Agribusiness and Applied Economics Report 705 January 2013

Quantitative Cost Model of HACCP Implementation

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Acknowledgements

We are sincerely grateful to Dr. Deland Myers, Dr. Robert Maddock, and Mr. David Saxowsky for their input on this project, Heather Rolla, Joel Dick and Joe Horton, who provided industry input, and Skip Taylor for his careful review of our work. It is always the case that our families and friends have provided us the support necessary to achieve great things, one step at a time.

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Abstract: Foodborne illness is an important public health problem in the United States. Hazard Analysis Critical Control Point (HACCP) is widely acknowledged as an effective method to ensure product quality and control foodborne hazards. The case-study method is applied to the Prevention-Appraisal-Failure model to identify contributing sources of cost associated with the implementation of HACCP plans in meat and specialty grain processing plants in the Red River Valley and develop a cost estimation model for calculating total quality cost.

Key words: food safety, Hazard Analysis Critical Control Point, HACCP, Prevention-Appraisal-Failure Model.

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Introduction

More than 48 million cases of foodborne illness occur annually in the United States, resulting in an estimated 128,000 hospitalizations and 3,000 deaths (Scallan, et al., 2011). And, the number of outbreaks reported represents only a portion of cases of foodborne illness that actually occur. Some outbreaks are never recognized, and those that are recognized frequently go unreported (Gould, et al., 2011). Scharff (2010) reports the annual cost of the health burden of foodborne illnesses in the United States to be approximately $152 billion, which includes the costs of medical bills, lost wages and lost productivity.

To reduce the frequency and severity of foodborne disease outbreaks, the U.S. federal government and its agencies enacted a number of laws. Legislation includes, e.g., the Federal Meat Inspection Act (1906), the Federal Food, Drug and Cosmetic Act (1938), the Food Quality Protection Act (1996), and the Food Safety Act (2010). These and other legislation helped establish inspection requirements for food products, set quality standards for food processors, and ensure food safety.

In 1996, United States Department of Agriculture (USDA) Food Safety and Inspection Service (FSIS) published the final rule on the Hazard Analysis Critical Control Points (HACCP) requirement for meat and poultry processing. HACCP focuses on reducing hazards throughout the production process. More specifically, a HACCP system establishes process control by identifying, monitoring and controlling critical control points (CCPs) in the production process. A CCP is a point at which a control can be applied to eliminate a hazard or reduce it to an acceptable level. In general, CCPs can be identified at any production stage, such as receiving, processing, cold storing and packaging.

Although evidence demonstrates implementation of HACCP plans reduce the potential for food safety problems, its cost effectiveness has been debated. An important argument favoring the system is that its preventive focus may be more cost-effective than testing products and then destroying or reworking those not meeting the quality standard (International Commission on Microbiological Specifications for Foods, 1988). This is especially important for foodborne microbial pathogens because their incidence is low and costs of testing and reworking are high (Unnevehr and Jensen, 1996). Lupin, et al. (2010), for example, found implementation of a compliant HACCP system in fish processing plants resulted in a decrease in the number of failed products and an increase in quality, and was cost effective.

However, costs of HACCP implementation can be significant, and will differ between firms different in characteristic and operation, making HACCP implementation more costly for some firms than for others. For example, Hinson and Whitley (2003) found not only that the costs of HACCP systems for oyster processors differed, but that it was difficult to generalize the effects of factors affecting cost differences. One important factor was the extent to which the HACCP plans exceeded

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what was required, especially to include the number of CCPs identified. Romano, et al. (2004) studied the costs of adopting HACCP systems in four meat and dairy plants in Italy. The data were collected using questionnaire-guided interviews. They also found that the HACCP systems were effective in decreasing product defects, and that the structure of HACCP costs differed among plants.

Differences in findings from the literature on the effect of firm size also support the conclusion that the cost-effectiveness of HACCP, while not size-neutral, also depends on other factors. For example, from their work, Roberts, Buzby and Ollinger (1996) concluded that smaller meat and poultry plants had higher per unit costs of HACCP. Alternatively, Herrera, et al. (1999) found diseconomies of size for HACCP plans for Mississippi catfish processors.

Because many factors such as type of facility, size and location affect cost of HACCP design and implementation, it is important that a firm evaluate the cost effectiveness of alternative HACCP plans for their specific plant(s) before implementation and continue to assess cost once the plan is in place and operational. This paper identified and summarizes the main types of costs of HACCP systems being used by two Red River Valley processors, builds a cost estimation model appropriate to estimate the costs of various HACCP systems for these and other like firms, and considers cost-contribution of components of the plan for the two firms.

Materials and Methods

The Prevention-Appraisal-Failure Model.

The concept of quality cost was used to define a framework for assessing net cost of HACCP plans. The specific framework applied was the Prevention-Appraisal-Failure (PAF) model developed by Feigenbaum (1961), and later applied to HACCP plan evaluation by others (e.g., Romano, et al., 2004; Zugarramurdi, et al., 2007; Lupin, et al., 2010). In this model, quality costs are divided into three categories: prevention, appraisal and failure costs. The basic assumption of the PAF model is that cost associated with prevention and appraisal activities will reduce failure costs.

By estimating (a prior) or observing (ex-ante) the changes in quality cost before and after the implementation of a HACCP plan, a manager can gauge the cost effectiveness of that plan. Modeling previous work, total quality cost (TQC) is reflected in Equation (1).

$$TQC = \sum C_P + \sum C_A + \sum C_F \qquad (1)$$

Where C_P = prevention cost, C_A = appraisal cost, and C_F = failure cost per period.

<u>Prevention costs</u> arise from designing and maintaining the HACCP system, and from training personnel. They are those costs associated with activities that, prior to the production process, reduce likelihood of production of an unsafe product. <u>Appraisal costs</u> arise from detecting and checking for process or product defects via inspections, tests, audits and recordkeeping. They are associated with collecting information about whether the quality of raw materials, and intermediate and final products conform to the standards identified in the HACCP plan. <u>Failure costs</u> are costs related to defects detected during processing (internal failure) or after the product is delivered (external failure) (Cao and Johnson, 2006). They reflect costs of reworking or destroying a product

or lost income, which can occur directly from lost sales associated with suspect products. External costs are associated with returns, recall, reputation and liability.

Firm Descriptions

Target firms of this study were selected which had existing HACCP plans and performed several functions including receiving and storage of raw materials, cleaning, processing, and packing product for market, storage of packed product, and shipment, with all steps prior to shipment taking place at one facility. Faculty involved in the North Dakota State University Food Safety program were asked to submit firms for consideration. Ten firms were suggested, and the two firms that explicitly met the research criteria were selected and agreed to participate.

Firm A has over thirty years of history in meat processing and has two plants in eastern North Dakota. The firm sells a wide variety of meat products, such as smoked sausages, smoked hams, ground beef and chicken. It serves the North Dakota, South Dakota, and Northwest Minnesota markets. The firm's business strategy includes building and maintaining its reputation of high quality, safe products. The firm's HACCP plan is perceived by management as one of the main tools to ensure product safety.

The firm controls food hazards beginning with the ordering and receipt of raw materials. For example, raw materials are ordered from a list of suppliers who have certificates guaranteeing the quality of their materials and each box of raw materials identifies the source (supplier and specific plant origin). The firm has seven HACCP plans, one for each production process. Two HACCP plans are implemented at the main plant, where ground beef, beef patty mix, ground chuck and beef patties are produced.

During two plant visits, the costs associated with HACCP implementation for ground beef in the main plant were elicited. This HACCP plan has been in effect since 1999 and is adapted as new products are developed, or USDA regulations change. As part of its plan, this firm renovated a microbiology laboratory for sampling raw materials and finished products, added an alarm in the cold storage room to warn of temperatures outside the acceptable range, and documents the HACCP system on a daily basis.

Firm B, located in Northwestern Minnesota, is one of the largest suppliers of custom-milled and whole grain blends in North America. Total output in 2010 was approximately 75 million pounds of product. The firm supplies the wholesale bread baking industry, and its products have been exported to 13 countries. The quality of raw materials is a high priority for this firm. Due to its location, the plant can immediately access premium raw materials, and the firm has had a strong, cooperative relationship with the supplying farming community for over 20 years. Suppliers are required to have certificates that guarantee the quality and safety of their raw materials.

The firm created a HACCP program in 2005 based on the guidelines of the American Institute of Baking. This HACCP plan was applied to six different production lines. The major hazards during processing are physical hazards, because its products are processed and moved directly by many pieces of equipment that could lead to metal contamination. To reduce physical hazards, this firm uses several magnets and sieves throughout processing, and metal detectors prior to product packaging in whole process lines. This is the CCP in the HACCP system and the recordkeeping of this CCP is maintained for three years. The risk from microbiological hazards is quite low because the steaming and toasting steps during product processing kill most harmful microorganisms.

Data Collection

Data were collected from face-to-face interviews conducted at the two firms. The first step was to identify requirements of the HACCP plans to aid in the development of a comprehensive PAF model. During follow-on interviews, activity and cost data related to HACCP plan development and implementation in the two firms were collected. Interviews based on a structured questionnaire were conducted with quality assurance managers and staff involved in the HACCP systems, following the method used in Caswell (1998) and Hinson and Whitley (2003). The questionnaire was developed based on costs identified from the literature review and the initial PAF model.

Face-to-face interviews guided by a formal questionnaire were selected over mail or phone surveys as a data-collection method because of the disadvantages associated with unaided questionnaires for current data requirements as noted by Hinson and Whitley (2003). Key disadvantages include potential for low response rate among the small number of qualified firms, reduced quality of information, its format as a one-way communication tool, and that general questions posed may not reflect the realities of HACCP implementation for unique firms. The latter is particularly important because the literature shows that variability in firm size, organization, product handled, process and the design and implementation of the HACCP plans will affect associated activities and cost.

Model Development

The preliminary PAF model was developed after initial plant visits. Cost items of HACCP implementation identified in the literature were deleted or grouped to reduce the number of cost categories. For example, for both firms the shipping step is not dependent on the HACCP system employed so this cost category was removed. The resulting prevention, appraisal and failure costs and sources for each cost type identified are shown in Table 1. Prevention costs incurred in HACCP systems are those associated with designing and developing a HACCP plan; training; cleaning and sanitation; and an antimicrobial system. Prior to HACCP adoption, both firms had adopted Good Manufacturing Practices (GMPs) and Sanitation Standard Operating Procedures (SSOPs). Appraisal costs are associated with ensuring processing conforms to the HACCP plan and final products meet the quality standard identified or required. These costs include those associated with working to ensure the quality of raw materials; sampling; calibrating and maintaining equipment; inspecting; record keeping; and facility improvements and equipment. Failure costs mainly result from non-conforming products. They are divided into internal and external failure costs. Internal failure costs are direct losses and include scrap, re-work, retest, and wastage costs.

Table 1. Types and Sources of Prevention, Appraisal, and Failure Costs of HACCP

Activities	Source of costs
Prevention costs (C_P)	
Designing and developing the HACCP plan (identification of CCPs and their critical limits)	HACCP expert's labor (internal or external)
Initial and follow-on training	HACCP expert's labor (internal or external)
Cleaning and sanitation of equipment and facility	Materials (e.g., disinfectants) and labor, or a cleaning service contract
Antimicrobial system[3]	Labor, chemicals, water, storage tanks, and microbial testing
Appraisal costs (C_A)	
Guaranteeing quality of incoming raw materials[4]	Labor and potential higher-cost raw materials
Sampling raw materials and final products	Labor and materials used for sampling (e.g., test kits) or external contract testing fees
Calibrating and maintaining equipment used for HACCP systems	Labor and/or service contract
Inspecting and verifying CCPs during processing	Labor
Record keeping	Labor
Costs of equipment and building improvements used for HACCP systems	Depreciation
Failure costs (C_F)[5]	
Internal failure costs (scraps, reprocessing, retest or spoilage)	Labor, operation, wastage (raw materials)
External failure costs (rejected and/or returned products, reputation effect, liability)	Lost income on product, other potential loss in income (e.g., reputation effect; liability), cost of implementing additional prevention steps

[3] The antimicrobial system was only present for Firm A, which processed meat. Microorganisms found on or in meat and poultry may contribute to meat spoilage, reduce shelf-life of meat and cause foodborne diseases. The firm used an antimicrobial treatment, spraying chemicals on the surface of meat to control microbial growth. The costs of labor, chemicals and storage tanks used for this system are the main cost items.

[4] Firm A has one microbiology laboratory in the main plant and samples the raw materials twice and the final products four times per year. Firm B has two microbiology laboratories samples only final products. This is done daily.

[5] Firm A did not retest and rework the products testing outside of acceptable limits, but sent them directly to a cooking company. Firm B had both wastage and re-work costs. Due to difficulty in estimating, the external failure costs were not considered in this initial study.

The Cost Estimation Model

Cost items were next categorized by the PAF model into four groups: labor, equipment, material and failure costs. The parameters used in the cost model are defined in Table 2. As previously noted, C_P, C_A, and C_F are prevention, appraisal and failure costs, respectively.

Table 2. Labor, Equipment, Material and Failure Costs

Costs items	Cost categories in PAF model
Labor costs (C_L)	
Designing and developing HACCP plan	C_P
Staff training	C_P
Follow-on training	C_P
Cleaning and sanitation of equipment and facility	C_P
Antimicrobial system	C_P
Calibrating and maintaining the equipment used for HACCP systems	C_A
Inspecting and verifying CCPs during processing	C_A
Sampling raw materials and final products	C_A
Record keeping	C_A
Equipment costs (C_E)	
Depreciation	C_A
Material costs (C_M)	
Testing kits or supplies for sampling	C_A
Raw materials and final products for sampling	C_A
Chemicals for antimicrobial system	C_P
Detergents and disinfectants for cleaning	C_P
Failure costs (C_F)	
Waste (products cannot be re-worked)	C_F
Re-work product (including retesting)	C_F

To calculate TQC associated with HACCP implementation, the labor, equipment, material, and failure costs are evaluated separately. In a food processing plant, many staff involved in the implementation of HACCP system, such as operators, cleaners, inspectors, microbiologists, and HACCP experts, are needed. Equation (2) calculates total labor cost.

$$\sum C_L = \sum_{i=1}^{n} (N_{oi} N_{hi} N_{di} R_i + C_i) \qquad (2)$$

Where: C_L= Annual labor cost; n = Number of different labor categories (based on wage rate); N_o= Number of employees or experts; N_h = working hours per day; N_d = annual working days; R_i = Labor rate per hour; and C_i = Annual cost of service contracts for cleaning the plant, calibration and maintenance of equipment, testing or other activities.

Some necessary equipment, such as testing and measuring instruments, were purchased by the case firms to evaluate the quality of products. The straight-line method was used to estimate the total depreciation cost. Material costs include the costs to sample and test, the antimicrobial system, and cleaning and sanitizing materials. Total material cost is established by equation (4).

$$\sum C_M = \sum_{i=1}^{n} (P_{wi} U_{wi}) \qquad (4)$$

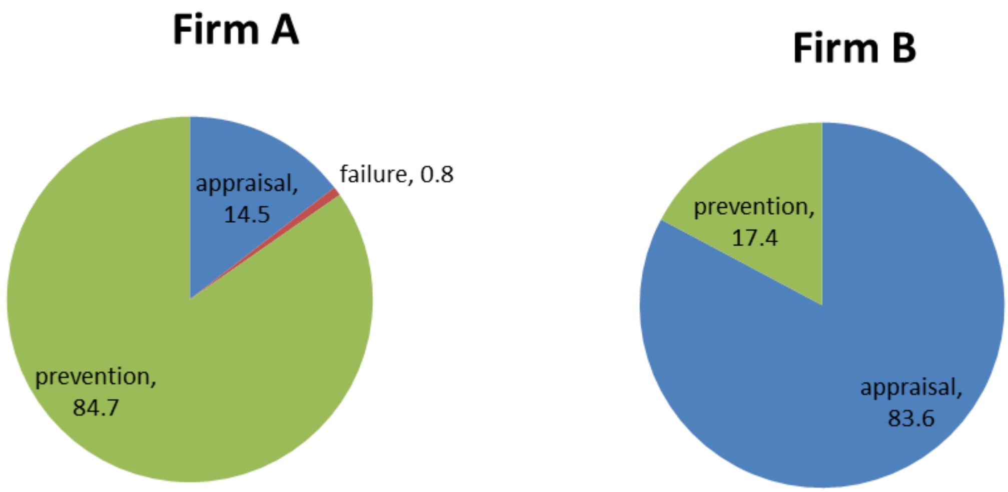
Where: C_M = Annual material cost; n = Number of different material costs; P_w = Purchase price of chemicals, testing kits, detergents and disinfectants, or raw materials, and selling price of final product; U_w = Chemicals, testing kits, detergents and disinfectants, raw materials, and final products used annually.

For failure costs, the costs of product wastage and re-work are listed because they are direct company losses. In theory, an increase of investment in prevention and appraisal activities should lead to a decrease in failure costs after completion of HACCP implementation, and there should be a point which represents the lowest value of TQCs. For an individual firm, the effectiveness of plan implementation can be evaluated through observing and analyzing the trend of each quality cost during the post-HACCP period and comparing it to the theoretical lowest TQC.

Results

To validate the cost estimation model, each cost item listed in Table 2 was collected from the two food processing plants. Prevention costs, appraisal costs and failure costs were estimated and expressed as percentages of TQC. Figure 1 shows the individual contribution of the three quality costs to the TQC for the two processes.

Figure 1. Estimated Prevention, Appraisal, and Failure Costs of TQC in Firms A and B (percentage contribution)[6]



The structure of TQC of HACCP implementation in the two firms is quite different. In Firm A, investments in prevention actions comprise most of estimated TQC (85%). Conversely, the appraisal costs in Firm B account for most (84%) of TQC. Firm A (the meat processing firm) focuses on prevention cost activities, while that of Firm B (the grain processing firm) focuses on appraisal cost activities (e.g., sampling and metal detecting).

Figure 2 shows the composition of prevention costs only for the two firms. Cost breakdown is similar for the two firms, with the primary difference being the cost of an antimicrobial system for Firm A. Cleaning and sanitation activities comprised approximately three-fourths of preventative costs for both firms. These are daily activities, while plan design and initial and recurrent training are not. Firm A used a service cleaning contract, while Firm B used internal labor. In both firms, initial and follow-up HACCP training occurred in-house.

[6] No elicited data from Firm B supports an estimate of failure costs. Its value depends on the working situation of the metal detectors. If there was a metal detector malfunction, the malfunction would result in internal failure costs (wastage and re-work) and potential external costs. The failure cost of Firm A in this study only includes the cost of cooking the products not meeting the quality standards and does not include external costs. Romano, et al. (2004) suggests that external costs in the meat sector can be reflected by cost of liability insurance. We suggest that reputation effects may also be important.

Figure 2. Sources of Prevention Costs (percentage contribution)

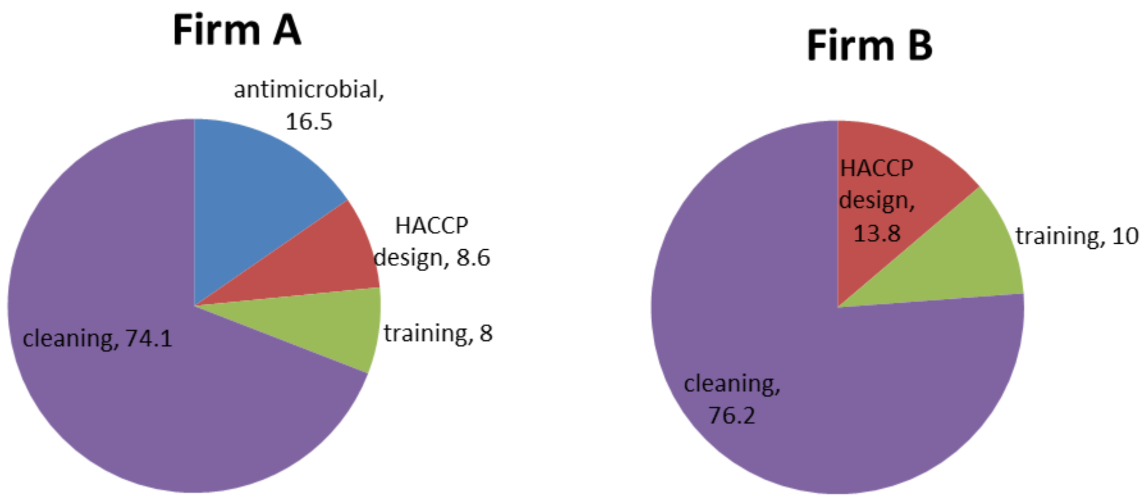
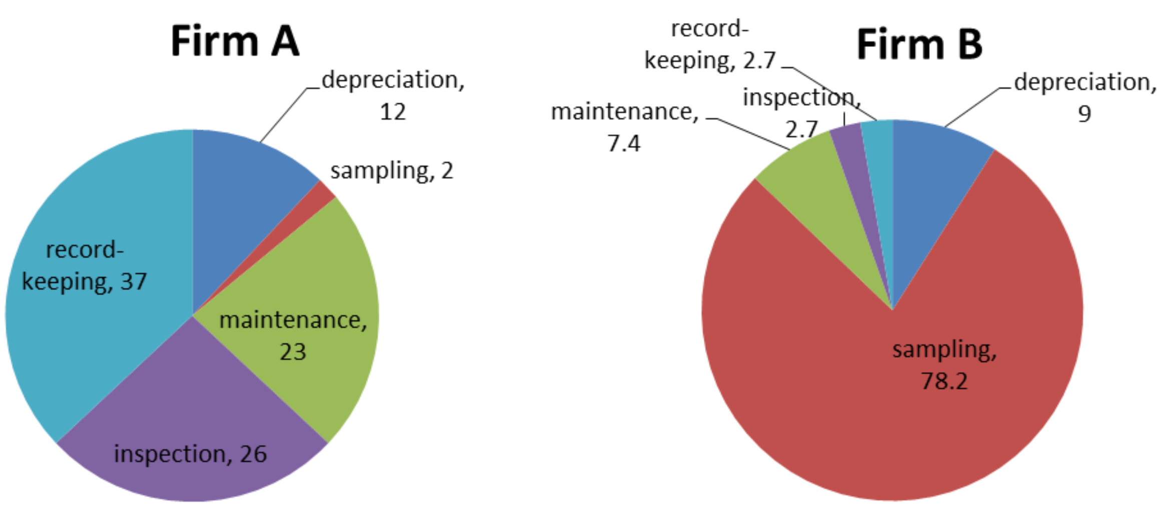


Figure 3 breaks appraisal costs into five cost items. It shows that record keeping is a slight majority of the appraisal costs for Firm A (37%). This is followed by inspection cost (26%). This concurs with the work of Deodhar (2003) who found the primary operating costs of HACCP among surveyed seafood processing firms in India to be recordkeeping and product testing. For Firm B, the main item of appraisal costs is sampling the final products (78.2%), because the firm had a relatively large product output and products are sampled daily.

Figure 3. Sources of Appraisal Costs (percentage contribution)



The PAF model also was reclassified into two groups: labor and other (equipment and material) costs. When failure costs are excluded, labor costs comprise most of the total of prevention and appraisal costs for both Firm A (88%) and Firm B (87%). This compares with Romano, et al. (2004) who found labor costs to range from 50 to 67% of TQC.

Discussion

The PAF model is one tool to classify and calculate quality costs associated with the implementation and use of a HACCP plan. In this study, the structure of the PAF model used in previous work was refined based on plant visits. The result was a model identifying TQCs as comprised of twelve cost items. To evaluate the quality costs (including prevention, appraisal, and failure costs), a quantitative cost model was proposed based on the refined PAF model and applied to two North Dakota food processing plants. By using the data known or reasonably estimated by the quality assurance managers of the two plants, the estimates of quality costs were calculated with the proposed model.

The cost model provides a good starting point for estimating the costs of HACCP implementation. It can help firms calculate the essential costs associated with the implementation of HACCP and allow firms to evaluate the long term efficiency of HACCP plans by comparing their quality costs over time. The model as applied here is not without limitations. First, variables, primarily external failure costs, were not considered that otherwise would have increased TQC. This was because they could not be estimated with reasonable accuracy, such as the cost of rejected products and food recalls. Inclusion of these variables would increase the validity of the model to reflect actual TQC. Second, although limiting the number of firms under consideration to two is appropriate for an investigative case study of this nature, inclusion of additional firms may increase the power of the model. Finally, consideration of changes in TQC over time may be helpful in further understanding how activities and costs change as firms increase their experience with their HACCP plans.

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