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Quality control of Dutch custard balanced against recall costs

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Abstract. The relation between the moment at which a recall of Dutch custard is initiated and the direct costs of this recall was investigated. A simulation model of the custard supply chain was developed to compare scenarios with and without a quarantine of 48 h at the storage of the production plant. The model consists of three parts; first the distribution of a 24,000 L batch of custard over the supply chain over time is simulated, second the time to detect spoilage bacteria with a recontamination test procedure is simulated, third the direct recall costs of custard over the different parts of the supply chain are calculated. Direct recall costs increase from about €25,000 per batch to €36,171 from 57 to 135 h in the situation without quarantine and from €25,000 to €36,648 from 123 h to 163 h for the situation with quarantine. Then costs decrease, because more and more custard is at the consumer level and only 0.13% of the consumers will ask for a refund. With low true contamination probabilities quarantine is not profitable, but at later detection moments with high probabilities it is. We conclude that a simulation model is a helpful tool to evaluate the efficiency of risk management strategies, like end-product testing and a quarantine situation.

Keywords: Quality control, milk quality, custard, recall, failure costs, recall costs

1. Introduction

Food business operators in the EU must not bring food to the market if it is unsafe (Article 14^[1]). If control during processing fails and unsafe food products have reached the market, these products must be withdrawn from downstream businesses and must be recalled from the consumer (Article 19^[1]). Food processors in the EU are responsible for recalls of unsafe food products and bear the financial consequences of the recalls, which can be quite significant^[2]. For public health, an early initiation of a recall is important, because it maximizes consumer protection from potential hazards and reduces the numbers of incidence of food-borne illnesses that can arise from consumption of the unsafe product.

Next to legally required recalls in case of unsafe food, companies can decide to recall their products in case of a quality deficiency that will not pose any health risk to the consumer, but may give rise to consumer complaints. We will call this defective food in this paper. A recall of defective food products aims to prevent market problems. The decision of a food processor to initiate a recall of defective food products depends on the costs of the recall, on the financial consequences of direct market problems that defective products create, and on the negative long term effects on profitability of the product and the related brands. Processors will not execute a recall if the costs outweigh the benefits.

Direct costs of a recall include costs for media announcements, transportation, warehousing costs, extra labor and destruction cost^[3, 4]. Indirect recall costs include reduced sales and revenues, a lower stock price in the capital market, costs incurred for brand rehabilitation, and crisis response expenses^[5]. Brand rehabilitation might be necessary to re-establish the reputation and market share of the affected product by investing in advertising campaigns, special promotions and consumer education. Crisis-response expenses include fees and expenses of outside consultants retained exclusively for the function of responding to the product contamination and recall. The indirect costs of a recall are hard to quantify^[6].

An early initiation of a recall minimizes indirect costs and helps to maintain consumer confidence^[7]. An efficient monitoring system, which is a continuous process of sampling and testing the product, the ingredients or the environment to control and guarantee the quality and safety of the food, can shorten the period between the detection of the problem and the execution of a recall^[8]. In addition, an effective traceability system, which provides data about the (previous) locations of food and food ingredients of

each batch along the production chain, can also shorten this period^[7, 9]. Finally, a smaller batch size, which is the quantity of products produced under uniform conditions, results in lower recall costs^[10]. Although due to economies of scale, the effect might be small.

The moment of detection of a problem is an important factor for the costs of a recall. However, the quantitative relation between this moment and recall costs has only recently received some attention and is still insufficiently understood. This relationship has only been quantified for spoilage of consumption milk, which is a simple product in terms of having one ingredient and only a few steps in the production process^[4]. Velthuis et al.^[4] did not focus on one food safety or food quality problem, and nor did she consider the detection speed of the monitoring program. In the current study we extend the existing knowledge by applying the simulation approach to spoilage of a more complex product, i.e. custard, and by including the detection speed of the monitoring program.

Dutch custard (or “vla” in Dutch) was chosen, because it is a homogeneous product with a limited number of ingredients and straightforward processing. Dutch custard is a sweet dairy dessert that can be poured from a pack with a viscosity similar to yoghurt. It is produced by mixing milk, sugar, flavors, colorants, and thickeners to form a liquid pudding. After mixing, the custard is pasteurized at a temperature of around 100°C to inactivate all bacteria, except for some thermophilic organisms and spores. The pasteurized product is stored for a limited period in silos and finally packed under aseptic conditions.

Microbial spoilage in sweet, non-acidified dairy products as custard, results either from Gram-positive bacteria which can survive pasteurization, or from any psychrophilic “cold-loving” Gram-negative bacteria which contaminate the product after the heat treatment. Most prevalent Gram-positive bacteria in dairy products are *Bacillus cereus*^[11, 12] and most prevalent Gram-negative bacteria are *Pseudomonas* species (*Pseudomonas* spp.).

Spoilage due to *Bacillus cereus* leads to sweet curdling and/or bitterness. However, because *Bacillus cereus* has a low growth rate under correct refrigeration conditions, spoilage due to *Bacillus cereus* does in general not occur before the use-by date of the product. Moreover, under correct refrigeration conditions, the level at which this bacteria may cause food borne illness is not reached. *Bacillus cereus* is therefore not considered to be a food safety hazard in Dutch custard.

Spoilage due to *Pseudomonas* spp. bacteria leads to the development of off-taste and off-odors. Under refrigerated and frozen conditions the growth rate of *Pseudomonas* spp. is much higher than the growth rate of Gram-positive bacteria. Consequently, the onset of spoilage is much earlier in packs contaminated with *Pseudomonas* spp. than in packs that contain Gram-positive bacteria only. The growth rate of *Pseudomonas* spp. can even result in spoilage before the intended use-by date. *Pseudomonas* spp. are not considered to be a food safety hazard, because the off-taste and off-odors are already very clearly present at a prevalence levels lower than that causes food borne illness. However, *Pseudomonas* spp. can be regarded as an indicator for any pathogenic or non-pathogenic heat-sensitive micro-organisms that have gained access to the product after the pasteurization step. For a dairy processor the main risk of *Pseudomonas* spp. contaminations is therefore not food safety but that the retail and consumers stop buying their custard. This study focuses on post-processing contamination with *Pseudomonas* spp. which originates from unclean lines or tanks downstream of the pasteurizer, the environment during filling, or defective packages.

To avoid the sale of products that are spoiled before the use-by date due to the presence of *Pseudomonas* spp., dairy companies implement rigid maintenance, cleaning and sanitation programs and monitor the microbiological quality of the final product, the so-called end-product testing. A further strategy is to implement a quarantine situation. In a quarantine situation, a batch of custard leaves the plant after the microbiological test results of that specific batch have shown no contamination. Eneroth et al.^[13] found that a quarantine period of 48 h is sufficient to identify a post-pasteurization contamination by *Pseudomonas* spp..

This paper aims to investigate the relation between the time at which the results of end-product testing become available and a recall may have to be initiated, and the direct costs of such a recall. We focus on the direct recall costs, because the mechanisms that determine the indirect recall costs are unknown and empirical information about these costs is lacking. We compare two scenarios: with and without a quarantine situation of 48 h.

2. Model description

The model consists of three parts; the first part simulates the distribution of a batch of custard over the supply chain over time (custard-supply-chain model), the second part simulates the time it takes to fulfill the recontamination test procedure to detect spoilage bacteria (end-product-testing model), and the third part calculates the direct recall costs of a batch of custard in each part of the supply chain (recall-cost model).

2.1. Custard-supply-chain model

The custard-supply-chain model simulates the amount of custard in each step in the supply chain at a certain moment in time. This model is a Monte Carlo simulation. It considers the flow of an average batch of Dutch custard in the supply chain from the production plant up to and including consumers (Figure 1). A batch is defined as all the packages produced and packed under similar conditions, containing the same unique identification code, which includes production-line number and use-by date.

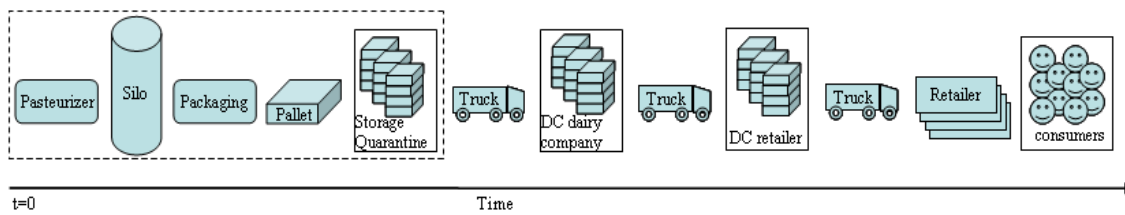


Figure 1. The Dutch custard production chain.

The stochastic variables of the model are the length of stay of each sub-batch of custard in each step in the chain. The length of stay is modeled with a triangular distribution described by a minimum value, a most likely value or mode and a maximum value^[14]. The triangular distribution is typically used as a description of an event for which there is limited data. A triangular distribution with its input based on expert opinion is a reasonable approximation of the actual value. The Monte Carlo simulation model was built in Microsoft Excel 2003 with the add-in program @Risk 4.5^[15].

The input values in Table 1 describe the distributions of each step in the supply chain. The values used in the calculations were determined with experts from a Dutch dairy cooperation. Monte Carlo simulation allows drawing for each sub-batch a time-value from the corresponding triangular distribution^[14]. For example, if the first number drawn from the triangular distribution that describes ‘filling the silo’ is 2.52, this means that the first silo with a content of 17,000 kilograms is filled in 2.52 h after the custard has passed the high pasteurization step.

The supply chain in our model starts after the pasteurization in the production plant at $t=0$ and ends at the moment the custard is consumed at the consumer’s home. The processing line before pasteurization is not considered since *Pseudomonas* spp. bacteria are effectively killed by pasteurization and the initial number of colony forming units at $t=0$ can therefore be assumed to be negligible.

The average batch size is 24,000 L. After pasteurization the custard is simultaneously pumped into two silos with each a capacity of 17,000 L which takes 2 to 3 h. So, to produce one batch of custard the contents of 1.4 silos are needed. The custard stays in the silos for between 5 to 7 h depending on the planning of the filling machines. Then the custard is pumped into filling machines in simulated sub-batches of 50 L where packages of the size of one L are filled. During the filling step four packages are filled simultaneously. It takes around 3 minutes to pump 50 L into the filling machine and fill the packages.

Once filled, the packages are moved to and put on a pallet. This procedure takes a few minutes. The moment the last package (i.e. package number 720) is put on a pallet, is used in the model as the starting time for moving this pallet to the cold storage. From this moment a new empty pallet is filled. The starting time for this second pallet to be moved to the cold storage is the moment package 1,440 is put on the pallet. This is repeated until all 6,000 packages are put on pallets. It takes around 8 minutes to move a full pallet to the cold storage. In total, 33 pallets and a third of a pallet are filled.

Table 1. Distribution characteristics of the length of stay, the number of L per draw and number of draws (based on a batch of custard of 24,000 L) of each distinguished step in the custard chain in the model

Steps in the Dutch custard chain	Distribution	Length of stay (h)			# L/draw	# draws
		Min	Mode	Max		
Filling the silo	Triangular	2.00	2.50	3.00	17,000.00	2
Storage in the silo	Triangular	5.00	6.00	7.00	50.00	480
Flowing from silo until filling machine	Triangular	0.01	0.05	0.08	50.00	480
Flowing from filling machine to pallet ¹	Triangular	0.05	0.06	0.22	4.00	6,000
Time until full pallet (720 packages) ²	time pallet = time last package on a pallet					
Moving full pallet to cold storage	Triangular	0.08	0.13	0.25	720.00	34
Storage in cold storage – without quarantine	Triangular	0.50	48.00	96.00	7,200.00	4
Storage in cold storage – with quarantine	Triangular	48.50	96.00	144.00	7,200.00	4
Time until a full truck (11 pallets) ³	time truck transport = time last pallet is available					
Transport from storage to DC ⁴ -dairy	Triangular	1.00	1.50	2.00	7,200.00	4
Storage in DC-dairy	Triangular	3.00	36.00	72.00	10,800.00	3
Transport from DC-dairy to DC retailer	Triangular	1.00	3.00	5.00	10,800.00	3
Storage in DC-retailer	Triangular	1.00	8.00	12.00	8,000.00	3
Transport from DC-retailer to retailer stores	Triangular	1.00	4.00	12.00	480.00	50
Storage in retailer store	Triangular	2.00	12.00	72.00	480.00	50
Storage at consumer until consumption ¹	Triangular	1.00	36.00	168.00	4.00	6,000

¹ In reality only two packages are filled simultaneously and consumers buy two packages on average. Assuming four packages are filled simultaneously and bought increases the speed of the simulations by reducing the number of draws from 12,000 to 6,000. A sensitivity analysis showed that this assumption did not change the results.

² or a multiplication as 1,440, 2,160, etc. until all 6,000 packages are on a pallet

³ or a multiplication as 22, 33, etc. until all 33 and one third of a pallet are on a truck

⁴ distribution centre

In the model we distinguish between two options for the dairy company. First, in the situation without quarantine the dairy company moves the products further in the chain even if test results are not available. Second, in a situation with quarantine, most batches of products leave the plant after the test results of that specific batch have shown no contamination. We assume a quarantine period of 48 h, because this should be sufficient to identify a possible post-pasteurization contamination by *Pseudomonas* spp. (Eneroth et al., 1998). Pallets stay in the cold storage between 30 minutes and 96 h for the no-quarantine situation, and between 48 h and 144 h in the quarantine situation.

After the cold storage, the batch is transported with four trucks, together with batches of other products to the distribution center of the dairy company (DC-dairy). We assume that the first three trucks each carry 11 pallets of this batch and the fourth truck one third of a pallet of this batch. Each drive takes between 1 and 2 h.

The pallets stay in the DC-dairy between 3 h and 3 d, before being transported to the DC of the retailers' organization (DC-retailer). Until the moment that a truck with the custard leaves the DC-dairy the dairy company is responsible for the custard. If this moment exceeds 8 d (or 192 h) the retailer will reject the (sub) batch and the custard will be destroyed.

The batch of custard is transported with three trucks, of which the first two trucks each carry 15 pallets and the last truck 3.3 pallets. Each drive takes between 1 and 5 h, depending on the location of the DC-retailer and the traffic. After arriving at the DC-retailer, the pallets stay there for 1 to 12 h. Then the batch is divided over 50 retailer trucks, each carrying 480 L of custard of the batch to a specific supermarket (next to other items). Each drive takes between 1 and 12 h.

Once the custard has arrived in a supermarket, it is sold between 1 h and 3 d. Each consumer buys 4 packages which are assumed to be consumed between 1 h and 7 d after purchase.

The custard-supply-chain model predicts the amount of custard in each step in the supply chain at the moment a recall is initiated. This moment is defined the 'recall moment' and it is presented with t , the number of h after the moment at which the first custard leaves the high pasteurization ($t=0$). The distribution of the amount of custard in each step in the supply chain is simulated with 1,000 recalls of custard batches. This distribution is used to calculate the direct recall costs per step and of the whole supply chain.

2.2. End-product-testing model

In the end-product-testing model the time to detect a contamination with *Pseudomonas* spp. in a batch of custard is simulated and the probability of detection given a true probability of contamination is calculated. Figure 2 provides the assumed test protocol. Of the final product 16 packs are taken randomly from the production line while they are put on a pallet to be tested for the presence of *Pseudomonas* spp.. The 16 packages are stored in a refrigerator at $<7^{\circ}\text{C}$ at the production site until 09:00 next morning when they are transported to an external lab. When production is on Saturday the packages remain in the refrigerator an additional 24 h until the packages are transported Monday morning. The storage time in the refrigerator has a uniform distribution over 1 to 24 h, supplemented with a binomial distribution with a probability of 1 in 7 for an additional 24 h for products produced on Saturday.

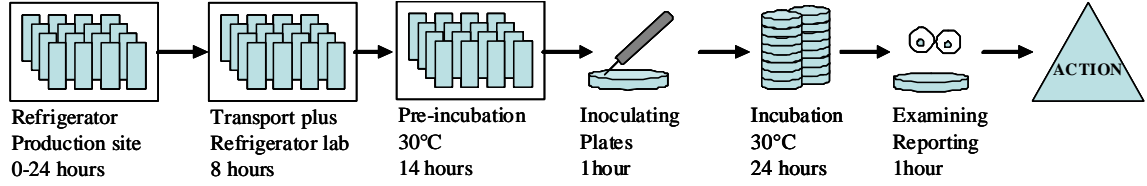


Figure 2. Protocol for sampling, testing and evaluating the end product for *Pseudomonas* spp..

In the lab the packages are stored in a refrigerator at $<7^{\circ}\text{C}$ for 8 h until the end of the working day at 18:00 h, when they are placed into a 30°C incubator for a fixed pre-incubation period of 14 h. Pre-incubation allows any micro-organism that may have contaminated the package to multiply to numbers that can be detected in the next step. The packages are left in the incubator for one h until the lab staff starts working at 9:00 am. After opening the pre-incubated packages, 50 μl of each package is inoculated onto agar plates with a medium that is selective for Gram-negative bacteria, followed by incubation at 30°C and reporting of the results to the factory. Inoculation, incubation, and reporting require 1, 24, and 1 h respectively and are assumed to be fixed. The time between reporting to the quality assurance manager and taking action in case of a recall has a triangular distribution and is assumed to be between 0 and 3 h, with a most likely value of 0.5 h.

2.3. Probability to detect contamination

The probability to detect at least one contaminated package of custard $\Pr(PS \geq 1)$, given a certain fraction of products in a batch that are truly contaminated, the so-called true contamination probability $\Pr(cont)$, and a number of samples taken n (i.e. 16 packages per batch) is calculated as:

$$\Pr(PS \geq 1) = 1 - (1 - \Pr(cont))^n \quad (1)$$

We assume that a recall will be performed if two or more samples are tested positive in the end-product test ($\Pr(PS \geq 2)$). It is calculated as:

$$\Pr(PS \geq 2) = \Pr(PS \geq 1) - \Pr(PS = 1), \quad (2)$$

where

$$\Pr(PS = 1) = n \cdot \Pr(cont) \cdot (1 - (1 - \Pr(cont)))^{n-1}, \quad (3)$$

in which $\Pr(PS = 1)$ is the probability of detecting exactly one positive sample. For the analysis $\Pr(cont)$ is varied over the range of 0.005 to 0.100 to reflect both the normal situation where incidental post-processing re-contamination occurs and the rare situations where bio-films cause contamination of a large percentage of the packages.

2.4. Calculation of the recall costs

The direct recall costs are calculated following the partial budgeting approach. This approach is based on the principle that a small change in the supply chain can eliminate or reduce some costs, eliminate or reduce some returns, cause additional costs to be incurred and cause additional returns to be received. The net effect of the change, in our case the recall, is the sum of the positive financial impact minus the sum of the negative financial impact^[16]:

$$NC_r = AC_r + RR_r + RC_r + AR_r, \quad (4)$$

where NC_r are the net costs of the recall, AC_r the additional costs, RR_r the reduced returns, RC the reduced costs and AR_r the additional returns in the whole supply chain.

The additional costs AC_r include various activities and are given by:

$$\begin{cases} AC_r = \sum_i (T_i + D_i + R_i + C_i) \cdot BS_i + \sum_j I_j + \sum_k L_k & \text{if } BS_{tr2} < 0 \text{ and } t \leq 600 \\ AC_r = \sum_i (T_i + D_i + R_i + C_i) \cdot BS_i + \sum_j I_j + \sum_k L_k + MA + RF & \text{if } BS_{tr2} \geq 0 \text{ and } t \leq 600 \\ AC_r = \sum_j I_j & \text{if } t > 600 \end{cases}, \quad (5)$$

where T are the transportation costs including the warehousing costs, D the destruction costs of the packed custard, R the fee to pay a feed company for re-using the unpacked custard, C the cleaning costs of the production lines including labor and BS_i the amount of the recalled batch that is located in the i^{th} step in the chain (see Table 1). The additional inspection costs I differ between internal, third party and governmental inspections, indicated by j . The extra labor L within the dairy company depends on task k : handling the recalled products, crisis management and labor for the consumer care line. We assume that the moment the first truck leaves the DC-dairy to the DC-retailer, indicated by BS_{tr2} , the recall becomes public and additional costs occur. The additional costs include the costs MA of a media announcement and the costs RF of refunds the consumers who bought a package of the recalled batch. If t exceeds the expiration date (which is 25 d or 600 h after pasteurization) only the costs of additional inspections remain.

The costs MA are based on criteria of the Dutch Food and Consumer Product Safety Authority of advertisements in at least two national newspapers, an official press release and an announcement on the website of the producer, and are calculated as:

$$MA = PR + (pr_{ad} \cdot Ads) + Others, \quad (6)$$

where PR are the costs for the dairy company to hire an external public relation specialist who makes the advertisements and a press release for €300, pr_{ad} are the costs of placing an advertisement in a national paper, Ads the number of advertisements in national newspapers, and $Others$ the costs of sending the press release to customers, governmental organizations and for the announcement on the producer's website.

The costs RF include the price of a postage stamp (pr_{stamp}) and the consumer price of a package of custard (pr_{cons}), multiplied by the percentage of consumers that returned barcodes of packages from the recalled batch ($cons$) and the amount of custard that is sold to consumers and not consumed (BS_{cons}):

$$RF = (pr_{stamp} + pr_{cons}) \cdot cons \cdot BS_{cons} \quad (7)$$

Only a few packages are usually sent back in case of a public recall. Based on a former recall, where 20 barcodes out of 15,000 were sent back, we assumed that 0.13% of packages bought are returned for a refund ($cons$).

The reduced returns RR_r of the dairy company include the forgone returns of the custard that replace the recalled batch that was recalled at the retailers. The reduced returns equal the price ($pr_{retailer}$) the dairy company receives from the retailer:

$$RR_r = pr_{retailer} \cdot BS_{retailer} \quad (8)$$

The reduced costs RC_r of the dairy company are the costs that do not have to be made in the rest of the chain for the part of a recalled batch that is still located somewhere in the supply chain. For example, custard of a recalled batch that is still located in the storage of the production plant at the initial moment of a recall does not have to be shipped to and stored in the DCs of the dairy company and retailer. These costs are the difference between the cost price of the product $CostPr$ of the end product in the supermarket and the costs $CostPr_i$ made until step i :

$$RC_r = \sum_i (CostPr - CostPr_i) \cdot BS_i \quad (9)$$

We assumed that there are no additional returns AR_r when recalling a batch of custard. Although the recalled custard can be used for the production of animal feed. Depending on the market of feed materials, the dairy company may receive additional returns for the batch from the feed producer. In this study we assumed that the dairy company has to pay the feed producer to reuse the spoiled batch. Furthermore, we assumed that the dairy company has no recall insurance and receives no insurance payments.

Table 2 gives the values of the different input variables for the economic model. The data have been assessed in cooperation with a Dutch dairy cooperation.

Table 2. Description and values of the values of the variables in the Net costs calculations of the recall costs of one batch of custard

Variable	Description	Value	Specifications
T_i	Transportation costs and warehouse costs (€/L)	0.05	All steps until consumer
D_i	Destruction costs of packed custard (€/L)	0.05	All steps after filling machine and before consumer
R_i	Fee to pay feed company to re-use unpacked custard (€/L)	0.03	All steps before filling machine
L_i	Cleaning costs	0.0083	Pipes before silo and silo
		0.0170	From silo until filling machine
I_j	Extra inspections (€/recall)	200	Internal
		300	Third party
		300	Governmental
L_k	Extra labor (€/L)	0.0125	All steps until consumer
PR	Costs for public relation specialist (€/recall)	300	
pr_{ad}	Costs placing advertisement in national journal (€/ad)	6,000	
Ads	Number of advertisements placed (#)	2	
$Others$	Other costs of external communication (€/recall)	1,000	
Pr_{stamp}	Price of postage stamp (€/stamp)	0.44	
Pr_{cons}	Consumers' price of custard (€/L)	1.15	
$cons$	Percentage of consumers asking for a refund	0.13%	
$Pr_{retailer}$	Retailers' price of custard (€/L)	0.90	
$CostPr$	Cost price of custard (€/L)		
$CostPr_i$	Cost price of custard (€/L)	0.411	Until filling storage tank
		0.422	Until storage tank
		0.506	Until filling machine
		0.527	Until palletizer
		0.558	Until storage
		0.600	Until DC1

The recall cost per average batch of custard produced (ARC) shows how much failure costs due to spoilage should be taken into account when producing custard. The ARC is calculated by multiplying the total recall costs (NC) of a recalled batch by the probability that a recall will be performed, i.e. if two or more samples are tested positive in the end-product test ($\Pr(PS \geq 2)$):

$$ARC = NC \cdot \Pr(PS \geq 2) \quad (10)$$

2.5. Calculation of costs for applying a quarantine situation

The net costs of applying a quarantine situation are calculated following the partial budgeting approach:

$$NC_q = AC_q + RR_q + RC_q + AR_q, \quad (11)$$

where NC_q are the net costs, AC_q the additional costs, RR_q the reduced returns, RC_q the reduced costs and AR_q the additional returns if applying a quarantine situation compared to a situation without quarantine.

The additional costs (AC_q) of a quarantine situation include the costs of building or renting additional storage space and maintenance of this space (BC), cooling of the additional storage space to 4°C (CC), and additional labor costs (L_q):

$$AC_q = BC + CC + L_q \quad (12)$$

The reduced return (RR_q) of a quarantine situation equal the lower retailer's price because of a reduced shelf life of two days ($\Delta pr_{retailer}$):

$$RR_q = \Delta pr_{retailer} \quad (13)$$

There are no reduced costs (RC_q) for applying a quarantine situation, whereas the additional returns (AR_q) equal the reduction of the ARC due to the quarantine situation $ARC_{quarantine}$ as compared to the non quarantine situation $ARC_{no_quarantine}$:

$$AR_q = ARC_{no_quarantine} - ARC_{quarantine} \quad (14)$$

Table 3 provides the data for calculation of the net costs of applying a quarantine situation compared to a non-quarantine situation.

Table 3. Input values for the calculation of the additional costs of a quarantine situation

Description	Variable	€/batch	€/L
Cost of extra storage space	BC	€ 6.67	€ 0.001
Maintenance extra storage	BC	€ 0.33	€ 0.001
Cooling to 4°C	CC	€ 2.00	€ 0.001
Labor	L_q	€ 150.00	€ 0.001
Reduction in retailer's price	$\Delta pr_{retailer}$	€ 240.00	€ 0.01

3. Results

3.1. Custard-supply-chain model

Figure 3 shows the distribution of one batch of custard over the supply chain in a situation without quarantine. Until 71 h after pasteurization the whole batch was at the dairy company. If the recall moment was before 71 h, it thus concerns an internal recall. One or more packages of a batch were at the retailer level between 71 and 275 h after pasteurization (3.0 - 11.5 d). The first package was bought by a consumer at 90 h and the last package at 431 h (3.8 - 18.0 d) after pasteurization. The first custard was consumed at 97 h (4.0 d) and the last custard at 432 h after pasteurization (18.0 d).

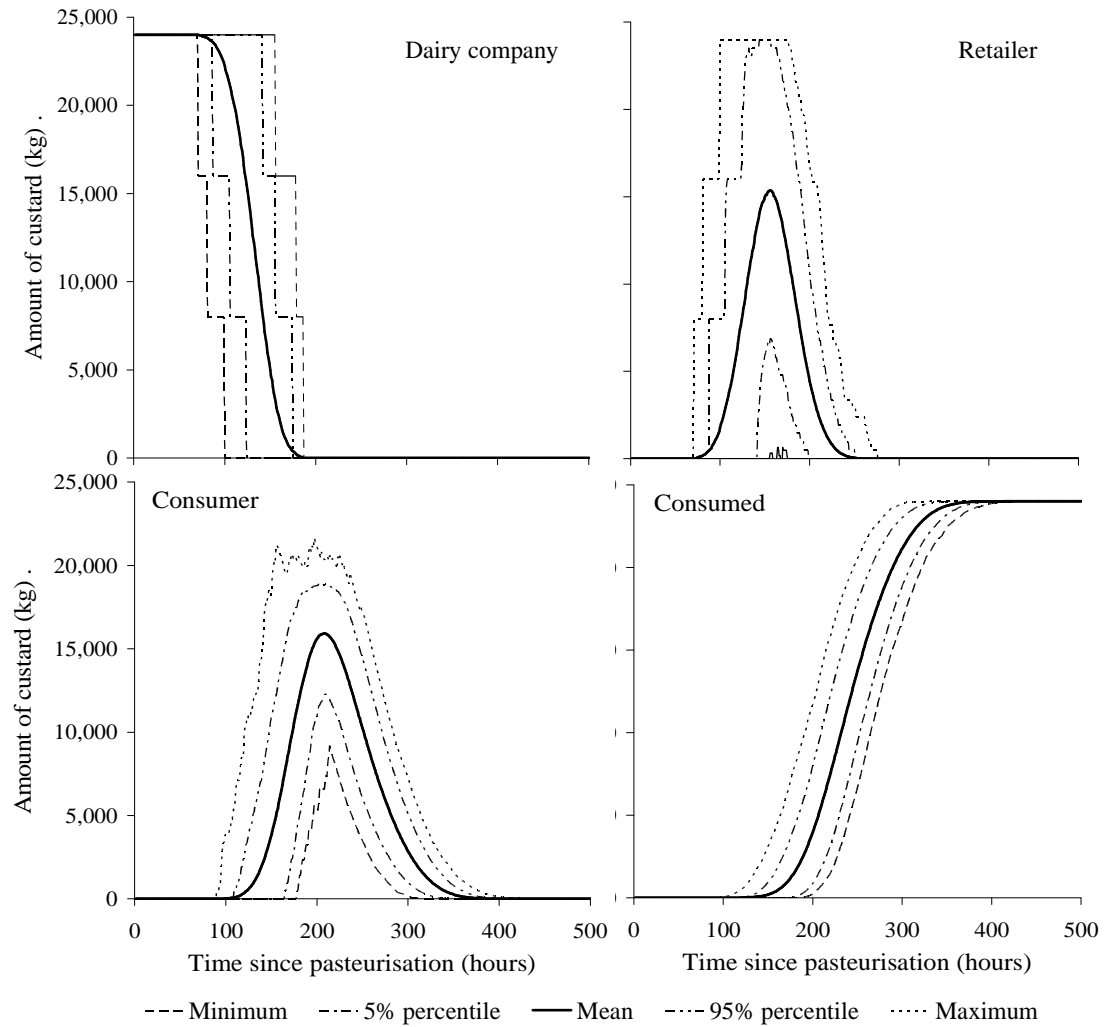


Figure 3. Location of the amount of custard of one batch (24,000 kg) over the supply chain in a situation **without** quarantine. Top left panel: dairy company stage, including the production site, transport and DC of the dairy company; top right panel: retailer stage, including de DC of the retailer, transport and stores; bottom left panel: the consumer stage; and bottom right: the consumed amount of custard.

In a situation with quarantine the flow of custard through the chain is delayed at the production plant of the chain (Figure 4). The whole batch was at the dairy company level until 115 h after pasteurization (4.8 d). With quarantine the packages of custard remained shorter at the retailer level compared to the non-quarantine situation: between 115 and 274 h (4.8 – 11.4 d), and also remained shorter at the consumer level: between 134 and 433 h (5.6 – 18.0 d). The first package of custard was consumed at 138 h after pasteurization (41 h later than in the non-quarantine situation), whereas the last custard was consumed at 433 h after pasteurization (18.0 d). This is before the end of shelf life of 600 h after pasteurization.

3.2. End-product-testing model

The minimum time to detect a contamination based on end-product-testing varies between 50.1 and 98.8 h with a mean value of 65.9 h (5% and 95% percentiles were 52.3 and 90.0 h respectively). The differences are due to the fact that samples collected on Saturday are sent to the lab on Monday and due to the time the packages are stored in the fridge.

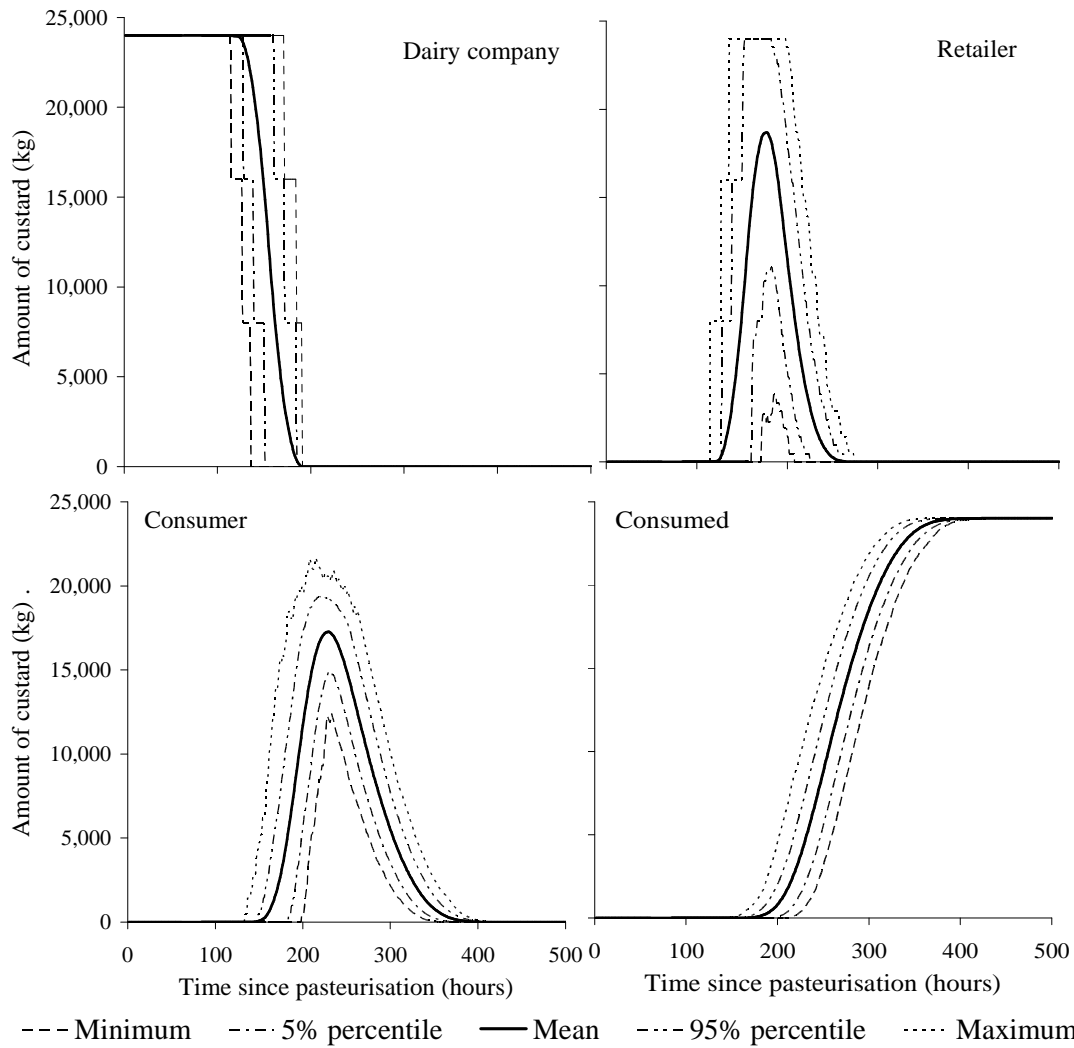


Figure 4. Location of the amount of custard of one batch (24,000 kg) over the supply chain in a situation **with** quarantine. Top left panel: dairy company stage, including the production site, transport and DC of the dairy company; top right panel: retailer stage, including de DC of the retailer, transport and stores; bottom left panel: the consumer stage; and bottom right: the consumed amount of custard.

3.3. Probability to have a recall

The probability of a recall $\Pr(PS \geq 2)$ increases with the true contamination level $\Pr(cont)$ (Figure 5). If the true level of contamination is low (e.g. 0.005; 120 out of 24,000 packages contaminated) the probability to detect two or more positives and consequently to conduct a recall is low (0.003). This probability is 36 times higher (0.189) if the true level of contamination is tenfold higher (0.050; 1200 out of 24,000 packages), and is 161 times higher (0.485) if the true level of contamination is twentyfold higher (0.200; 4800 out of 24,000 packages).

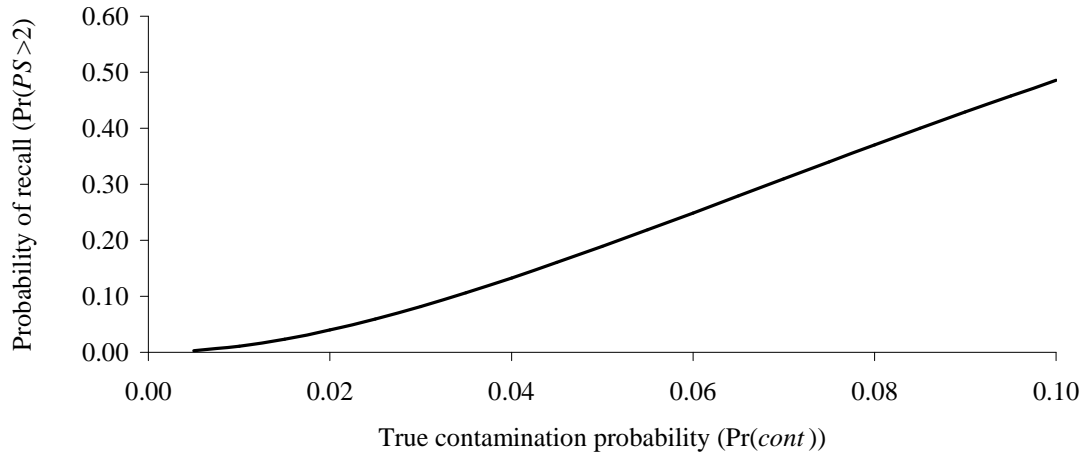


Figure 5. The probability of a recall $\Pr(PS \geq 2)$ related to the true contamination probability with *Pseudomonas* spp. $\Pr(cont)$.

3.4. Net recall costs

The net recall costs of a contaminated batch of custard (NC_r) depend on the recall moment as illustrated in Figure 6 for a situation without quarantine and in Figure 7 for a situation with quarantine. Net recall costs are around €21,000 if the recall moment is within 9 h after pasteurization. If the recall moment is 9 h or more after pasteurization the net recall costs are higher, because from 9 h onwards some of the custard has been packaged and cleaning of the packaging line requires a lot of labor. However, since contamination is detected by the end-product test and test results are with 90% certainty available from 52.3 to 90.0 h after pasteurization, the recall moment can only be in the interval as indicated with the grey areas in Figures 6 and 7.

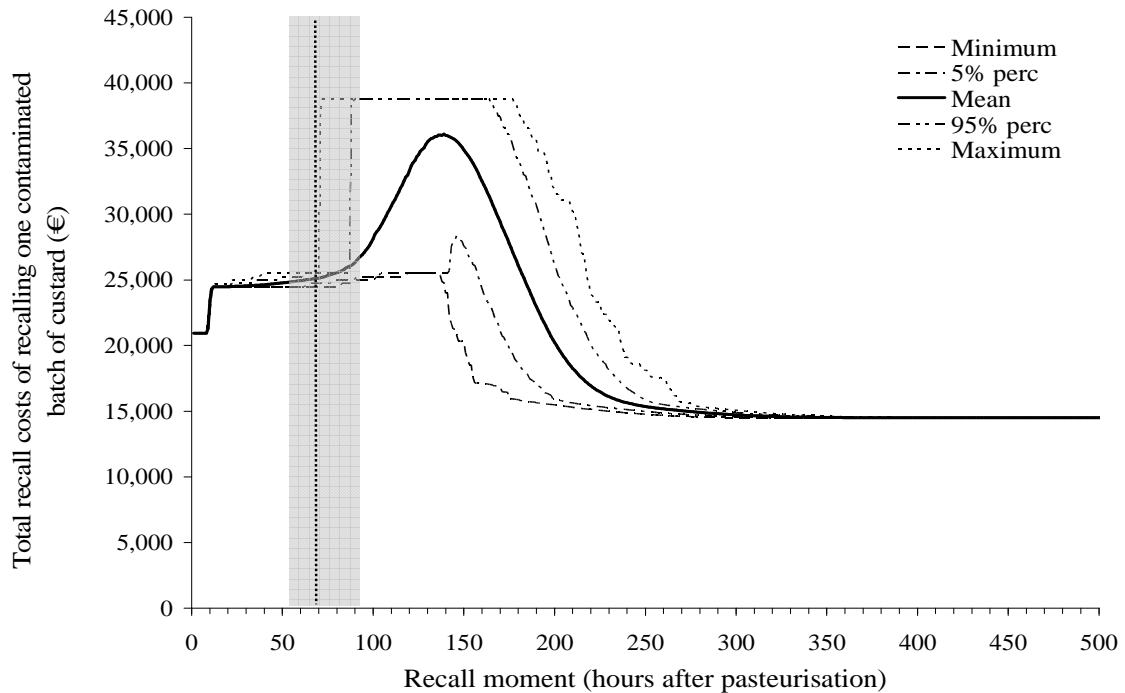


Figure 6. Net recall costs (NC_r) of a batch of custard contaminated with *Pseudomonas* spp. in relation to the recall moment (i.e. h after pasteurization) in a situation **without** quarantine. The grey area indicates the period between the 5% and 95% percentiles of the moment at which the test results are available, where the dashed vertical line indicates the mean value.

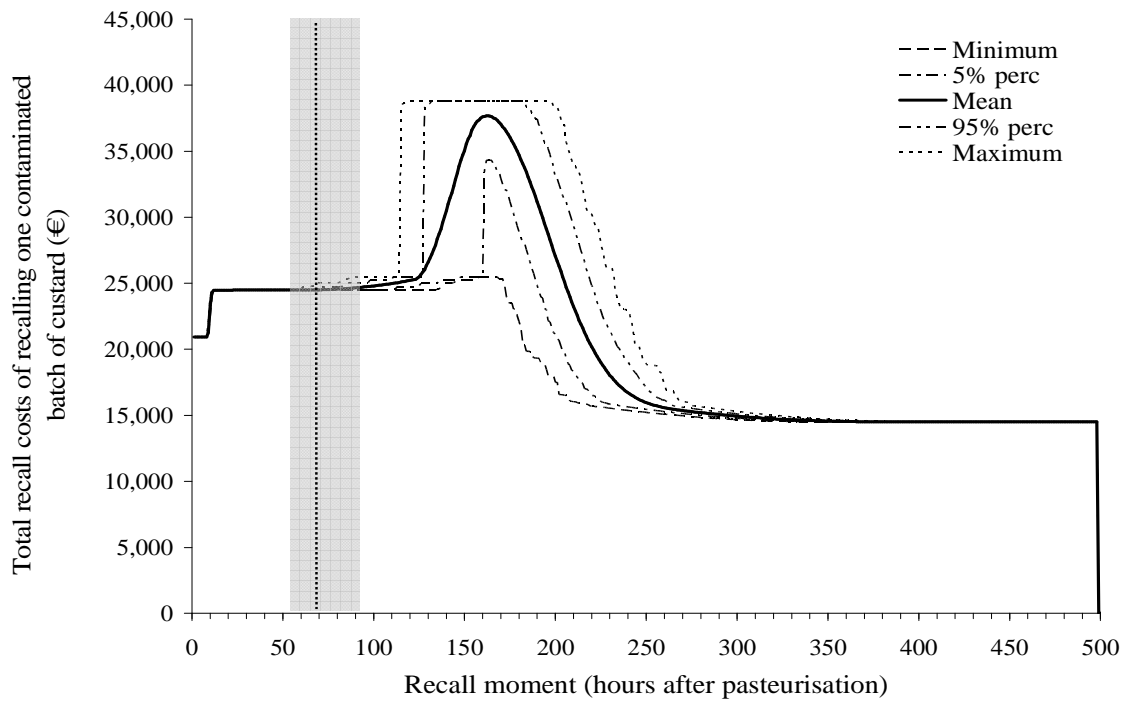


Figure 7. Net recall costs (NC_r) of a batch of custard contaminated with *Pseudomonas* spp. in relation to the recall moment (i.e. h after pasteurization) in a situation **with** quarantine. The grey area indicates the period between the 5% and 95% percentiles of the moment at which the test results are available, where the dashed vertical line indicates the mean value.

The NC_r values sharply increase around 70 h and 110 h for the situation without and with quarantine, respectively. The increase in NC_r is mainly caused by the costs of a media announcement related to a public recall (€14,500). For the quarantine situation this means that the moment a recall is initiated by the end-product-test precedes the further increase of the mean total recall costs. This moment even precedes the further increase in the worst case scenario (maximum) if products move very fast through the chain. The NC_r reach a maximum of €36,171 and €36,648 at 139 and 165 h for the non-quarantine and quarantine situation, respectively. After this moment NC_r decrease, because more and more custard is at the consumer level and consumed. This reduces NC_r because only 0.13 % of the consumers that detect spoilage will ask for a refund and because for consuming spoiled custard does not induce costs. However, additional company costs can occur if consumers that have detected spoilage stop buying their custard. In addition, consuming spoiled custard might lead to consumer illness with associated societal costs. In both situations without and with quarantine, the total recall costs from around 280 h onwards almost only consist of media announcement costs.

3.5. Recall costs per average batch custard

The ARC depends on the true contamination probability ($\Pr(cont)$) because the probability of a recall ($\Pr(PS \geq 2)$) depends on $\Pr(cont)$ (Table 4). Also, ARC depends on the recall moment. Recall moments of 66 and 90 were chosen, since they reflect the mean and the 95% percentile of time of detection. Recall moments of 125 and 155 were chosen to reflect the time frame in which contamination at the production plant with *Pseudomonas* spp. is likely to be detected based on consumer complaints. Consumer complaints after approximately 155 h are often due to other causes of spoilage than *Pseudomonas* spp. The mean ARC is lower than €100 if $\Pr(cont)$ is 0.005 or $\Pr(PS \geq 2)$ is 0.003, whereas the ARC exceeds €12,000 when $\Pr(cont)$ is 0.100 or $\Pr(PS \geq 2)$ is 0.485. The recall moment has a large impact on ARC. A recall moment when part of a batch has just left the dairy company, results in the highest costs. A recall moment if the whole batch is still at the dairy company or a substantial part of the batch is already at consumers, results in the lowest costs. Quarantine has hardly an effect on the mean ARC. However, quarantine reduces the range between the 5% and 95% percentiles. For recall moments up to and including $t=125$ it reduces the range to zero.

Table 4. Recall costs per average batch of custard produced as function of the true contamination probability ($\text{Pr}(\text{cont})$) and the probability of a recall ($\text{Pr}(PS \geq 2)$)

		Recall costs per average batch (€)							
Pr(cont)	Pr(PS≥2)	66 h		90 h		125 h		155 h	
		Mean	95-5P ¹	Mean	95-5P	Mean	95-5P	Mean	95-5P
Without quarantine									
0.005	0.003	72	2	75	38	100	38	96	36
0.010	0.011	274	8	287	145	381	145	368	138
0.015	0.023	590	18	616	312	818	312	790	296
0.020	0.040	1,001	30	1,046	530	1,388	530	1,341	502
0.025	0.059	1,493	45	1,561	791	2,072	791	2,001	749
0.050	0.189	4,751	143	4,966	2,517	6,592	2,517	6,367	2,385
0.075	0.340	8,538	257	8,925	4,523	11,846	4,523	11,442	4,286
0.100	0.485	12,183	367	12,736	6,454	16,903	6,454	16,327	6,115
With quarantine									
0.005	0.003	73	0	73	0	74	0	106	38
0.010	0.011	279	0	279	0	282	0	403	145
0.015	0.023	599	0	599	0	606	0	866	312
0.020	0.040	1,016	0	1,016	0	1,028	0	1,470	530
0.025	0.059	1,517	0	1,517	0	1,534	0	2,193	791
0.050	0.189	4,826	0	4,826	0	4,881	0	6,978	2,517
0.075	0.340	8,672	0	8,672	0	8,772	0	12,540	4,523
0.100	0.485	12,374	0	12,374	0	12,516	0	17,893	6,454

¹ The range between the 5% and the 95% percentile

3.6. Net recall costs of applying quarantine

Figure 8 summarizes the net recall costs if a quarantine situation is in place (NC_q). The mean NC_q is positive (costs exceed benefits) for $\text{Pr}(\text{cont})$ values up to and including 0.020 for the recall moments indicated. In contrast, mean NC_q is negative (quarantine can be profitable) for relatively high $\text{Pr}(\text{cont})$ at $t=90$ and $t=125$. However, in all these cases the 95% NC_q is positive indicating that it is possible that quarantine is not profitable.

4. Discussion

The relation between the moment at which a recall of a batch of Dutch custard due to spoilage with *Pseudomonas* spp. is initiated and the direct costs of the recall was analyzed. Furthermore, the consequences of a quarantine of 48 h after testing a batch on the net recall costs were quantified. A simulation approach was used because the distribution of a batch of custard over the chain over time is not fixed. We showed that the net recall costs depend on the moment a recall is initiated. This moment determines the distribution of a batch of custard along the supply chain depends. The net recall costs increase with the recall moment, but after reaching a maximum of about €36,500 decrease because more and more custard is consumed.

Quantification of how recall costs vary with the moment a recall is initiated provides insight as to where innovative testing, monitoring, traceability, and management systems can be located and what their possible impacts are. When considering new systems along the custard chain and the probability of having a recall, the costs and benefits of a new system should be taken into account as well.

The indirect recall costs can increase with the recall moment. A later recall moment increase the risk of damaging consumer confidence in the specific type of custard, the company's name, or the whole sector, as has been observed in consumer milk by Velthuis^[4]. Further research is needed to include the indirect recall costs into a model to quantify the relationship between the recall moment and corresponding cost.

The true contamination probability ($\text{Pr}(\text{cont})$) can be difficult to calculate in practice, because it includes both the incidental post-processing contamination incidents and possible bio-film incidents. The latter can lead to contamination probabilities of 0.2 till 0.5 increasing the $\text{Pr}(\text{cont})$ too high values^[17, 18].

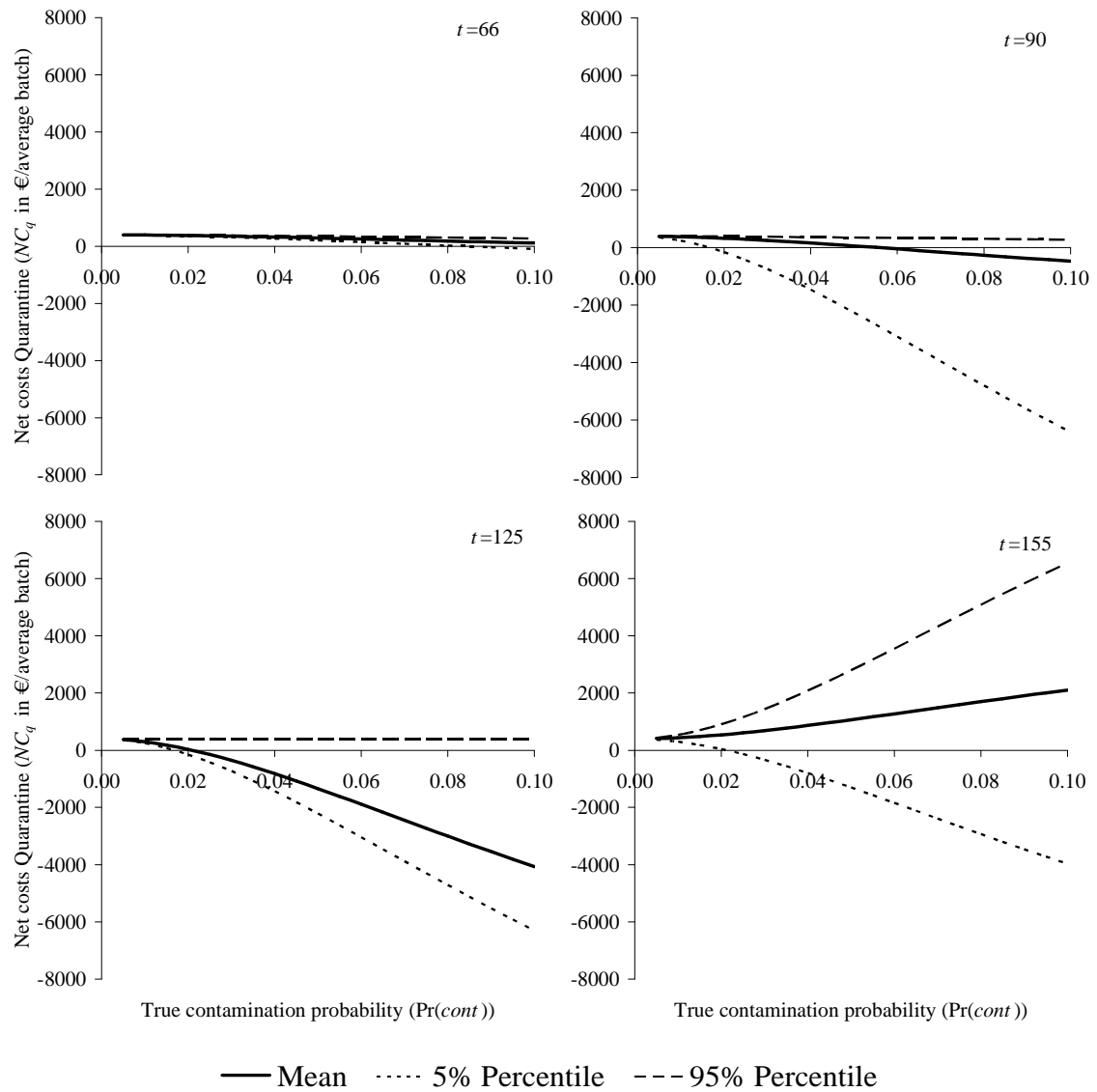


Figure 8. Mean, 5% and 95% percentiles of the simulated net recall costs of quarantine NC_q for different recall moments depending on the true contamination probability $\text{Pr}(\text{cont})$.

Although this research focuses on recalls based on spoilage problems that are detected with the end-product testing, it includes situations where despite the end-product testing consumers experience spoilage and contact the consumer-care line. These incidents can occur from approximately 100 h after pasteurization up to the end of shelf life in the situation without quarantine and from 130 h after pasteurization in a situation with quarantine.

The results of this study can also be used in the decision whether to invest in a faster test protocol for end-product testing. For example, if the time of detection can be reduced by 24 h the 95% percentile of the recall costs in a non-quarantine situation is reduced significantly. However, the mean of the recall costs is not reduced by the improvement. In a quarantine situation a faster test protocol does not reduce the mean or 95% percentile of the total recall costs.

The testing protocol currently in use takes between two and four days. Increasing the speed of the test by using a new test and thereby having the results faster can reduce quarantine period and associated costs. For example the fluorescence in situ hybridization (FISH) method can be used to detect and count *Pseudomonas* spp. in milk in two h. The sensitivity of this method is good but could be increased by combining it with membrane filtration^[19]. However, this test is more expensive. Additional research is

needed to determine the economic optimal quality control protocol, since the costs of less optimal logistical process or another test should outweigh the benefits of having the information quicker.

In the Netherlands, the procedure for recalling food depends on the nature of the problem. The procedure for unsafe food has different priorities than the procedure for unsuitable food. If an unsafe food product is found on the market, the processor of this product should inform the Food and Consumer Product Safety Authority (VWA) immediately. In addition, it should inform consumers by a public announcement and by an announcement on its own website. If this is not done properly, the minister of Health, Welfare and Sport can compel the company to issue a public warning. If a food product is found on the market that is unsuitable for consumption, the processor should notify the VWA. However what further measures have to be taken is decided on in consultation with the VWA and depends on the seriousness of the noncompliance. Therefore, it is important for the individual food producers to study the different options in the quality management in relation to the economic impact of recalling batches that are unsuitable for consumption. With this study we show that for decisions at plant level to improve the quality of the product can be supported by decision models that include not only technical but also economic information.

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