due to the disposition alternatives: disposed (19), redirected for other use (20), downgraded (21), and reprocessed (22). However, in preponement transportation costs to bring products back to the factory are categorized disposition alternative costs that will arise when the affected product is allocated as downgraded or reprocessed. In addition, the decision variable for the allocation of products recalled from customers and products from the same batch remaining in the factory is distinguished because the allocation of products recalled from customers is considered as a binary variable. Constraint (23) represents the production capacity in each period to process new material and to reprocess the affected product. Constraint (24) represents the material capacity in each period to support the production process during the recall period, which can occur due to the limitation of supplier capacity or the limitation of material storage capacity. Constraint (25) is the storage capacity for the downgraded product. Constraint (26) is the storage capacity for the reprocessed product. The downgraded product and reprocessed product are stored in different storage tanks. Constraint (27) expresses the fulfillment of compensation and demand in period 1. The quantity of remaining products in period 1 that will be stored as stock to be used in the next period is calculated by equation (28). After period 1 there is no compensation responsibility to be paid to the affected customers so constraint (29) is needed. Equation (30) is used to calculate the stock of reprocessed product from the remainder after period 1. Constraint (31) expresses the fulfillment of demand for the downgraded product. Equation (32) is used to calculate the stock of downgraded product. Constraint (33) expresses the fulfillment of demand for redirected-for-other-use product.

Table 3
Hypothetical data related to customer.

i	a_i (kg)	$tr_{fi/if}$ (IDR)	p_i	in_i (IDR)
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	4000	5,625,000.00	0.8	3,500,000.00
8	27,000	8,235,000.00	0.75	3,500,000.00

Any excess product to be redirected for other use will be disposed. Equation (34) is used to calculate the excess quantity. The idea of the preponement model is to assign the affected product from each customer to a single disposition alternative, so constraint (35) is used to ensure that the condition is fulfilled. Constraint (36) ensures all product remaining from the same batch as the affected batch is allocated to all disposition alternatives. Constraint (37) ensures the binary decision variable. Constraint (38) is the last constraint for ensuring the non-negative decision variables.

4.4. Additional equations related to the industry characteristics

4.4.1. Yield for reprocessed product

In the process industry there will be material lost during the production process which can be caused by material quality. The lower the quality of materials, the greater the loss of production is. Meanwhile, storage time affects the decrease in product quality. Therefore, the yield will never be 100%. The yield of the production process can be estimated using equation (39) that we propose from empirical studies by observing real data patterns.

$$\gamma_{4t} = \delta - \varepsilon . t \quad (39)$$

where.

γ_{4t} = yield when the affected product or new material is reprocessed or processed in period t

δ = constant which can be obtained from regression analysis or yield in period t = 1

ε = ratio of yield decreases over time

t = processing period.

4.4.2. Demand equation for reprocessed product and redirected-for-other-use product

Edible oil is categorized as a commodity product and has many substitute products so there is a strong relationship between price and demand. The real data pattern of price and demand that we observed, by removing the outlier demand due to, for example, seasonal variation, in the short term follows the general demand function proposed by Chen and Simchi-Levi (2004) with relatively small errors. Therefore, equation (40) is used to calculate the effect of product pricing on demand. This equation applies to reprocessed and redirected-for-other-use products because they have different markets.

$$D_{j't'} = \alpha - \beta_{j'} . P_{j't'} \quad (40)$$

where.

$D_{j't'}$ = demand for product j' in period t' (kilogram).

α = constant which can be obtained from regression analysis or $D^{max}_{j't'}$

$\beta_{j'}$ = conversion factor from price to demand for product j'

$P_{j't'}$ = the price of product j' in period t' (IDR/kilogram).

4.4.3. Demand equation for downgraded product

The demand for downgraded product is influenced by the downgraded product pricing (P_3) and the acceptance of customers for downgraded product (ρ). The price of downgraded product is always lower than the price of reprocessed product (P_4). Thus, this condition can be written as $P_4 > \frac{P_3}{\rho}$ or $P_3 < \rho P_4$. This phenomenon is identical to the demand function for selling a product through online channel versus offline channel stated by Widodo et al. (2011). In addition, the results of this model when validated with real data show relatively small errors. Thus, the demand for downgraded product ($D_{3t'}$) can be calculated by equation (41).

$$D_{3t'} = \frac{\beta_3 . (\rho . P_{4t'} - P_{3t'})}{\rho . (1 - \rho)} \quad (41)$$

where.

$D_{3t'}$ = demand for downgraded product in period t' (kilogram).

$P_{3t'}$ = downgraded product price in period t' (IDR/kilogram).

Table 4
Hypothetical data related to cost and price.

Cost (IDR)				Price (IDR)			
Pr	P_m	H_f	dc	P_e	P_{21}/P_{22}	P_{31}/P_{32}	P_{41}/P_{42}
500	7000	50	1000	10,000	5000	7000	10,000

Table 5
Hypothetical data related to demand.

Period 1			Period 2		
D_2	D_3	D_4	D_2	D_3	D_4
2000	20,000	100,000	2000	20,000	100,000

Table 6
Hypothetical data related to stock and capacity.

E	s_{40}	Cap^m_t	Cap^{pr}_t	$Cap^l_{j'}$	Cap_{rc}
5000	40,000	200,000	400,000	150,000	150,000

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

4.5. A numerical example

To illustrate how the postponement and the preponement models work a numerical example from a set of hypothetical data was calculated by using the proposed models. The numerical example involves eight randomly selected customers who are in various locations and with varying quantities of product purchased. The recall process is targeted to be completed in two periods following the company's procedure. Table 3 shows the number of products that must be recalled from each customer and the associated costs. Table 4 shows the parameters related to prices and costs. Table 5 shows the demand for each product in each period. Table 6 indicates the initial stock and the capacity. All hypothetical data is then converted as parameters in the mathematical models that have been developed for each respective decision. The mathematical models for the two decisions are solved using Lingo 11 and the optimal solutions are illustrated in Fig. 5 and Fig. 6.

The solution of the postponement model can be seen in Fig. 5. The minimum recall cost following the postponement model with hypothetical data is obtained if:

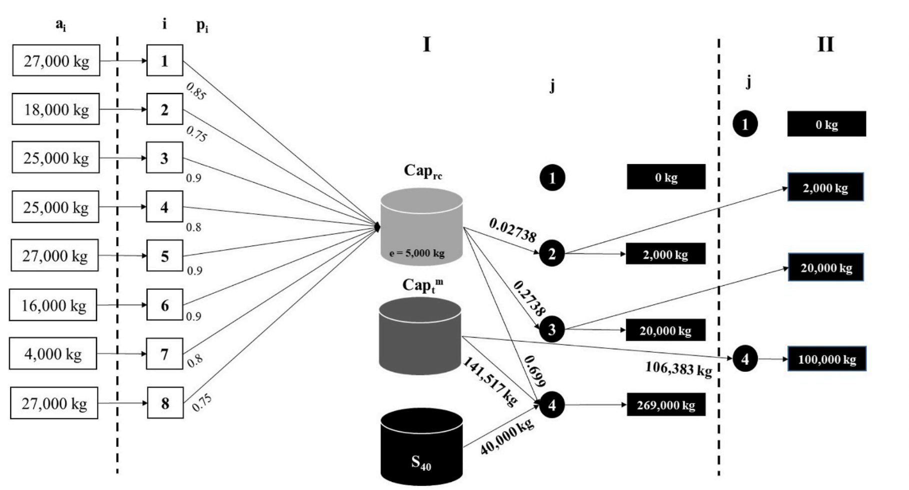

Fig. 5. Postponement model optimal solution.

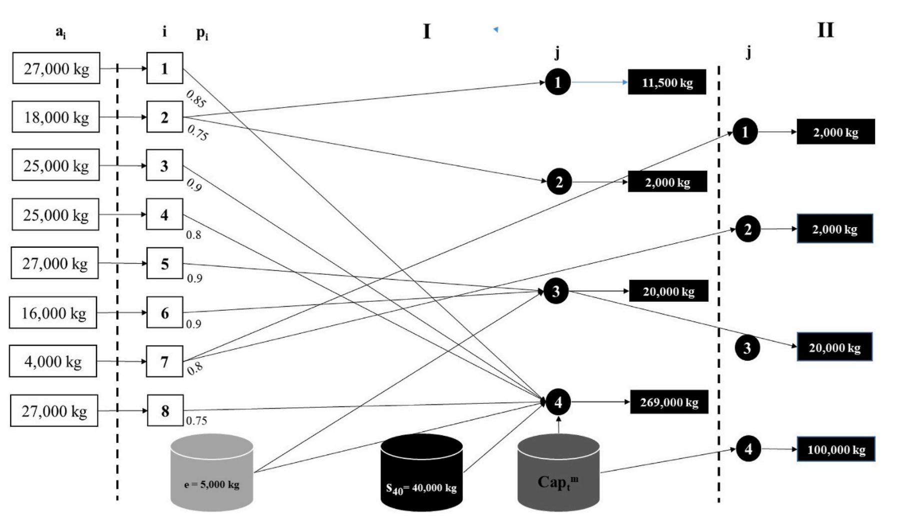

Fig. 6. Preponement model optimal solution.

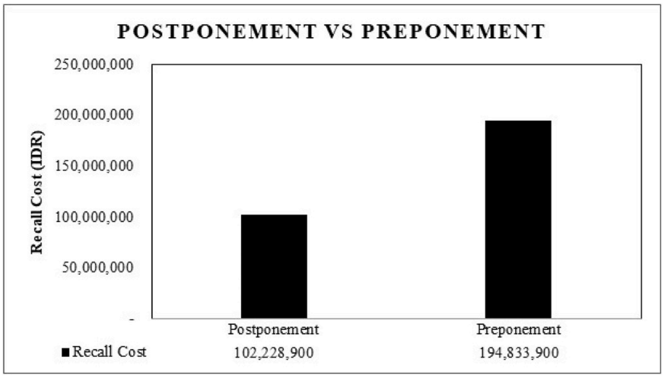

Fig. 7. A comparison of the total recall costs of the postponement and preponement decisions in the numerical example.

- 2.73% of the total affected product is redirected for other use in periods 1 and 2.
- 27.38% of the total affected product is downgraded in periods 1 and 2.
- 69.9% of the total affected product is reprocessed in period 1 and the shortage in period 1 is fulfilled with new material.
- Demand for reprocessed product in period 2 is fulfilled from new material.

The solution of the preponement model can be seen in Fig. 6. The minimum recall cost following the preponement model with hypothetical data is obtained if:

- Product recalled from customers 1, 3, 4, 8, and 74% of the remaining product from the same batch as the affected batch is reprocessed to meet demand in period 1. New material (154,217 kg) is added to cover the shortage.
- Product recalled from customer 2 is redirected for other use to meet the demand in period 1 and the rest will be disposed.
- Product recalled from customer 5 is downgraded to meet the demand in period 1 and the remainder is allocated to meet demand in period 2.
- Product recalled from customer 6 and 26% of the remaining product from the same batch as the affected batch is downgraded in period 1 to meet the demand in period 1 and 2.
- Product recalled from customer 7 is redirected for other use to meet demand in period 2 and the rest will be disposed.
- Demand for reprocessed product in period 2 is fulfilled from new material.

The total recall cost for the postponement model is IDR102,228,900

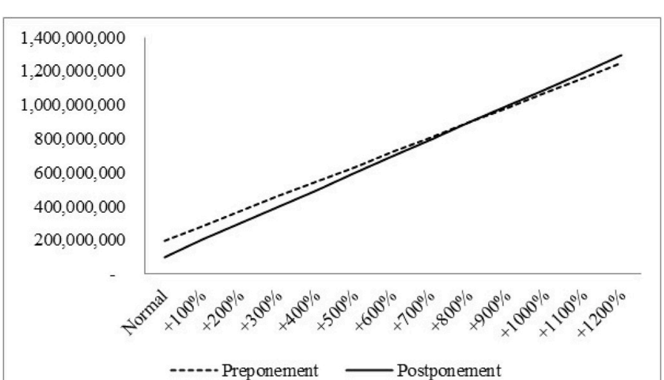

Fig. 8. Sensitivity analysis of the two decisions in the numerical example.

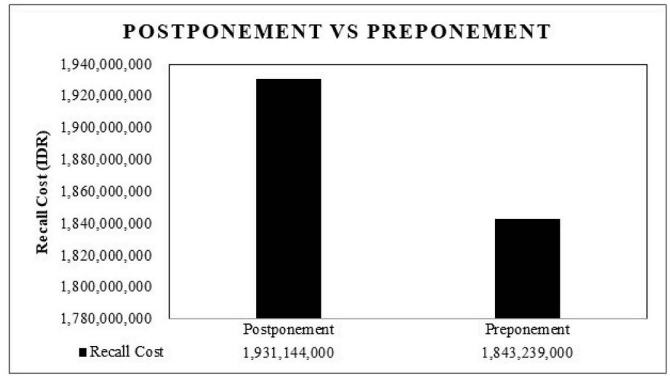

Fig. 9. A comparison of the total recall costs of the postponement and preponement decisions in the real case.

and the total recall cost for the preponement model is IDR194,833,900 (see Fig. 7). In the postponement model the storage tank capacity provided for the affected product is sufficient, whereas in the preponement model there is an amount of affected product that must be disposed.

However, postponement is not always better than preponement. Therefore, sensitivity analysis was carried out to investigate the behavior of the two models which was achieved by increasing the transportation costs. This analysis showed that at a certain point preponement will provide a lower recall cost than postponement (see Fig. 8). This finding indicates that when a product is distributed abroad, for example, preponement may incur a lower recall cost.

4.6. *A real case*

This study uses a real recall case from the edible oil industry in Indonesia in 2014. A customer's complaint regarding the out-of-specification color of coconut cooking oil (RBDCNO) resulted in a product recall. The complaint which was evidenced by retain sample testing led the company to recall its products. The rapid decline in the coconut cooking oil color quality was due to a failure in production testing when the supporting material, bleaching earth, was changed. This recall involved 24 customers that had bought the product.

The traceability data was processed and used as parameters in the model. Values of β_2, β_3, β_4 were sought through a trial and error process from historical data to get the expected demands ($D_{2t'}$, $D_{3t'}$, and $D_{4t'}$). The ρ value was set at 0.93 assuming 93% of customers will accept the 'downgraded' product. While the α value was the estimated highest demand that could be supplied for redirected-for-other-use product. Equations (42)–(44) are used to determine demand using market prices at the time of recall. Equation (45) is used to predict the yield of reprocessing affected product or processing new material. The time allocated for the completion of the recall (targeted recall time) was two periods, with each period consisting of five working days.

$$D_{4t'} = 350,000 - 25P_{4t'} \tag{42}$$

$$D_{3t'} = \frac{25.(0.93P_{4t'} - P_{3t'})}{0.93(1 - 0.93)} \tag{43}$$

Table 7
Decision recommendation based on quality recall size and transportation cost.

Indicator	Status	Decision Recommendation
Quantity of affected product	Higher that storage capacity	Preponement
	Lower than storage capacity	Postponement
Transportation cost	Low	Postponement
	High	Preponement

$$D_{2t'} = 75,000 - 25P_{2t'} \quad (44)$$

$$\gamma_{4t} = 0.943 - 0.003.t \quad (45)$$

The postponement and the preponement models sought the optimal solutions using Lingo 11. The result of the real case differs from that of the numerical example. In the real case using traceability data as a model parameter the recall cost is lower in the preponement. The total recall cost for the postponement is IDR 1,931,144,000 while the total recall cost for the preponement is IDR 1.843,239,000 (see Fig. 9). In the numerical example the postponement showed a lower recall cost. This result is in line with the finding of the sensitivity analysis in the numerical example. In the real case the product was distributed abroad.

The optimal solution proposed for the preponement model in the real case is that the recalled products from customers 7, 9, 11, 12, 17, 18, 23, and 24 are redirected for other use in period 1. Recalled products from customers 4, 8, 10, and 15 are redirected for other use in period 2. Recalled products from customers 4, 12, 21, and 7.6% of the remaining products from the same batch are downgraded in period 1.39.17% of the remaining product from the same batch is downgraded in period 2. Recalled products from customers 1, 2, 3, 5, 6, 13, 16, 19, 22, and 53.22% of the remaining products from the same batch are reprocessed in period 1 to meet demand and used as compensation for the affected customers.

5. Discussion

Blackburn et al. (2004) stated that postponement leads to an efficient reversed supply chain while preponement leads to a responsive reversed supply chain. However, this is not the case in this study as the models developed carry the concept of targeted recall time. The discussion emphasizes the determination of disposition timing that results in lower recall costs with an equal recall completion time. The advantage of postponement in this case is that coordination is less complex because there is only a single request from the logistics department. In contrast, preponement requires more complex coordination so that the chance of error is greater which may result in higher recall costs and the targeted time of recall not being met.

This study differs from others that focus only on reducing recall costs in cases of large-scale recall (Watanabe et al., 2018). If we assume the numerical example is a small-scale recall case and the real case is a large-scale recall case, a comparison of the postponement and the preponement models shows that the percentage difference in recall costs between the two models is greater in small-scale recall than in large-scale recall. Therefore, food recall needs to pay attention to the during-recall phase.

This study illustrates that transportation costs have a strong influence in determining disposition timing. This is in line with Ginantaka et al. (2015) that transportation costs are an important component in the during-recall phase. Based on the results of this study we recommend two indicators: the quantity of affected product and the cost of transportation. Preponement is more suitable if the quantity of affected product is greater than the available storage capacity and/or the transportation costs are high. Postponement is more suitable if the quantity of affected product is smaller than the available storage capacity and/or the transportation costs are low. The task for the company is to determine the threshold for transportation costs that is considered low or high because it will differ for each company. It is also necessary to consider the trade-off between transportation costs and the quantity of product that has to be disposed due to limited storage capacity. This recommendation can be seen in Table 7.

The use of postponement and preponement models in different cases needs to consider two things: the type of bulk food product involved and the typology of the supply chain. The postponement and preponement models proposed in this study require minor modifications when applied to different bulk food products. This is due to the different characteristics of the production process, the characteristics of the final product, and the shelf-life of bulk food products. If the production process involves new materials for the mixing process, the yield parameter (γ_{4t}) used in this model, especially the use of equation (40), needs to be adjusted. In addition, bulk food products that have solid characteristics, such as grain, powder, or crystals, are feasible to separate during storage. Thus, the Cap_{rc} parameter and equation (15) in the postponement model, which are based on the assumption that recalled products that exceed Cap_{rc} will be disposed, can be dropped from the model. Furthermore, for food products that have a short shelf-life, alternative dispositions need to consider time. Disposition alternatives such as downgrade or reprocessing may become infeasible over time so there is a dynamic decision as well. Finally, the developed model is able to provide optimal results as long as bulk product measurements are carried out continuously. However, if the product is calculated discretely, it is necessary to add new constraints to ensure optimal results.

Most bulk food products are traded with direct distribution channels or manufacturers selling directly to customers. Thus, disposition decisions are centralized and the manufacturer makes decisions for all disposition alternatives. However, if the bulk food product trade involves distributors or indirect distribution channels, disposition decisions may become decentralized. Manufacturers and distributors share the authority to make disposition decisions for nonconforming products. The disposition alternatives: reprocessed and redirected for other use can be executed by the manufacturer. Meanwhile, the disposition alternatives: downgraded and disposed can be carried out by distributors. Thus, the supply chain's typology demands modification of the model by adding parameters and indices. For example, previously there was only tr_{ip} as transportation cost for transporting a_ip_i from customer (i) to factory (f). The addition of distributors would add tr_{id} as transportation cost for transporting a_ip_i from customer (i) to distributor (d). Furthermore, recall capacity (Cap_{rc}) in the postponement model will be divided into factory capacity (Cap_f) and distributor capacity (Cap_d).

6. Conclusion

This study succeeds in modeling a recall process in the bulk edible oil industry. The two disposition timing models developed aim to minimize recall costs by optimizing product allocation for each disposition alternative. The results are compared to make the best decision about disposition timing. The models can be used in other bulk food industries such as sugar, grain, or wheat by making minor modifications. However, the concept of postponement and preponement in food recall decisions can only be generalized for trade recall. For consumer recall the remaining value of recalled products for reprocessing is often very small. In the postponement model disposition alternatives are determined after all products have been sent back to the factory. In the preponement model disposition alternatives are determined when the affected products are still with the customers. The results of the numerical example show that the postponement model produces lower recall costs than the preponement model. However, the preponement model resulted in a lower recall cost when a sensitivity analysis was carried out by significantly increasing transportation costs.

In the real case the two disposition timing models were processed using Lingo 11. Model parameters were obtained from the traceability data of the edible oil industry in Indonesia that recalled its same-batch product from 24 customers in 2014 due to the rapid decline in the coconut cooking oil quality. Preponement is better in this case because the product was distributed overseas with high transportation costs. These results provide an insight for decision makers in the edible oil industry when deciding on a trade recall. The models developed for the postponement and preponement extend the body of literature about recall modelling. This study also produces recommendations for determining postponement and preponement decisions based on the quantity of products affected and transportation costs.

The limitation of the two disposition timing models include that they have not considered seasonal changes in demand or potential demand uncertainty and only accommodate a recall process with a dyadic relationship. The computing time of the preponement model with certain parameters will take a long time (more than 48 h) so further research needs to develop models that accommodate stochastic parameters. Models that accommodate a recall process with a chain relationship or a network relationship could also be developed. To reduce the computational time a heuristic or a meta-heuristic approach for the preponement model is recommended. A more comprehensive sensitivity analysis of a real case using the models could also be a future research direction.

Authorship contributions

I. Gunawan: Conception and design of study, acquisition of data, analysis and/or interpretation of data, drafting the manuscript, and revising the manuscript critically for important intellectual content. I. Vanany: Conception and design of study, analysis and/or interpretation of data, drafting the manuscript, and revising the manuscript critically for important intellectual content. E. Widodo: Conception and design of study, analysis and/or interpretation of data, drafting the manuscript, and revising the manuscript critically for important intellectual content.

Declaration of competing interest

The authors have declared no conflict of interest.

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References

Alderson, W., 1950. Marketing efficiency and the principle of postponement. Cost Profit Outlook 3, 15–18.
Aung, M.M., Chang, Y.S., 2014. Traceability in a food supply chain: safety and quality perspectives. Food Control 39, 172–184.
Bakhtavoryan, R., Capps Jr., O., Salin, V., 2014. The impact of food safety incidents across brands: the case of the Peter Pan peanut butter recall. J. Agric. Appl. Econ. 46 (4), 559–573.
Bamgboje-Ayodele, A., Ellis, L., Turner, P., 2016. A food recall case study in Australia –Towards the development of food safety applications for consumers. Int. J. Food Stud. 5 (1), 84–94. https://doi.org/10.7455/ijfs/5.1.2016.a8.
Berman, B., 1999. Planning for the inevitable product recall. Bus. Horiz. 42 (2), 69–78.
Blackburn, J.D., Guide Jr., V.D.R., Souza, G.C., Van Wassenhove, L.N., 2004. Reverse supply chains for commercial returns. Calif. Manag. Rev. 46 (2), 6–22.
Byun, K.A.K., Duhan, D.F., Dass, M., 2020. The preservation of loyalty halo effects: an investigation of the post-product-recall behavior of loyal customers. J. Bus. Res. 116, 163–175.
Cao, R.Z., He, X.Y., Zhang, H., Wang, F.C., 2011. Establish trust from whole chain traceability. In: Proceedings of 2011 IEEE International Conference on Service Operations. Logistics, and Informatics (SOLI), pp. 325–330. https://doi.org/10.1109/soli.2011.5986579.
Charlebois, S., Von Massow, M., Pinto, W., 2015. Food recalls and risk perception: an exploratory case of the XL foods and the biggest food recall in Canadian history. J. Food Prod. Market. 21 (1), 27–43.
Cheah, E.T., Chan, W.L., Chieng, C.L.L., 2007. The corporate social responsibility of pharmaceutical product recalls: an empirical examination of US and UK markets. J. Bus. Ethics 76 (4), 427–449.
Chen, Y., Ganesan, S., Liu, Y., 2009. Does a firm's product-recall strategy affect its financial value? An examination of strategic alternatives during product-harm crises. J. Market. 73 (6), 214–226.
Chen, X., Simchi-Levi, D., 2004. Coordinating inventory control and pricing strategies with random demand and fixed ordering cost: the finite horizon case. Oper. Res. 52 (6), 887–896.
Cleeren, K., Van Heerde, H.J., Dekimpe, M.G., 2013. Rising from the ashes: how brands and categories can overcome product-harm crises. J. Market. 77 (2), 58–77.
Comba, L., Belforte, G., Dabbene, F., Gay, P., 2013. Methods for traceability in food production processes involving bulk products. Biosyst. Eng. 116 (1), 51–63.
Dai, B., Nu, Y., Xie, X., Li, J., 2020. Interactions of traceability and reliability optimization in a competitive supply chain with product recall. Eur. J. Oper. Res. 290 (1), 116–131.
Dai, H., Yang, N., Yan, N., 2015. A pricing strategy to align supply chain interests for product recall. In: 2015 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM). IEEE, pp. 285–289. https://doi.org/10.1109/ieem.2015.7385653.
Diallo, T.M., Henry, S., Ouzrout, Y., 2014. Using unitary traceability for an optimal product recall. In: IFIP International Conference on Advances in Production Management Systems. Springer, Berlin, Heidelberg, pp. 159–166.
Diallo, T.M.L., Henry, S., Ouzrout, Y., 2016. Effective use of food traceability in product recall. In: Advances in Food Traceability Techniques and Technologies. Woodhead Publishing, pp. 263–273.
Fan, J., Ni, D., Tang, X., 2015. Product recall decisions in supply chains under product liability. In: 2015 12th International Conference on Service Systems and Service Management (ICSSSM). IEEE, pp. 1–5. https://doi.org/10.1109/icsssm.2015.7170219.
Gao, J., Bansal, P., 2013. Instrumental and integrative logics in business sustainability. J. Bus. Ethics 112 (2), 241–255.
Ginantaka, A., Djatna, T., Arkeman, Y., 2015. An optimization of product recall cost for frozen milkfish in traceability system. Int. J. Innov. Manag. Technol. 6 (2), 122–125.
Guide Jr., V.D.R., Souza, G.C., Van Wassenhove, L.N., Blackburn, J.D., 2006. Time value of commercial product returns. Manag. Sci. 52 (8), 1200–1214.
Gunawan, I., Vanany, I., Widodo, E., 2017. The influence of traceability system practice to product recall capability in bulk food industry: observation and interview. In: Proceedings of the 2017. IEEE Industrial Engineering and Engineering Management, Singapore, pp. 1688–1692. https://doi.org/10.1109/ieem.2017.8290179.
Gunawan, Ivan, Vanany, I., Widodo, E., 2019. Cost-benefit model in improving traceability system: case study in Indonesian bulk-liquid industry. Supply Chain Forum Int. J. 20 (2), 145–157.
Gunstone, F.D., Martini, S., 2010. Chemical and physical deterioration of bulk oils and shortenings, spreads and frying oils. In: Chemical Deterioration and Physical Instability of Food and Beverages. Woodhead Publishing, pp. 413–438.
Hora, M., Bapuji, H., Roth, A.V., 2011. Safety hazard and time to recall: the role of recall strategy, product defect type, and supply chain player in the US toy industry. J. Oper. Manag. 29 (7), 766–777.
Hsu, L., Lawrence, B., 2016. The role of social media and brand equity during a product recall crisis: a shareholder value perspective. Int. J. Res. Market. 33 (1), 59–77.
International Organization for Standardization, 2005. Food Safety Management Systems-Requirements for Any Organization in the Food Chain. ISO 22000:2005.
Jabbarzadeh, A., Fahimnia, B., Sabouhi, F., 2018. Resilient and sustainable supply chain design: sustainability analysis under disruption risks. Int. J. Prod. Res. 56 (17), 5945–5968.
Kong, D., Shi, L., Yang, Z., 2019. Product recalls, corporate social responsibility, and firm value: evidence from the Chinese food industry. Food Pol. 83, 60–69.
Kumar, S., 2014. A knowledge based reliability engineering approach to manage product safety and recalls. Expert Syst. Appl. 41 (11), 5323–5339.
Law, A.M., Kelton, W.D., Kelton, W.D., 2000. Simulation Modeling and Analysis, vol. 3. McGraw-Hill, New York.
Li, T., Bernard, J.C., Johnston, Z.A., Messer, K.D., Kaiser, H.M., 2017. Consumer preferences before and after a food safety scare: an experimental analysis of the 2010 egg recall. Food Pol. 66, 25–34.
Liu, A.X., Liu, Y., Luo, T., 2016. What drives a firm's choice of product recall remedy? The impact of remedy cost, product hazard, and the CEO. J. Market. 80 (3), 79–95.
Lu, C., Zhang, Y., 2010. Reformation of voluntary food recall system from the angle of the theory of risk society. Agric. Agric. Sci. Procedia 1, 296–300.
Memon, M.S., Lee, Y.H., Mari, S.I., 2015. Analysis of traceability optimization and shareholder's profit for efficient supply chain operation under product recall crisis. Math. Probl Eng. 1–8.
Ni, J.Z., Flynn, B.B., Jacobs, F.R., 2014. Impact of product recall announcements on retailers′ financial value. Int. J. Prod. Econ. 153, 309–322.
Pagh, J.D., Cooper, M.C., 1998. Supply chain postponement and speculation strategies: how to choose the right strategy. J. Bus. Logist. 19 (2), 13–33.
Piramuthu, S., Farahani, P., Grunow, M., 2013. RFID-generated traceability for contaminated product recall in perishable food supply networks. Eur. J. Oper. Res. 225 (2), 253–262.
Pozo, V.F., Schroeder, T.C., 2016. Evaluating the costs of meat and poultry recalls to food firms using stock returns. Food Pol. 59, 66–77.
Richards, T.J., Nganje, W., 2014. Welfare effects of food safety recalls. Can. J. Agric. Econ. 62 (1), 107–124.
Saltini, R., Akkerman, R., 2012. Testing improvements in the chocolate traceability system: impact on product recalls and production efficiency. Food Control 23 (1), 221–226.
Schoder, D., Skandamis, P., Wagner, M., 2013. Assessing in-house monitoring efficiency by tracing contamination rates in cheese lots recalled during an outbreak of listeriosis in Austria. Int. J. Food Microbiol. 167 (3), 353–358.
Sezer, A.D., Haksöz, Ç., 2012. Optimal decision rules for product recalls. Math. Oper. Res. 37 (3), 399–418.
Souiden, N., Pons, F., 2009. Product recall crisis management: the impact on manufacturer's image, consumer loyalty and purchase intention. J. Prod. Brand Manag. 18 (2), 106–114.
Velthuis, A.G.J., Reij, M.W., Baritakis, K., Dang, M., Van Wagenberg, C.P.A., 2010. Recall costs balanced against spoilage control in Dutch custard. J. Dairy Sci. 93 (6), 2779–2791.
Watanabe, T., Kanno, T., Furuta, K., 2018. Social simulation for analyzing product recall systems using co-evolution model with price competition. J. Math. Syst. Sci. 8, 25–43.
Widodo, E., Takahashi, K., Morikawa, K., Pujawan, I.N., Santosa, B., 2011. Managing sales return in dual sales channel: its product substitution and return channel analysis. Int. J. Ind. Syst. Eng. 9 (1), 67–97.
Xin, L., Yanxia, S., Dinghui, W., 2015. Optimization of recall in food supply chain using modified artificial bee colony algorithm. In: 2015 34th Chinese Control Conference (CCC). IEEE, pp. 2581–2587. https://doi.org/10.1109/chicc.2015.7260035.
Yang, B., Burns, N., 2003. Implications of postponement for the supply chain. Int. J. Prod. Res. 41 (9), 2075–2090.
Yao, L., Parlar, M., 2019. Product recall timing optimization using dynamic programming. Int. J. Prod. Econ. 210, 1–14.
Zhao, X., Li, Y., Flynn, B.B., 2013. The financial impact of product recall announcements in China. Int. J. Prod. Econ. 142 (1), 115–123.