codex alimentarius commission

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

WORLD HEALTH ORGANIZATION

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Agenda Item 4(b) **CX/FH 06/38/4-Add.1**
September 2006

JOINT FAO/WHO FOOD STANDARDS PROGRAMME

CODEX COMMITTEE ON FOOD HYGIENE

Thirty-eighth Session

The Intercontinental Hotel, Houston, United States of America

ANNEX III: EXAMPLES OF THE USE OF FOOD SAFETY OBJECTIVES, PERFORMANCE OBJECTIVES, PROCESS AND PRODUCT CRITERIA AT STEP 3

Prepared by United States of America and Australia

Governments and interested international organizations are invited to submit comments on the document below, especially on Section containing recommendations, and should do so in writing **to**: Mr S. Amjad Ali, Staff Officer, Food Safety and Inspection Service, U.S. Department of Agriculture, Room 4861, 1400 Independence Avenue, SW, Washington, D.C. 20250, USA, FAX +1-202-720-3157, or email syed.ali@fsis.usda.gov with a copy **to**: Secretary, Codex Alimentarius Commission, Joint WHO/FAO Food Standards Programme, FAO, Viale delle Terme di Caracalla, 00100 Rome, Italy, by email codex@fao.org or fax: +39-06-5705-4593 **by 15 October 2006.**

Introduction

At its 37th Session, the Codex Alimentarius Committee on Food Hygiene (CCFH) advanced the "Proposed Draft Principles and Guidelines for the Conduct of Microbiological Risk Management" and two of its three annexes to step 5. However, CCFH concluded that Annex III, "Examples of Approaches for Utilizing Quantitative Microbial Risk Assessment Techniques to Link the Stringency of Control Measures to Hygiene Outcomes and Metrics," required additional work and de-coupled the annex from the rest of the document so that it could proceed at a different pace. The United States delegation volunteered to take over the drafting of the annex and was joined by the delegations of Argentina, Australia, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Republic of Korea, New Zealand, The Netherlands, Norway, ICMSF, IDF, IFEH, FAO, and WHO.

In addressing the charge by CCFH, the Working Group found that a detailed consideration of examples that would be needed to fully describe all the potential means by which a quantitative

microbiological risk assessment would be used to establish food safety risk management metrics such Food Safety Objectives, Performance Objectives, and Performance Criteria was well beyond the capabilities of the working group. Accordingly, the Working Group decided to employ a single example as a means of introducing concepts, data needs, and the types of modeling required. However, even with a single example, the Working Group found itself in a quandary. The fully articulated example was highly technical and required extensive explanatory information; and it proved almost impossible to achieve the detailed that the risk assessors felt was necessary to understand the subject adequately while at the same time achieving the brevity requested by the risk managers.

Recommendations

The Working Group felt that the most prudent approach was to seek guidance from CCFH. To that end, the Working Group has drafted two documents, one (Annex IIIA) that provides a reasonable level of detail such that the values cited could be reproduced by qualified experts, and a second (Annex IIIB) that focuses on the framework, processes, data needs and review criteria that a competent authority should consider when it establishes food safety risk management metrics that are linked via a quantitative microbiological risk assessment to public health outcomes. The Working Group is submitting both to CCFH for guidance on which direction the Working Group should embrace or if it should consider a completely different approach.

ANNEX IIIA. EXAMPLES OF APPROACHES FOR UTILIZING QUANTITATIVE MICROBIAL RISK ASSESSMENT TECHNIQUES TO LINK THE STRINGENCY OF CONTROL MEASURES TO HYGIENE OUTCOMES AND METRICS

1. Introduction

The rapid advancement of quantitative microbiological risk assessment (QMRA) techniques is producing new capabilities for linking traditional means for establishing the stringency of food safety systems (e.g., microbiological criterion (MC), process criterion, product criterion) to the level of public health protection that the system is intended to achieve. The availability of increasingly sophisticated risk assessment models makes it possible for risk assessors to predict the relative risk reductions that can be achieved through the inclusion of different risk mitigations strategies (i.e., control measures), including estimating the number of foodborne disease prevented. Conversely, the same tools make it possible to start with public health and derive the degree of stringency required of a food safety system to achieve the desired level of protection. These new capabilities are dramatically changing the level of scientific rigor and transparency associated with the establishment of food safety requirements and/or guidance. It has also led to a series of new food safety risk management concepts and metrics, such the food safety objective (FSO), Performance Objective (PO), Performance Criteria (PC), that provide a framework for operationalizing the concepts envisioned in the WTO SPS Agreement.

While these concepts are increasingly being embraced by the risk assessment community as a logical extension of QMRA to describe the performance needed of food safety systems to achieve a desired degree of public health protection, their practical application within an international or national food safety risk management framework is still in its infancy. In particular, the risk assessment tools for linking the establishment of traditional criteria and other guidance for the hygienic manufacture, distribution, and consumption of foods and its anticipated public health impact can be complex and not always intuitive. However, as outlined in the "Proposed Draft Principles and Guidelines for the Conduct of Microbiological Risk Management," the ability to articulate requirements in terms of the risk reductions expected is a critical component of the Codex Alimentarius risk analysis paradigm.

2. Scope

The purpose of this document is to provide guidance to Codex and national governments on approaches for using risk assessment techniques to establish metrics that can be used to establish, communicate and verify the level of stringency needed for a food safety system. However, each application of risk assessment to inform decision making is unique and as such it is not possible to describe all potential applications. Instead, the annex will use an example, *Listeria monocytogenes* in cold smoked salmon, to describe some of the concepts and approaches that should be considered in using a quantitative risk assessment to develop risk management criteria such as FSO, PO, and PC to relate the degree of stringency required of a food safety system to the desired level of public health protection. In addition, the example examines how these food safety metrics can be used to establish MC as one potential means of verifying that the desired level of control is achieved.

It is important to note that the example is for illustrative purposes only, and is being used only to describe some of the concepts that should be considered in developing food safety risk management criteria. The concepts and approaches used in the example are by no means inclusive or may not be optimal for other applications. Instead, this annex has been developed to describe the thought processes that could benefit risk managers and risk assessors as they apply risk analysis tools to the establishment of risk management criteria.

Since each future application of the tools will be unique, the annex also describes potential procedural approaches that can be useful in ensuring that applications are consistent with Codex risk analysis principles. This annex should be used in conjunction with the Codex "*Working Principles for Risk Analysis for Application in the Framework of the Codex Alimentarius*," "*Principles and Guidelines for the Conduct of Microbiological Risk Assessment*," and "*Proposed Draft Principles and Guidelines for the Conduct of Microbiological Risk Management*." Its application is also dependent on having risk assessment and risk management teams that are familiar with the concepts, tools and limitations of both risk management and risk assessment. Accordingly, it is recommended that the members of such teams use this annex in conjunction with standard references such as the technical information developed by the World Health Organisation (WHO), the Food and Agriculture Organisation (FAO) and the Codex Alimentarius (e.g. FAO/WHO Expert Consultation on Risk Management and Food Safety-Paper N°65, Rome 1997; WHO Expert Consultation - The Interaction between Assessors and Managers of Microbial Hazards in Food, Kiel, Germany, March 2000 - The Principles and Guidelines for Incorporating Microbiological Risk Assessment in the Development of Food Safety Standards, Guidelines and Related Texts, Report Kiel, Germany, March 2002), and standard references on techniques in risk assessment, predictive microbiology, and microbiological criteria (e.g., "*Quantitative Risk Analysis*" (Vose, 1996); "*Microorganisms in Foods 7: Microbiological Testing in Food Safety Management*" (ICMSF, 2002); "*Modeling microbial responses in food*" (McKellar and Lu, 2004); *Practical Considerations on Food Safety Objectives* (Zwietering, 2005); *Determining the Microbiological Criteria for Log Rejection from the Performance Objective or Food Safety Objective* (Whiting et al., 2006).

3. Relationship between Various Risk Management Metrics

Traditional criteria for establishing the stringency of one or more steps in a food safety system include product criteria, process criteria, and microbiological criteria.

- A product criterion typically establishes a chemical or physical characteristic of a food (e.g., pH, water activity) that needs to be achieved for safety. Typically, product criteria are used to articulate conditions that will not support growth of a pathogen of concern, thereby decreasing the potential for risk to increase during subsequent distribution, marketing and preparation. Underlying a product criterion are a series of risk management decisions related to the frequency and level of the contamination in the food and/or raw ingredients that is likely to occur, the effectiveness of the control measure, the sensitivity of the pathogen to the control measure, the conditions of product use, and related parameters that ensure that a product will not have the pathogen when the product is consumed. Ideally, each of these factors that determine the effectiveness of a product criterion would be transparently considered when the criterion was being established. Used primarily with ready-to-eat products that do not support the growth of the microorganism of concern, a product criterion effectively establishes the FSO for the product.
- A process criterion (PrC) establishes the specific conditions of treatment that a food must undergo at a specific step in its manufacture to achieve a desired decrease in microbiological risk. For example, a milk pasteurization requirement of a heat treatment of 72°C for 15 seconds specifies the specific time and temperature needed to reduce the risk of *Coxiella burnettii* to an acceptable level. Underlying a process criterion should be a transparent articulation of the factors that influence the effectiveness of the treatment and the risk management decisions based on them. For the milk pasteurization example, this would include factors such as the level of the pathogens of concern in raw milk, the thermal resistance among different strains of the microorganisms, the variation in the ability of the process to deliver the desired heat treatment, and degree of risk reduction required. A fully

transparent PrC would effectively require the articulation of a PC which in turn would be based on a PO for that step in the product's manufacture.

- A MC is based on the examination of foods to determine if the frequency and/or level of a pathogen in a food exceed a pre-established limit. Such microbiological testing can either be employed as a direct control measure (i.e., each lot of food is tested and unsatisfactory lots removed) or as periodic means of verifying that a food safety system is functioning as intended. As a technologically-based, statistically based tool, a MC requires articulation of the number of samples to be examined, the size of those samples, the sensitivity of the method employed, the number of "positive" that will result in the lot of food being considered unacceptable or defective (i.e., has a concentration or percentage of contaminated servings beyond the pre-determined limit), and the probability that the pre-determined limit has not been exceeded. The effective use of a MC is dependent on a selection of a sampling plan based on the above parameters to establish the appropriate level of stringency. Since the levels of a pathogen in many foods can change over the course of their manufacture, distribution, marketing and preparation, a MC is generally established at a specific point in the food chain and that MC may not be pertinent at other points. The establishment of a MC requires articulation of a microbiological limit which is effectively a PO.

The FSO, PO and PC provide a conceptual framework for communicating the level of stringency required of a food safety system that links those values to public health outcomes predicted by an underlying risk assessment. However, their practical application requires their use to be "operationalized" through the practical defining of what is meant by "maximum frequency and/or concentration of a hazard". For example, as indicated above one use for a PO would be to identify the microbiological limit that must be specified when developing a microbiological criterion. However, such limits actually represent a specified point on what is typically assumed to be an unbounded distribution (e.g., a log normal distribution is commonly assumed). Thus, a food safety system could be operating as intended and still have a small percentage of the individual servings that exceed the PO if based solely on a frequency or concentration value. This can be avoided by either (1) developing a PO based on the distributions of both frequency and concentration, or by articulating the frequency at which the PO could be expected to be exceeded in terms of a single frequency or concentration and still be considered acceptable in relation to the overall performance of the food safety system.

As risk assessors and risk managers explore the potential uses of FSO, PO, and PC concepts, specific applications will be based on risk management decisions derived from an iterative evaluation of the impact of different PO values, both in terms of public health and practical feasibility. However, it is important to note that with a fully integrated risk assessment model and sufficient data, it should be possible to start at any of the metrics and derive the others (Figure 1). Thus, if a PO is articulated, then the FSO and the corresponding level of public health protection can be calculated. Conversely, it should also be possible to start with a public health goal (e.g., no more than 1 case of foodborne disease per 1,000,000 servings) and determine the PO, MC, and level of compliance needed at different points in the food chain to achieve that goal. However, there are specific rules and requirements for moving "forwards" and "backwards" through a risk assessment model. Risk assessment experts who are familiar with the model should be consulted to ensure proper application and interpretation of the model to risk management applications.

4. Overview of Process

The purpose of establishing metrics such as FSO, PO, and PC is to articulate in as objective and transparent manner as possible the stringency that is expected of food safety system to achieve a

level of public health protection. Key to understanding this process is that the various metrics are interconnected and ideally would be integrated so that the establishment of a metric at one point in the food chain can be related to the outcome at another. The process of establishing such metrics can be highly flexible; the process can begin with the establishment of a level of disease control that must be achieved (ALOP), a level of control of a hazard that must be achieved (PO), a required processing outcome at a specific step (PC), a microbiological criterion, etc. A risk assessment model is then used to relate to each other the various sites in the food chain where a metric is being considered to the likely public health protection outcome. This is done in a manner that the relative stringency of the system can be considered by the risk manager so that an informed decision can be taken. The steps likely to be needed in this process are:

a. Develop an appropriate risk assessment model for the product of concern.

b. Establish one or more sites along the food chain for this product where a risk management metric would be pertinent and useful for measuring the effective implementation of a food safety program. This can be anywhere along the food chain, including the public health outcome, but in most instances the likely metric will be a PO.

c. Use the risk assessment to determine the impact of different levels of control of the hazard at the points selected as PO to establish the relationship between the food safety system's degree of stringency and the consumers' exposure. Consideration of a range of potential values at that site would be beneficial to the subsequent decision-making process.

d. Use the risk assessment to derive the other risk management metrics and outcomes that would be a consequence at each of the levels of control considered.

e. Use the risk assessment to derive the criteria (MC, process criteria, product criteria) that will be used to verify that a level of stringency is being achieved.

f. Evaluate the feasibility of achieving the specific level of stringency being considered including consideration of how to assure that that level is control is being routinely met.

g. Reach a decision on the specific risk management metrics values and the corresponding verification criteria, and implement risk management program.

h. Periodically review the program using the risk assessment to evaluate the effectiveness of the initial decision.

This process follows the principles and guidance in the "*Proposed Draft Principles and Guidelines for the Conduct of Microbiological Risk Management*" to ensure transparency, scientifically sound decisions, and appropriate involvement of stakeholders.

5. Direct Use of a QMRA versus Intermediary Metrics

It is possible to directly incorporate a QMRA into the risk management process such that all acceptable risk management options are incorporated into the risk assessment model. In this approach each control measure is included as a component of the model and the level of risk achieved by the system is directly considered in terms of levels of disease expected. This effectively avoids the need to establish intermediary metrics such as PO, PC, and FSO values by directly incorporating verification criteria (MC, process criteria, product criteria) into the risk assessment model. For example, if a uniform microbiological testing program is being considered to control a foodborne hazard, the ability of the proposed sampling plan to detect unacceptable lots could be directly incorporated into the risk assessment model. This type of an approach was recently used in the risk assessment that was part of the recent international evaluation of the safety of powdered

infant formula ("*Enterobacter sakazakii* and *Salmonella* in Powdered Infant Formula" (FAO/WHO, 2006)).

It most likely that the direct use the risk assessment to determine and implement the appropriate control measures would be most applicable to situations where:

- the number of control measures (or risk management options) is limited,
- the segment of the food industry under consideration is highly uniform,
- the number of individual companies in the industry sector is small, and/or
- the risk assessment model is relatively straightforward.

In those cases, the ability to derive control measures from the risk assessment might best be in the hands of a national food safety agency or other competent body that performs the what-if scenarios needed to consider different options proposed. This would be typically used when a single or limited number of control measures would be used across the entire industry and there was a single or limited number of ways for verifying achievement of the selected level of stringency.

The direct use of risk assessment model to implement risk management decisions would be more difficult when:

- the industry is composed of a large number of individual firms,
- there is substantial diversity among the firms (e.g., risk management formulations, size of firms, technologies used to produce product, geographical conditions),
- a substantial portion of the food is imported,
- the companies propose to mitigate that risk by controlling the hazard at different or multiple sites in the food chain, and/or
- there are large differences in the percentage of a food produced by individual companies.

In the last instance, the risk would have to be limited to a "risk per serving basis" because of the small percentage of the total production (and thus overall risk) that would be attributable to any single small firm. When individual manufacturers employ substantially different combinations of control measures to manage a hazard, the ability to accurately assess their ability to achieve required levels of hazard control will require that a modified version of the risk assessment be available to consider their particular option(s). This would require that the national food safety agency, the industry, or the individual firm be able to modify the risk assessment to customize it for the individual industry's situation.

In such instances greater implementation flexibility would be achieved by establishing intermediary performance metrics that specify the level and/or frequency of contamination that should not be exceeded at specific locations in the food chain to achieve the desired level of public health protection. By knowing the degree of stringency required through the establishment of the a PO or PC, and the degree of confidence that the control authority requires to ensure that the limit is not exceeded, the industry can then develop the appropriate means for verifying that this risk-based level of pathogen control is attained. This approach also allows control authorities deal with the issues of equivalence that arises when there are both domestic and imported firms providing a food. For example, a PO could be established for an imported food at port of entry and a separate one at point of manufacture for domestic product. Using an appropriately designed risk assessment model it would be possible to set these values so that they provide an equivalent degree of public health

protection, and allow the two different segments of the industry to develop individual control measures and verification approaches.

6. Example: *Listeria monocytogenes* in cold smoked salmon

The following example was selected on the basis of it being a relatively simple product in terms of formulation, processing, manufacturing and marketing. As stated before, the example should be used for illustrative purposes only since there have been a number of simplifying assumptions to facilitate y the underlying calculations. A substantial number of studies have been conducted with this pathogen/product pair, but as expected, there are still uncertainty associated with different aspects of the pathogen and its interaction with the product. A simple quantitative risk assessment model was developed for the purpose of providing reasonably realistic examples of calculations leading to intermediary food safety risk metrics (see section 5.4). The risk assessment model can be accessed at the JIFSAN Food Safety Risk Analysis Clearinghouse (http://www.foodrisk.org/index.cfm).

6.1 The Product

Smoked seafood includes a wide variety of products including both smoked finfish and smoked bivalve shellfish. Smoked salmon is the most widely marketed species in most parts of the world. Smoked salmon is manufactured and marketed in two primary forms, cold smoked and hot smoked product. Cold smoked product is the focus of the current example. A generic flow chart for the manufacture and marketing of cold smoked salmon used in the example is depicted in Figure 1. There is substantial variation between manufacturers in terms of the details of the individual unit operations. For example, the specific timing of butchering, trimming, skinning, and slicing can vary. The salting process differs markedly between different processors; some use dry salting, others brine injection, and others submersion in brine. A portion of cold smoked salmon is distributed initially as whole fillets for subsequent slicing at the retail establishment. However, only cold smoked salmon sliced at the manufacturing plant was considered in the current example. A portion of both hot and cold smoked salmon is further processed to produce “minces”, “spreads”, and “seafood salads”. These products will not be considered in this example.

6.2 The Product and the Pathogen

There are a number of steps within the manufacture of cold-smoked salmon which influence the frequency and extent of *L. monocytogenes* contamination, but there is no distinctly listeriocidal treatment. The typical temperatures used during cold smoking are generally below 32ºC. However, the drying and exposure to smoke phenolics have been reported to produce some reduction in *L. monocytogenes* in some studies. *L. monocytogenes* contamination is dependent, in part, on the incidence of the pathogen on the incoming fish. However, the primary factors affecting the frequency and extent of *L. monocytogenes* contamination in cold-smoked product appear to be the degree of contamination from the manufacturing environment prior to final packaging and the adequacy of the cold chain during manufacturing, distribution, marketing, and consumption. The primary source of *L. monocytogenes* is the manufacturing environment, though the pathogen may be present on the raw fish entering the plant. The relative importance of the latter source increases as the degree on contamination in the manufacturing environment is reduced through effective implementation of GHP and HACCP programs. There are several steps within the manufacturing sequence (e.g., brining, thawing, slicing) where there is a high potential for the transfer of *L. monocytogenes* from one fish to another.

Smoked salmon will support the growth of *L. monocytogenes* at refrigeration temperatures, with the rate of growth being primarily dependent on the temperature of storage. The pathogen can reach elevated level (e.g., > 10^6 CFU/g) though in some instances the competing microflora can limit

growth to lower maximum values. The use of a competing microflora was not considered in the current example; it is assumed that the microorganism can reach levels of 10^8 CFU/g.

6.3 Approach for Establishing Risk Metrics

The general approach for establishing food safety risk management metrics used in this example was to:

- Initiate the process by identifying the locations of POs along the food chain,
- Identify the potential range of values for the one of the PO selected,
- Derive the corresponding values for the other POs using the risk assessment,
- Derive the FSO and corresponding level of protection (LOP) that should be achieved through the application of the corresponding set of POs.
- Derive any appropriate PC and subsequent Process Criteria that would be needed to achieve the corresponding PO,
- Derive any MC would be needed to verify that the PO was being attained.
- Consider the effectiveness of microbiological criteria as a control measure or as a means of verifying efficacy of food safety system.

Three locations along the food chain were selected for this example: the raw salmon as it enters the manufacturing facility, the product immediately after final packaging, and the product at the point of sale. These PO locations were established based on their being clearly identifiable points for all manufacturers and the likelihood that these would be the locations most likely to be used to verify the effectiveness of a manufacturer's food safety program through inspection and/or testing.

The use of a risk assessment to derive potential PO values and the subsequent metrics derived from them (e.g., PC, MC, FSO) will likely require a series of assumptions and/or simplifications. These should be clearly identified and articulated. In the current example, two such assumptions were that the concentration of *L. monocytogenes* within lots is log-normally distributed (the log values are normally distributed), and concentration across all lots is also log-normally.

The two assumptions above establish that the risk assessment is assuming unbounded distributions, i.e. there is always the potential for a high concentration value at a low frequency despite the fact that the food safety system is operating as intended. Thus, an additional assumption is the portion of the overall distribution that would exceed the PO and the distribution still considered as meeting the PO. In the current example, it is assumed that "operationalized" definition used in the risk assessment is that the PO is set at the 95 percentile, i.e., less than one serving 20 would exceed that value. Selection of this value was arbitrary but should be a value that includes most of the distribution being considered. This is not to imply that one must assume that the current level of performance is acceptable. Instead, this is done to establish the risk at different levels of stringency, i.e., multiple PO representing different levels of control are considered using the risk assessment model.

The approach taken to derive the three POs in this example was to arbitrarily establish a series of potential PO values for PO-1 (raw fish entering the cold-smoked salmon manufacturing plant) based, in part, on data available in the scientific literature. The corresponding values for the other two POs (i.e., after final packaging and at retail) were then derived using the risk assessment and the conceptual equation of the ICMSF (ICMSF, 2002) in combination with the data available from the FDA/FSIS (2003) and FAO/WHO (2004) risk assessments and the scientific literature. The ICMSF conceptual equation depicts the fact that the ability to achieve a PO (or an FSO) is dependent on the

sum of the initial contamination burden (H_o), the factors that increase extent of contamination either by permitting growth or contamination (ΣI), and the factors that decrease the level of contamination (ΣR). Thus, a PO will be achieved when:

$$\mathbf{H_o + \Sigma I - \Sigma R \leq PO}$$

When considering a product production pathway, the steps with the pathway can each be described by the same equation applied only to the preceding portion of the pathway. Thus, the PO for one segment of the manufacturing process becomes the H_o for the subsequent stage of manufacturing. This conceptual equation was used below to describe the factors affecting each of the POs for cold-smoked salmon.

As indicated above, the current example starts with the raw fish and moves its way through the manufacturing, distribution, and utilization chain. It would have been alternatively possible to start at another point in the chain (e.g., after final packaging) and derive the other PO values. However, a caution is that there are specific mathematical rules that must be followed when moving "forward" and "backward" through a risk assessment model. Experts in modeling should be routinely consulted when developing and using these models.

6.4 Risk Assessment.

As indicated above, a simple risk assessment model was developed for the purposes of this annex as a means of demonstrating a number of concepts and approaches. While greatly simplified, the model and the data values used were consistent with the scientific literature, prior and ongoing risk assessments for *L. monocytogenes,* and advice obtained from cold-smoked fish production experts. A probabilistic model was developed to demonstrate the impact of considering the variability and uncertainty associated with biological entities and responses, and approaches with dealing with them in the development of food safety risk management metrics. The variable input parameters and the range of values considered in the model are summarized in Appendix 1. It must be emphasized that, while the current risk assessment model has attempted to be realistic in terms of approach and output, the model was developed for illustrative purposes only and should be used for that purpose only.

The exposure assessment phase of the risk assessment model is divided into four segments roughly corresponding to the POs and FSO under consideration. This includes (1) the initial frequency and extent of contamination, (2) the changes in contamination levels during the manufacturing of cold-smoked salmon, (3) the changes in contamination levels between final packaging and purchase of the product, and (4) the changes in contamination levels between purchase and time of consumption. The exposure assessment is initiated by assuming one of five levels (i.e., rare, uncommon, occasional, common, very often) of initial contamination based on a frequency on contamination (i.e., 0.01, 0.1, 1, 10 and 90%, respectively). The simple exponential model for the susceptible population that was employed in the FAO/WHO *L. monocytogenes* risk assessment was used to describe the dose-response relationship in the current example. The exposure assessment and the dose-response relationship were then combined to generate a risk per serving estimate. A diagrammatic representation in the risk assessment model is provided in Figure 1.

6.5 PO-1: *Listeria monocytogenes* on the Incoming Raw Fish.

While there are some exceptions, salmon are largely slaughtered and filleted at facilities distant from the cold-smoked salmon manufacturing facility (e.g., Chilean salmon is the raw material for much of the cold-smoked salmon produced in the United States). While it is unlikely that a control authority would establish a PO for raw salmon (due to its multiple potential uses for filleted salmon), it would be advantageous for the cold-smoked salmon manufacturer to be able to articulate science-based, risk-based specification for incoming fish. Available studies generally indicate that the incidence

and concentration of *L. monocytogenes* on raw fish is typically low; however, fish from certain slaughterhouse may have a high frequency of contamination due to harborage within the plant. Using the ICMSF conceptual equation, the attainment of PO-1 would be dependent on the control of the H_o, ΣR, and ΣI for the raw fish up to the point of receipt.

$$\mathbf{PO\text{-}1 \geq H_{o\text{-}1} + \Sigma I_1 - \Sigma R_1}$$

The achievement of PO-1 would be dependent on activities happening largely outside the manufacturing facility:

- Control the initial level of *L. monocytogenes* on the fish prior to slaughter ($H_{o\text{-}1}$),
- Limit increases in *L. monocytogenes* due to growth and further contamination at slaughter and during transport (ΣI_1), and
- Intervention technologies and hygiene programs that reduce the level of contamination (ΣR_1).

Two simplifying assumptions made in the risk assessment related to PO-1 were (1) the levels of *L. monocytogenes* on any contaminated fish had a known distribution with median value of 1 CFU/g and (2) immediately after receipt the contaminated and uncontaminated fish were co-mingled such that the contamination was evenly distributed across all fish within a production lot. This allowed the frequency of contamination to be calculated (Table 1).

Table 1. The mean log concentrations of *Listeria monocytogenes* on raw fish after co-mingling based the initial frequency of contamination and an assumed initial median concentration level on the contaminated fish of 1 CFU/g (Log(CFU/g) = 0)(lognormal distribution, standard deviation = 3 CFU/g (Log(CFU/g) = 0.477)).

Initial Frequency of Contaminated Fish (%)	Mean of theLog Concentration After Co-mingling [Log(CFU/g)]	Upper 95% Value [Log(CFU/g)]
0.01	-4.00	-3.31
0.1	-3.00	-2.21
1.0	-2.00	-1.21
10.0	-1.00	-0.21
90.0	-0.50	+0.74

Assuming that PO-1 has been operationally defined as the upper 95% value than the effective PO at this stage based on initial frequency of contamination would effectively be -3.31, -2.31, -1.31, -0.21, +0.74 Log(CFU/g) for a contamination rates of 0.01, 0.1, 1, 10, and 90%, respectively. These values are arrayed in Table 2.

Table 2. Potential PO-1 values based on levels (Log(CFU/g)) of *Listeria moncytogenes* in raw fish entering a manufacturing facility derived using the risk assessment from arbitrarily selected values for the frequency of contamination of raw salmon.

PO-1 [Log(CFU/g)]	PO-2 [Log(CFU/g)]	PO-3 [Log(CFU/g)]	FSO [Log(CFU/g)]	LOP [Log(Probability of a case of listeriosis per serving)]
-3.31				
-2.21				
-1.21				
-0.21				
+0.74				

6.6. PO-2: *Listeria monocytogenes* in Product after Final Packaging

Once in the manufacturing site and co-mingled, *L. monocytogenes* on the raw fish have the potential to grow, depending on the time and temperature of the manufacturing process. Furthermore, the primary source of *L. monocytogenes* in most manufacturing facilities is believed to be the manufacturing environment. If *L. monocytogenes* from the manufacturing environment contaminate the fish, they also have the potential to grow to an extent that is a function of the times/temperatures of the manufacturing process. The risk assessment model considers both of these as the primary factors affecting the level of *L. monocytogenes* in the product.

The second PO was selected as the level (Log(CFU/g)) of *L. monocytogenes* in the product immediately after final packaging. Again using the ICMSF conceptual model, the ability to attain PO-2 can be expressed by:

$$\mathbf{PO\text{-}2 \geq H_{o\text{-}2} + \Sigma I_2 - \Sigma R_2}$$

For PO-2, the H_{o-2} value is the level of contamination on the raw fish which is, in turn, determined by the manufacturer's ability to ensure that PO-1 value has been achieved.

Using the input values for this stage of the risk assessment depicted in Appendix 1, the predicted mean log concentration for each of the potential levels of *L. monocytogenes* on the raw fish were used to calculate the levels expected when the product is packaged (Table 3). Again assuming that PO-2 is operationalized at the 95% level, than the corresponding PO-2 values for each PO-1 value is summarized in Table 4.

Table 3. The mean of the log concentrations of *Listeria monocytogenes* on cold-smoked salmon immediately after final packaging predicted by the risk assessment based on initial frequency of contamination raw fish, additional environmental contamination in the manufacturing facility and growth of the microorganism during the manufacturing process.

Initial Frequency of Contaminated Fish (%)	Mean of theLog Concentration at Final Packaging [Log(CFU/g)]	Upper 95% Value [Log(CFU/g)]
0.01	-2.95	-2.14

0.1	-1.95	-1.14
1.0	-0.95	-0.14
10.0	+0.05	+0.86
90.0	+1.01	+1.82

Table 4. Potential PO-2 values derived from the risk assessment based on levels (Log(CFU/g)) of *Listeria moncytogenes* predicted in the cold-smoked salmon at the point of final packaging.

PO-1 [Log(CFU/g)]	PO-2 [Log(CFU/g)]	PO-3 [Log(CFU/g)]	FSO [Log(CFU/g)]	LOP [Log(Probability of a case of listeriosis per serving)]
-3.31	-2.14			
-2.21	-1.14			
-1.21	-0.14			
-0.21	+0.86			
+0.74	+1.82			

6.7. PO-3. *Listeria monocytogenes* in Cold-smoked Salmon at Point of Sale

The point of sale was selected as the site for PO-3. The level of *L. monocytogenes* in the product at that point is the initial level of the microorganism at the point of final packaging ($H_{o-3,}$ which is dependent of PO-2) plus any growth.

$$\textbf{PO-3} \geq H_{o-3} + \Sigma I_3 - \Sigma R_3$$

The extent of growth is dependent on the temperature and duration of storage during distribution and marketing. Since the product is typically in a sealed package, ΣI_3 is not affected by additional environmental contamination. Since there are no antimicrobial or listericidal treatments at this point, $\Sigma R_3 = 0$. The distribution of times and temperatures considered in the risk assessment model are provided in Appendix 1. The levels of *L. monocytogenes* predicted in the product at the point of sale for the original raw fish contamination groups is depicted in Table 5 and the potential PO-3 values based on the 95% value is depicted in Table 6.

Table 5. The mean log concentrations of *Listeria monocytogenes* on cold-smoked salmon at time of sale predicted by the risk assessment based on initial frequency of contamination raw fish, additional environmental contamination in the manufacturing facility and growth of the microorganism during the manufacturing process and subsequent distribution and marketing.

Initial Frequency of Contaminated Fish (%)	Mean of theLog Concentration at Point of Sale [Log(CFU/g)]	Upper 95% Value [Log(CFU/g)]
0.01	-2.38	-1.51
0.1	-1.38	-0.51
1.0	-0.38	+0.49
10.0	+0.62	+1.49
90.0	+1.57	+2.44

Table 6. Potential PO-3 values derived from the risk assessment based on levels (Log(CFU/g)) of *Listeria moncytogenes* predicted in the cold-smoked salmon at the point of sale.

PO-1 [Log(CFU/g)]	PO-2 [Log(CFU/g)]	PO-3 [Log(CFU/g)]	FSO [Log(CFU/g)]	LOP [Log(Probability of a case of listeriosis per serving)]
-3.31	-2.14	-1.51		
-2.21	-1.14	-0.51		
-1.21	-0.14	+0.49		
-0.21	+0.86	+1.49		
+0.74	+1.82	+2.44		

6.8. FSO: Level of *Listeria monocytogenes* Present in a Cold-Smoked at the Time of Consumption

The fourth and final phase of the exposure assessment phase of the risk assessment was the period between purchase and consumption. The initial level of the pathogen during this phase is the level in the package at the time of sale, i.e., Ho_{-4}, which is determined by PO-3. As in the preceding phase, the product can support growth, with the extent of growth being dependent on the temperature and duration of storage within the home prior to consumption. For the sake of simplicity it was assumed that the product remained sealed until consumed so that ΣI_4 is not affected by additional environmental contamination. Again, since there are no antimicrobial or listericidal treatments prior to consumption, $\Sigma R_4 = 0$. Since the phase ends in the consumption of the product, the value being considered is an FSO instead of a PO.

$$\mathbf{FSO \geq H_{o\text{-}4} + \Sigma I_4 - \Sigma R_4}$$

The distribution of times and temperatures considered in the risk assessment model are provided in Appendix 1. The levels of *L. monocytogenes* in the product at the time of consumption predicted for the original raw fish contamination groups are depicted in Table 7 and the potential FSO values based on the 95% confidence level is depicted in Table 8.

Table 7. The mean log concentrations of *Listeria monocytogenes* on cold-smoked salmon at point of consumption predicted by the risk assessment based on initial frequency of contamination raw fish, additional environmental contamination in the manufacturing facility and growth of the microorganism during the manufacturing process, subsequent distribution and marketing, and storage in the home before consumption.

Initial Frequency of Contaminated Fish (%)	Mean of the -Log Concentration at Consumption [Log(CFU/g)]	Upper 95% Value [Log(CFU/g)]
0.01	-1.26	+0.13
0.1	-0.26	+1.13
1.0	+0.74	+2.13

10.0	+1.74	+3.13
90.0	+2.69	+4.09

Table 8. Potential FSO values derived from the risk assessment based on levels (Log(CFU/g)) of *Listeria moncytogenes* predicted in the cold-smoked salmon at the point of consumption.

PO-1 [Log(CFU/g)]	PO-2 [Log(CFU/g)]	PO-3 [Log(CFU/g)]	FSO [Log(CFU/g)]	LOP [Log(Probability of a case of listeriosis per serving)]
-3.31	-2.14	-1.51	+0.13	
-2.21	-1.14	-0.51	+1.13	
-1.21	-0.14	+0.49	+2.13	
-0.21	+0.86	+1.49	+3.13	
+0.74	+1.82	+2.44	+4.09	

6.9. Calculation of the Level of Protection

Once the exposure assessment is completed, the next phase is to generate the risk characterization by combining the level of *L. monocytogenes* expected in the product, the amount of the product consumed, and the dose-response relationship. The amount of product consumed is a variable and the current example considered a range of serving sizes (see Appendix 1). The risk is expressed in terms of Log(probability of an illness from a serving of cold-smoked salmon). Thus, a risk of -6.0 would be that one serving per million would lead to a case of listeriosis. The predicted levels of protection associated with the product predicted based on the original grouping of contamination levels for original raw fish are depicted in Table 9. Again assuming that this is operationalized at a 95% confidence level, the LOP values for each initial contamination level is provided in Table 10.

Table 9.

Initial Frequency of Contaminated Fish (%)	MeanPredicted Cases of Listeriosis per Serving [Log(cases/ serving)]	Upper 95% Value [Log(cases/serving)]
0.01	-11.53	-10.11
0.1	-10.53	-9.11
1.0	-9.53	-8.11
10.0	-8.53	-7.11
90.0	-7.53	-6.11

Table 10. Potential LOP values derived from the risk assessment based on the predicted number of *Listeria moncytogenes* consumed per serving of cold-smoked salmon.

PO-1 [Log(CFU/g)]	PO-2 [Log(CFU/g)]	PO-3 [Log(CFU/g)]	FSO [Log(CFU/g)]	LOP [Log(Probability of a case of listeriosis per serving)]
-3.31	-2.14	-1.51	+0.13	-10.11
-2.21	-1.14	-0.51	+1.13	-9.11
-1.21	-0.14	+0.49	+2.13	-8.11
-0.21	+0.86	+1.49	+3.13	-7.11
+0.74	+1.82	+2.44	+4.09	-6.11

7. Selecting the ALOP

The approach taken in the example was to use the risk assessment to explore a range of potential PO values and their derived FSO and LOP starting with an initial contamination level on the raw fish and assuming series of assumed of increases and reductions. This approach was considered to have the advantage of not having the risk assessors make the decision concerning what is the appropriate level of protection (ALOP). In this example it is important to distinguish between a LOP and an ALOP. The LOP is the degree of public health protection that would be achieved if a specific level of control (i.e., stringency) was attained. However, it does not become the ALOP until it has been selected and implemented as the level of stringency that is expected or required of a food safety system.

At this point the risk managers would need to evaluate the risk assessment derived "what-if" scenarios above to determine the feasibility and impact of the different PO values considered. It is presumed that the risk managers have data available regarding the current capabilities of the industry plus the potential for mitigation. This information would need to be balanced against the public health impact. It is important that the risk managers fully understand the likely impact that setting a specific PO value will have in terms of both public health impact and regulatory outcomes. If for example a PO is set at a value that encompasses 99.9% of the current capability and output of the industry that would indicate that the current level of stringency is adequate and appropriate. Conversely, if the PO was set at a point that encompasses only 80% of the industry, this would require a substantial increase in stringency once the corresponding LOP was accepted as the ALOP. The immediate impact of establishing such a PO will mean that the application of other derived metrics (e.g., MC) used to verify will result in rejection of a substantial portion of food lots, particularly for manufacturers that consistently produce product containing the hazard at concentrations close to the PO (see Section 9).

It is also important to note that the decision to select a specific LOP as the ALOP is a complex risk management decision that should involve the principles and practices recommended in the Codex Alimentarius Committee on Food Hygiene "*Proposed Draft Principles and Guidelines for the Conduct of Microbiological Risk Management*." As hopefully demonstrated with the above example, the ability to utilize risk assessment tools to link control measures and/or intermediary metrics to public health outcomes can be a highly useful tool for taking a decision on an ALOP.

8. Alternate Approaches

The current annex describes one example in detail and mentions another briefly. There are a number of potential approaches for using risk assessment to help establish performance metrics to link the stringency of a food safety system to its public health outcome. For example, the current example used a probabilistic risk assessment to establish the relationship between the stringency of the food safety system and ultimate exposure of the cold-smoked salmon consumer to *L. monocytogenes*. Alternatively, a deterministic model could have been employed, an approach that offers both advantages and limitations.

The current example started with the consideration of different PO values at selected points in the food chain on the LOP, the selection of one such LOP as the ALOP, and the subsequent derivation of a MC. However, alternative approaches could have started with a consideration of public health outcome (e.g., an incidence of disease), a microbiological criterion, or a processing criterion. . One such approach could be to use the risk assessment to determine the exposure anticipated produced under a HACCP system using agreed upon "best practices." The PO could then operationalized by considering the lots with the highest level of *L. monocytogenes* that would be expected when the best practices are being followed (e.g., set the PO = mean + 3 standard deviation). An MC could then be calculated to ensure that lots that exceed the PO are rejected at a high probability. A third approach could be to determine the distribution of *L. monocytogenes* levels in existing production lots and set a MC on the basis of public health concerns and industry capabilities such that lots with the highest concentration levels would be rejected. The risk assessment could be used to calculate the effective PO at that point in the food chain that the product is subjected to microbiological testing and the resultant FSO and ALOP at point of consumption. As an evolving area of endeavor, a variety of other new approaches, applications, and techniques will undoubtedly be suggested and tried in the future. As such, it is important that each such risk evaluation be appropriately reviewed for technical accuracy, preferably by risk assessment experts, subject matter experts, and interested stakeholders.

It is impossible to provide guidance that will cover all potential future applications. In such instances, this diversity of approaches requires means for assessing the validity of the metrics derived. This can be augmented through the principles and guidance provided in the Codex Alimentarius "*Principles and Guidelines for the Conduct of Microbiological Risk Assessment*," and "*Proposed Draft Principles and Guidelines for the Conduct of Microbiological Risk Management*." In particular, the application of principles of transparency and involvement of stakeholders can help ensure that risk assessment techniques to the establishment of food safety performance metrics. A number of national governments have specific requirements for the peer review and involvement of stakeholders in the development of risk assessments and their application to risk management decision making. Furthermore, a key principle for the conduct of both risk management and risk assessment is the periodic review of decisions and evaluations.

9. Verifying Achievement of Food Safety Performance Metrics through the Establishment of Microbiological Criteria.

An FSO is not likely to be verified since it reflects the level of control at the time on consumption. Instead, verification of the ongoing ability of a food safety system to achieve a specified level of stringency would most likely be at the site of a PO. As discussed in the "*Proposed Draft Principles and Guidelines for the Conduct of Microbiological Risk Management,*" there are several different approaches to verifying compliance with a PO. One approach, when appropriate, is microbiological testing against established microbiological criteria. It is important to note that a MC is distinctly different from a PO; the PO is the value from which the MC can be derived to link its stringency to a specific level of protection.

The traditional use of MC has been as a control measure to test each individual lot of a product to ensure at a specified probability that a lot of a food conforms to an established standard or limit. It is based on the assumption that the examiner has no previous knowledge of the lot. Often termed "lot-by-lot testing" or "within-lot testing," a sampling and testing plan is developed to reject lots, that at a designated probability, that exceed the PO. The other form of MC is to periodically verify that a food safety system is functioning as intended by taking a limited number of samples over time across multiple lots. Referred to as "between-lot testing" or "process control verification testing," this involves limited, periodic testing of multiple lots produced by a single manufacturing facility. This type of microbiological testing is well suited for a facility working under a HACCP program as a verification tool. This type of testing is most effective when based on extensive knowledge of the product and how it was manufactured. For the purposes of the current example, the relationship between MC and PO will be examined only for lot-by-lot testing, i.e., for simplicity it was assumed that every lot was being tested. Standard references are available to describe the differences between the two approaches (ICMSF, 2002).

When a manufacturer or a control agency need to use microbiological testing to verify that a PO is being achieved, they must, of necessity, move from a PO to a MC. This reflects the fact that a PO establishes a decision point between what is considered safe and what is not, whereas a MC establishes the testing scheme to determine if that limit is achieved. In addition to establishing the microbiological limit, the MC also specifies the methods, sampling plans, the type of testing (i.e., attribute (presence/absence) vs. variable (quantitative) testing), decision criteria, and the actions that are to be taken when the limit is exceeded. Standard references on the types of microbiological testing programs and the statistical basis for sampling plans are available (ICMSF, 2002). Experts in microbiological testing and sampling plans should be consulted when developing an MC.

9.1. Example: MC for PO-3

For the purpose of demonstrating one approach to establishing a MC based on a PO, the development of a MC was considered for use in conjunction with PO-3 (PO at retail, see 5.7). For the purpose of the current example, it has been assumed that the MC entails a 2-class attribute sampling plan that will accept or reject the lot being sampled. A 2-class attribute sampling plan is used in conjunction with presence/absence data or with "binned" quantitative data such as < 1 CFU/g vs. ≥ 1 CFU/g. Presence/absence attribute testing involves taking a specific number of samples (n) of a specific size (s) and testing them independently for the presence of the pathogen using a method that is capable of detecting the pathogen at a specified level (m). For the current example, it is assumed that the methods used are capable of detecting 1 CFU with the sample examined. An MC includes a term, c, which indicates the number of samples that can be positive and still have the lot considered acceptable. However, the c for an infectious agent such as *L. monocytogenes* is typically set at $c = 0$ (i.e., any positive sample is sufficient to reject the lot). The overall stringency of the MC can be set by manipulating the n, m, and c values. The MC also includes a probability that a non-conforming lot will be detected and rejected.

The approach taken was to consider the three most stringent PO-3 values described in Table 6. The general approach was to select a lot of cold-smoked salmon that was just at the "operationalized" PO-3 value, i.e. 95% of the samples taken from the lot will not exceed the PO-3 value. The mean of the log concentrations of that lot was then calculated. This requires an estimate of the "within-lot" standard deviation (as opposed to the total standard deviation for all lots that was originally calculated in the risk assessment). In the current example it is assumed that the "within-lot" standard deviation is 0.25 Log(CFU/g). This implies that the mean log concentration of the lot that is just rejected is 1.64 standard deviations lower than the PO-3, i.e., the mean of the log concentrations = PO - (1.64 x 0.25) = PO - 0.41. After the m-value was set for the level of contamination expected,

the number of samples required was calculated for different rejection probabilities. These calculations are summarized in Table 11.

Table 11. Potential microbiological criteria for PO-3 to verify with a specified degree of confidence that PO-3 is not exceeded.

PO-3 [Log(CFU/g)]	Mean Level of *L. monocytogenes* in a Lot that Just Fails PO-3 [Log(CFU/g)]	Sample Size (g)	Sensitivity of the Method (m) [Log(CFU/g)]	Number of Samples Required to Achieve Specific Probability of Rejecting the Lot (P_{rej})		
				0.90	0.95	0.99
-1.51	-1.92	100	-2.0	3	3	5
		50	-1.7	11	15	22
-0.51	-0.92	10	-1.0	3	3	5
		5	-0.7	11	15	22
+0.49	+0.08	1	0.0	3	3	5
		0.5	+0.3	11	15	22

*Calculated values round up to the nearest whole sample.

The establishment of a MC by a food safety authority is typically based on controlling the risk to the consumer, i.e. ensuring to a high probability that a non-conforming lot would be detected and thus rejected. However, it is important to note that in the actual implementation of a MC there will be a calculable number of lots that actually meet PO-3 that would be detected as exceeding it based on the detection of *L. monocytogenes* during testing. The extent to which lots that meet the PO are rejected is dependent on the operating characteristics of the sampling plan (i.e., required P_{rej}, m, n, c) and the mean log concentration of *L. monocytogenes* in the lot being evaluated. From the current example (Table 11), if a PO-3 = -0.5.1 Log(CFU/g) was selected and used to establish a MC where n = 15, m = -0.699 Log(CFU/g), and c = 0, the probability that a lot would be rejected as a function of the mean of the log concentration of the lot being examined is depicted in Table 12.

Table 12. The effect that the mean of the log concentration of *L. monocytogenes* has on the rejection of lots for a sampling plan having n = 15, m = 0.669 Log(CFU/g), and c = 0 based on a PO-3 of -0.51 CFU/g (see Table 11).

Mean Concentration of *L. monocytogenes* in a Lot [Log(CFU/g)]	Percentage of Time Such a Lot Would Be Rejected (%)
-1.750	0.0
-1.500	1.0
-1.375	5.0
-1.313	10.0
-1.200	29.0
-1.150	41.9
-1.100	56.7
-1.050	71.4
-1.000	83.8
-0.927	95.0
-0.855	99.0
-0.700	100.0

It is readily apparent that a manufacturer could not economically continue to operate with this sampling plan at levels that approaches the PO. Often referred to as the producer's risk, the manufacturer would have to increase the stringency of their operations to reduce the level of positive findings (both true and false positives). In the current example (Table 12), if the manufacturer could ensure that the worst lot did not exceed a mean log concentration of -1.500, then their rejection rate would be less than 1%. This could be accomplished by decreasing the overall mean log concentration of *L. monocytogenes* in the lots of products that it produces (without changing the standard deviation), decreasing the variability between individual lots (without changing the mean), or a combination of the two. Potentially, decreasing the within lot standard deviation would produce a small decrease in the rejection rate, but this effect is generally minimal.

In practice, reducing the producer's risk is generally achieved through a combination of both approaches. Such reductions in the overall mean of the log concentrations or standard deviations of lots would require modifications of the parameters effecting the growth and/or survival at earlier steps in the process. For example, in the current example it might be achieved by reducing the frequency of fish initially contaminated with *L. monocytogenes* was less than 0.1% (PO-1) or the implementation of a HACCP program that help ensure that the increase in *L. monocytogenes* concentration between PO-1 and PO-2 was less than the currently calculated 1.07 Log(CFU/g).

The relationship between the overall mean of the log concentration of L. monocytogenes and the corresponding standard deviation is explored in more detail in the examples depicted in Figure 3 using the PO-3 = -0.51 Log(CFU/g) from Table 10 and the n = 15 / m= -0.699 Log(CFU/g) sampling plan from Table 11. It is apparent that the operating characteristics of this sampling plan are such that the sampling plan ensures a high probability that the lots exceeding the PO are rejected (i.e., low consumer risk), but also results in a substantial number of lots that meet the PO also being rejected (i.e., high manufacturer risk) (Figure 3A). Three hypothetical responses by manufacturers are considered as a result of the implementation of the PO. The first is a modification of the manufacturing process or plant environment such that the mean of the log concentration of *L. monocytogenes* in the lots of foods is reduced without reducing the standard deviation (e.g., implementation of a listericidal step for incoming raw fish, enhanced sanitation program) (Figure 3B). The second is a change that results in a reduction in the standard deviation among the lots without affecting the mean (e.g., initiation of a HACCP program) (Figure 3C). The final one example is implementation of a series of mitigations that reduce both the lot means and the standard deviation (e.g., enhanced sanitation program plus inclusion of listeriostatic ingredient) (Figure 3D).It is important to note that such programs that when a manufacturer implements a higher level of stringency to reduce their risk of lot rejection, this adds an additional degree of risk reduction for consumers beyond that which was estimated in setting the original PO and MC.

10. Summary

The application of quantitative risk assessment techniques to food hygiene is increasingly allowing the impact of control measures to be more quantitatively linked to food safety outcomes. The current annex provides a limited number of examples of how the embracing of a risk analysis paradigm by Codex Alimentarius can be implemented, at least for food hygiene. However, it is beyond the scope of the annex to outline all potential approaches and applications. Instead, the use of risk assessment techniques to better inform the development, implementation, and review of food hygiene risk management programs will require the ongoing interaction between CCFH and the scientific and risk assessment community both through the involvement of experts in the delegations to CCFH, and through the interaction of CCFH with international organizations that provide scientific advice (e.g., FAO, WHO, ICMSF) and groups that support them (e.g., WHO Collaborating Laboratories).

11. References

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Whiting, R. C., Rainosek, A., Buchanan, R. L., Miliotis, M., LaBarre, D., Long, W., Ruple, A., and Schaub, S. Determining the Microbiological Criteria for Log Rejection from the Performance Objective or Food Safety Objective. Internat. J. Food Micribiol. 110:263-267. 2006.

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12. Figure Legends

Figure 1. Relationship between the various food safety metrics.

Figure 2. Flow chart for the manufacture of cold-smoked salmon.

Figure 3. Examples of reducing the manufacturer's risk of lot rejection associated with a microbiological criterion by reduction in mean of the log concentration of *Listeria monocytogene*s of lots and/or reduction in the standard deviation of lots.

Baseline probability of rejection based on original risk assessment scenario (see text).

A. Implementation of a control measure(s) that reduces the mean of the log concentration of lots without affecting the standard deviation.

B. Implementation of a control measure(s) that reduces the standard deviation among lots without affecting the mean concentration.

C. Implementation of a control measure(s) that reduces both the mean concentration and standard deviation of lots.

Appendix 1. Inputs for the Smoked fish risk assessment baseline model with environmental contamination

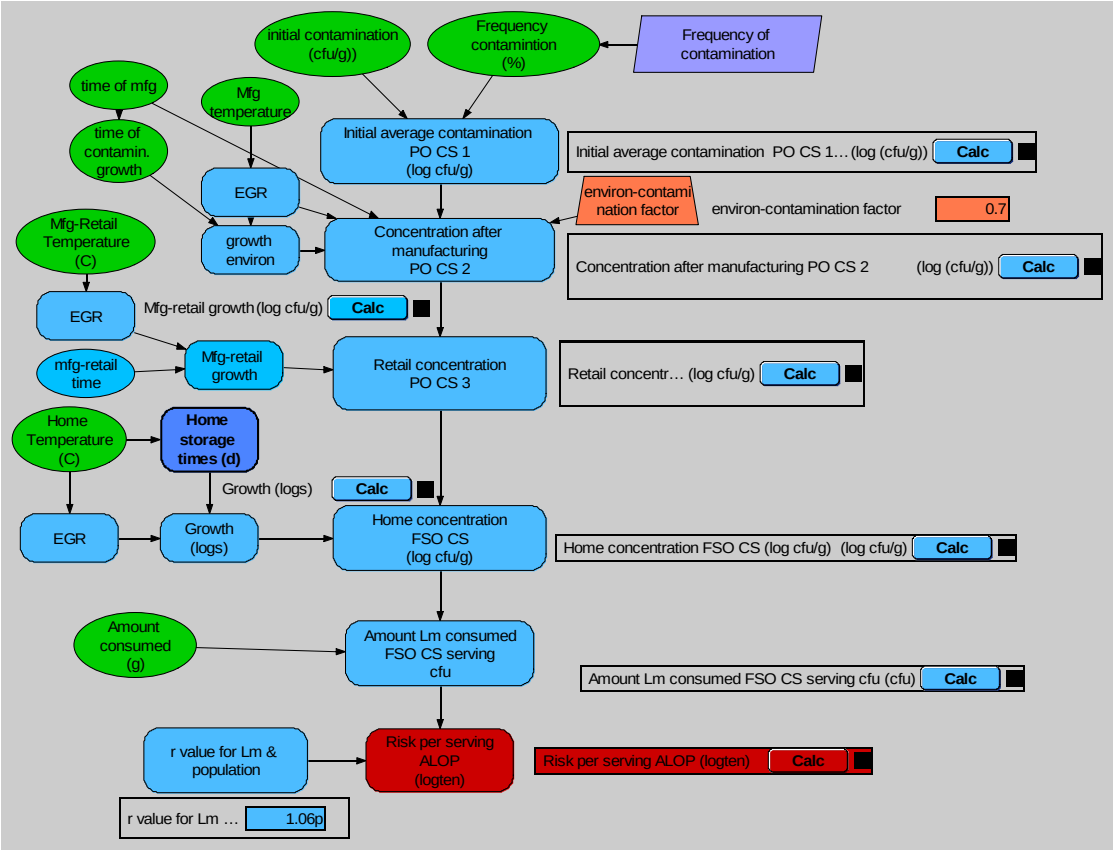
Initial contamination	lognormal (1, 3)		cfu/g
Frequency of contamination	very low	0.01	%
	rare	0.1	
	on occasion	1.0	
	common	10	
	very often	90	
Manufacturing temp	triangle (2, 4, 6)		°C
Manufacturing time	triangle (3, 3.5, 4)		d
Time for environmental contamination	uniform (1, Manf. Time)		d
Environmental contamination factor	0.7		
contamination	Note: inverse Log = 5, ratio of from fish:environment is 1:5		
Exponential growth rate	= 0.152 * ((temp – 1.18)/6.18)^2		
Manufacture-retail storage temperature	normal (3.0, 0.3)		°C
Manufacture-retail storage time	Weibull (3, 9)		d
Home temperature	beta (2.0, 5.0, 0, 18)		°C

Home storage time matrix

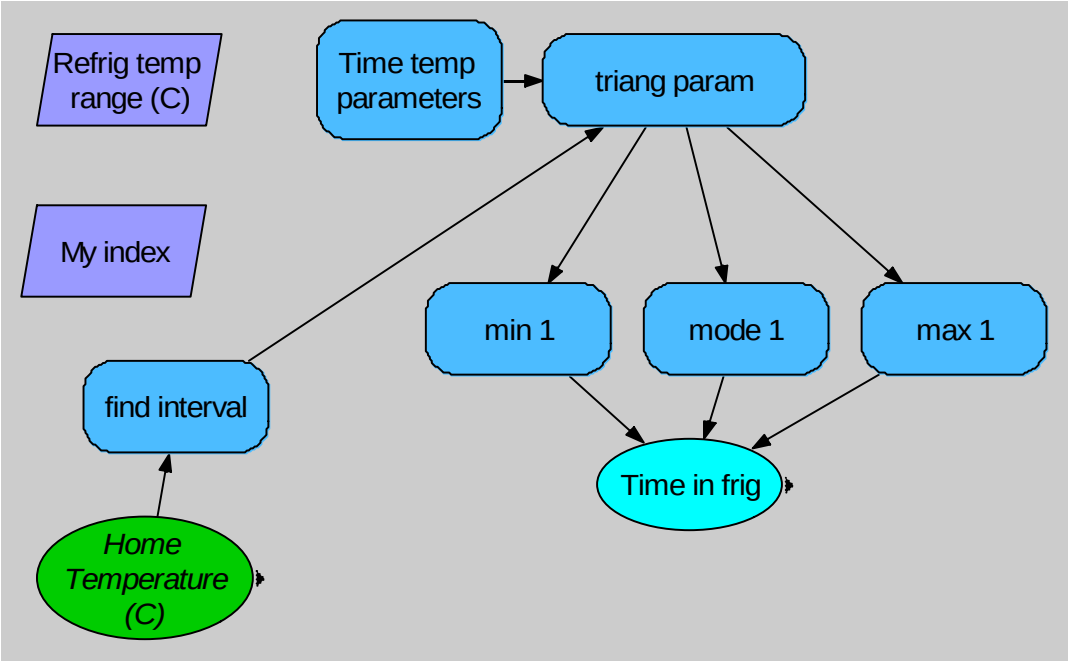
Temp	Storage time (triangle dist) (d)		
(°C)	minimum	mode	maximum
0	0	7	30
2	0	6	23
4	0	5	16
6	0	4	12
8	0	3	8
10	0	2	6
12	0	1	4

Amount consumed	Triangle (5, 46, 120)	g
r-value	1.06×10^{-12}	
Exponential model	$p = \log (1 - \exp(-Nr))$ illnesses per	
	N not in logarithms	serving

Influence diagram of risk assessment model



Influence diagram of home storage times (d) module



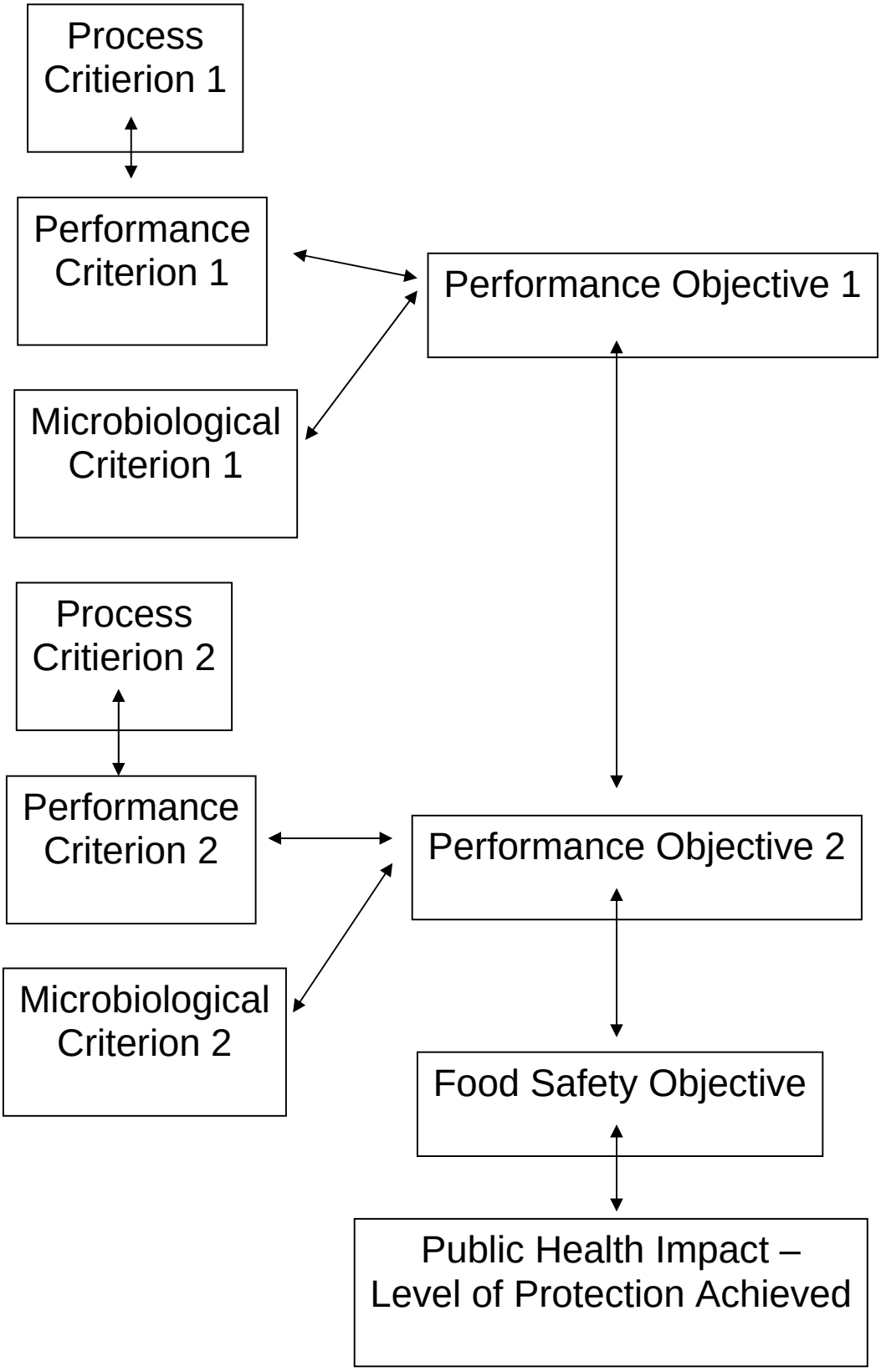

Process Critierion 1
Performance Criterion 1
Performance Objective 1
Microbiological Criterion 1
Process Critierion 2
Performance Criterion 2
Performance Objective 2
Microbiological Criterion 2
Food Safety Objective
Public Health Impact – Level of Protection Achieved

Figure 1.

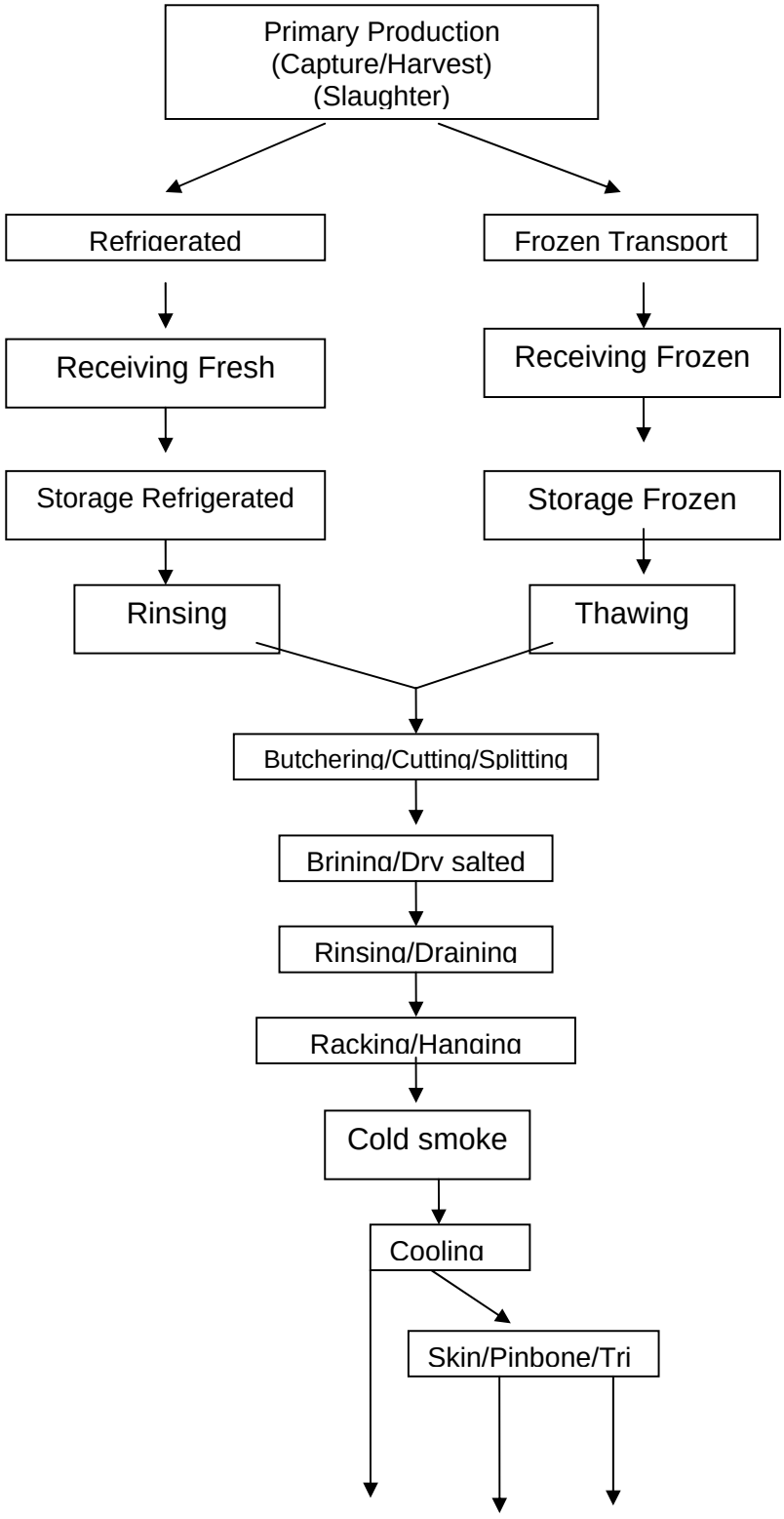

Primary Production
(Capture/Harvest)
(Slaughter)
Refrigerated
Frozen Transport
Receiving Fresh
Receiving Frozen
Storage Refrigerated
Storage Frozen
Rinsing
Thawing
Butchering/Cutting/Splitting
Brining/Dry salted
Rinsing/Draining
Racking/Hanging
Cold smoke
Cooling
Skin/Pinbone/Tri

Figure 2.

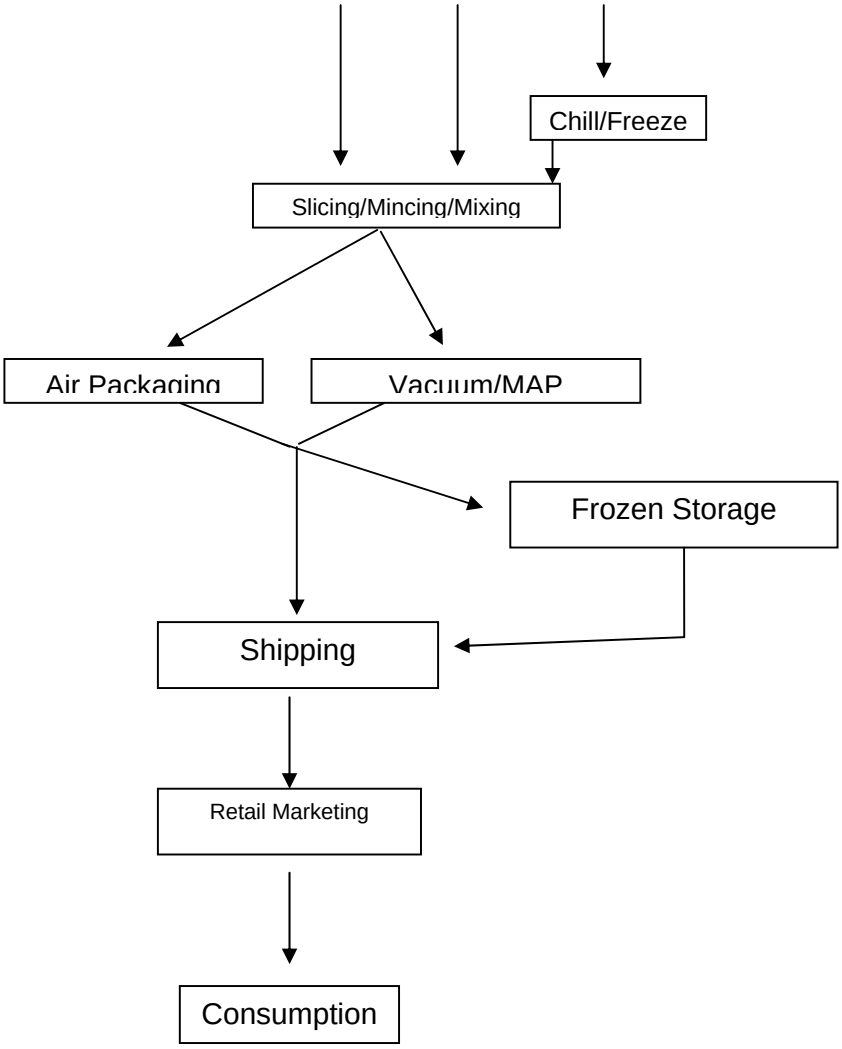
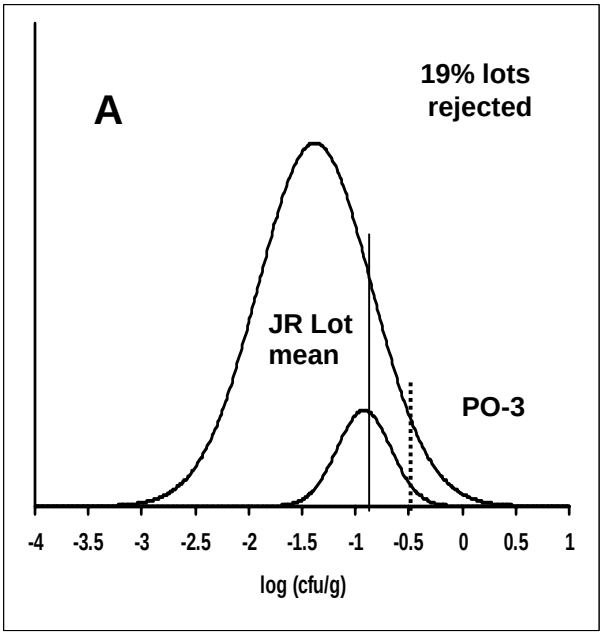


Figure 2. (continued)

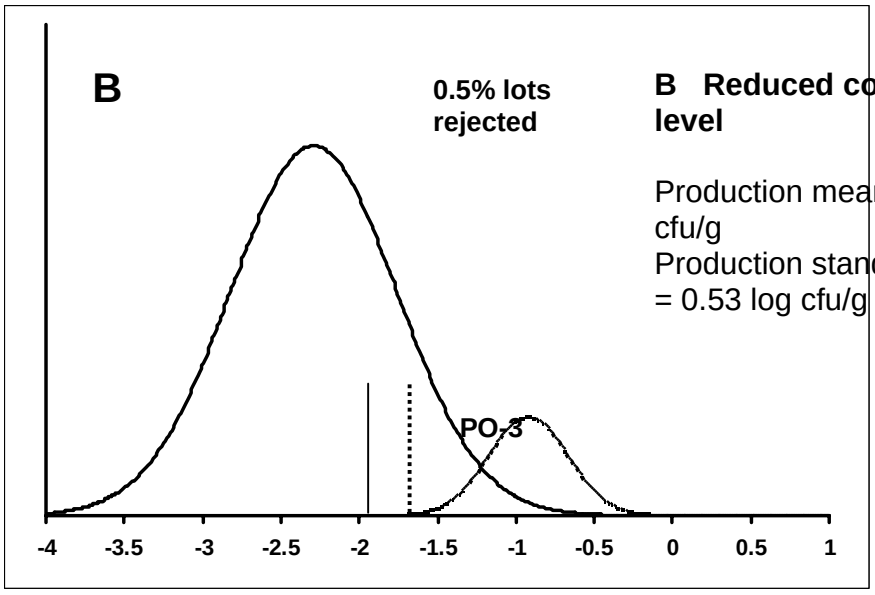


A Original parameters from risk assessment

0.1% Contamination
PO-3 set at 95% of lots = -0.51 log cfu/g

Production mean = -1.38 log cfu/g
Production standard deviation = 0.53 log cfu/g

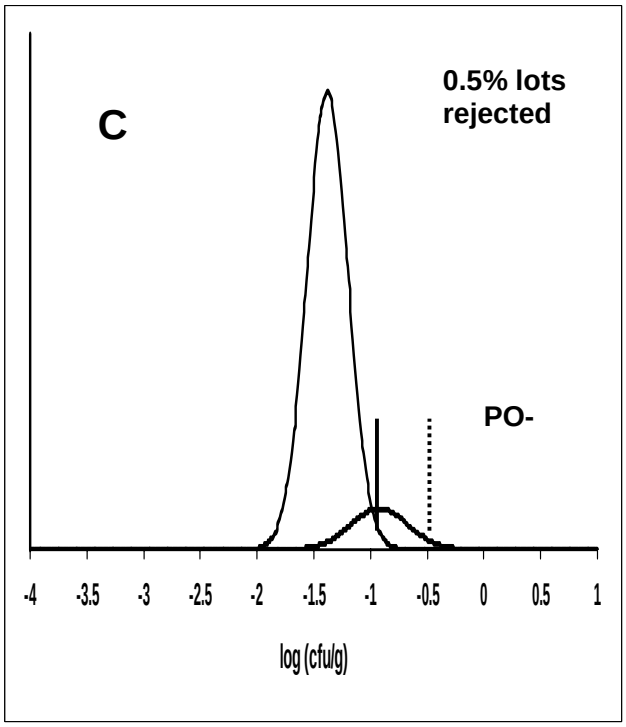
MC
Just Reject lot mean = -0.92 log cfu/g
Lot standard deviation = 0.25 log cfu/g
Sample = 5 g, m = -0.70 log cfu/g
C = 0, n = 15, 95% CL



B Reduced contamination level

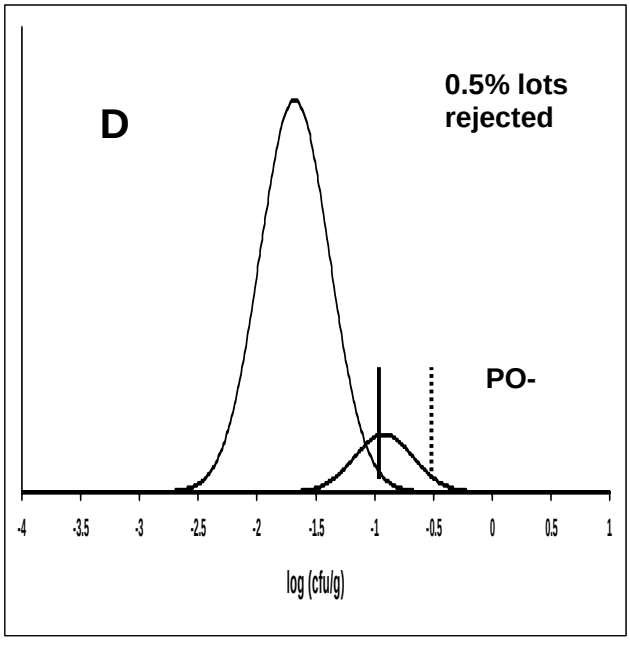
Production mean = -2.29 log cfu/g
Production standard deviation = 0.53 log cfu/g

Figure 3.



C Reduced standard deviation

Production mean = -1.38 log cfu/g
Production standard deviation = 0.18 log cfu/g



D Reduced standard deviation and mean

Production mean = -1.68
Production standard deviation = 0.295

Figure 3, continued

ANNEX IIIB. EXAMPLES OF APPROACHES FOR UTILIZING QUANTITATIVE MICROBIAL RISK ASSESSMENT TECHNIQUES TO LINK THE STRINGENCY OF CONTROL MEASURES TO HYGIENE OUTCOMES AND METRICS

7. Introduction

The rapid advancement of quantitative microbiological risk assessment (QMRA) techniques is producing new capabilities for linking traditional means for establishing the stringency of food safety systems (e.g., microbiological criterion (MC), process criterion, product criterion) to the level of public health protection that the system is intended to achieve. The availability of increasingly sophisticated risk assessment models makes it possible for risk assessors to predict the relative risk reductions that can be achieved through the inclusion of different risk mitigations strategies (i.e., control measures), including estimating the number of foodborne disease prevented. Conversely, the same tools make it possible to start with public health and derive the degree of stringency required of a food safety system to achieve the desired level of protection. These new capabilities are dramatically changing the level of scientific rigor and transparency associated with the establishment of food safety requirements and/or guidance. It has also led to a series of new food safety risk management concepts and metrics, such the food safety objective (FSO), Performance Objective (PO), Performance Criteria (PC), that provide a framework for "operationalizing" the concepts envisioned in the WTO SPS Agreement.

While these concepts are increasingly being embraced by the risk assessment community as a logical extension of QMRA to describe the performance needed of food safety systems to achieve a desired degree of public health protection, their practical application within an international or national food safety risk management framework is still in its infancy. In particular, the risk assessment tools for linking the establishment of traditional criteria and other guidance for the hygienic manufacture, distribution, and consumption of foods and its anticipated public health impact can be complex and not always intuitive. However, as outlined in the "Proposed Draft Principles and Guidelines for the Conduct of Microbiological Risk Management," the ability to articulate requirements in terms of the risk reductions expected is a critical component of the Codex Alimentarius risk analysis paradigm.

8. Scope and Purpose

The purpose of this document is to provide guidance to Codex and national governments on approaches for using risk assessment techniques to establish metrics that can be used to establish, communicate and verify the level of stringency needed for a food safety system. However, each application of risk assessment to inform decision making is unique and as such it is not possible to describe all potential applications. Furthermore, the details of each application are highly technical and beyond the scope of the current document. Instead, this annex provides a general framework within which these tools can be applied. As a means of providing practical guidance example of how this framework could be applied, a simple example, *Listeria monocytogenes* in cold smoked salmon, is used to describe the information and factors that may need to be considered in using a quantitative risk assessment to develop risk management criteria such as FSO, PO, and PC to relate the degree of stringency required of a food safety system to the desired level of public health protection. In addition, the example examines how these food safety metrics can be used to establish MC as one potential means of verifying that the desired level of control is achieved.

It is important to note that the example is for illustrative purposes only, and is being used only to describe some of the concepts that should be considered in developing food safety risk management criteria. The concepts and approaches used in the example are by no means inclusive or may not be

optimal for other applications. Instead, this annex has been developed to introduce a general approach whereby risk managers and risk assessors can use risk analysis tools to more effectively link risk management criteria with public health outcomes.

Since each future application of the tools will be unique, the annex also describes potential procedural approaches that can be useful in ensuring that applications are consistent with Codex risk analysis principles. This annex should be used in conjunction with the Codex "*Working Principles for Risk Analysis for Application in the Framework of the Codex Alimentarius*," "*Principles and Guidelines for the Conduct of Microbiological Risk Assessment*," and "*Proposed Draft Principles and Guidelines for the Conduct of Microbiological Risk Management*." Its application is also dependent on having risk assessment and risk management teams that are familiar with the concepts, tools and limitations of both risk management and risk assessment. Accordingly, it is recommended that the members of such teams use this annex in conjunction with standard references such as the technical information developed by the World Health Organisation (WHO), the Food and Agriculture Organisation (FAO) and the Codex Alimentarius (e.g. FAO/WHO Expert Consultation on Risk Management and Food Safety-Paper N°65, Rome 1997; WHO Expert Consultation - The Interaction between Assessors and Managers of Microbial Hazards in Food, Kiel, Germany, March 2000 - The Principles and Guidelines for Incorporating Microbiological Risk Assessment in the Development of Food Safety Standards, Guidelines and Related Texts, Report Kiel, Germany, March 2002), and standard references on techniques in risk assessment, predictive microbiology, and microbiological criteria (e.g., "*Quantitative Risk Analysis*" (Vose, 1996); "*Microorganisms in Foods 7: Microbiological Testing in Food Safety Management*" (ICMSF, 2002); "*Modeling microbial responses in food*" (McKellar and Lu, 2004) *Practical Considerations on Food Safety Objectives* (Zwietering, 2005)).

9. Relationship between Various Risk Management Metrics

Traditional criteria for establishing the stringency of one or more steps in a food safety system include product criteria (PrC), process criteria (PoC), and microbiological criteria.

- A PoC typically establishes chemical and/or physical characteristics of a food (e.g., pH, water activity) that is necessary or contributes to the achievement of microbiological safety. Typically, PoC are used to articulate conditions that will not support growth of a pathogen of concern, thereby decreasing the potential for risk to increase during subsequent distribution, marketing and preparation. Alternatively, they may include a factor that must be controlled for a control measure to be effective (e.g., effect of pH on the thermal resistance of salmonellae). Underlying a PoC are a series of risk management decisions related to the frequency and level of the contamination in the food and/or raw ingredients that is likely to occur, the effectiveness of the control measure, the sensitivity of the pathogen to the control measure, the conditions of product use, and related parameters that ensure that a product will not recent a significant microbiologial threat to the consumer when the product is consumed. Ideally, each of these factors that determine the effectiveness of a PoC would be transparently considered when the criterion was being established. Used primarily with ready-to-eat products to ensure that the food does not support the growth of the microorganism of concern, a PoC may effectively establish the FSO for the product.
- A PrC establishes the specific conditions of treatment that a food must undergo at a specific step in its manufacture to achieve a PC, and thus a desired decrease in microbiological control. For example, a milk pasteurization requirement of a heat treatment of 72°C for 15 seconds specifies a specific time and temperature that will ensure a reduction in the risk of *Coxiella burnettii* to an acceptable level. Underlying a PrC should be a transparent

articulation of the factors that influence the effectiveness of the treatment and the risk management decisions based on them. For the milk pasteurization example, this would include factors such as the level of the pathogens of concern in raw milk, the thermal resistance among different strains of the microorganisms, the variability in the ability of the process to deliver the desired heat treatment, and degree of risk reduction required. A fully transparent PrC would effectively require the articulation of a PC that specifies the level of reduction in contamination desired. This PC, in turn, would be based on a PO for that step in the product's manufacture.

- A MC is based on the examination of foods to determine if the frequency and/or level of a pathogen in a food exceed a pre-established limit. Such microbiological testing can either be employed as a direct control measure (i.e., each lot of food is tested and unsatisfactory lots removed) or as periodic means of verifying that a food safety system is functioning as intended. As a technologically-based, statistically-based tool, a MC requires articulation of the number of samples to be examined, the size of those samples, the sensitivity of the method employed, the number of "positive" that will result in the lot of food being considered unacceptable or defective (i.e., has a concentration or percentage of contaminated servings beyond the pre-determined limit), and the probability that the pre-determined limit has not been exceeded. The effective use of a MC is dependent on a selection of a sampling plan based on the above parameters to establish the appropriate level of stringency. Since the levels of a pathogen in many foods can change over the course of their manufacture, distribution, marketing and preparation, a MC is generally established at a specific point in the food chain and that MC may not be pertinent at other points. The establishment of a MC requires articulation of a microbiological limit which is effectively a PO.

The introduction of additional risk management metrics such as FSO, PO and PC provide a conceptual framework for communicating the level of stringency required of a food safety system and linking those values to public health outcomes predicted by an underlying risk assessment. However, their practical application requires their use to be "operationalized" through the practical defining of what is meant by "maximum frequency and/or concentration of a hazard". For example, one use of a PO would be to identify the microbiological limit that must be specified when developing a microbiological criterion. However, such limits actually represent a specified point on what is typically assumed to be an unbounded distribution (e.g., a log normal distribution is commonly assumed). Thus, a food safety system could be operating as intended and still have a small percentage of the individual servings that exceed the PO if based solely on a frequency or concentration value. This can be avoided by either (1) developing a PO based on the distributions of both frequency and concentration, or by articulating the frequency at which the PO could be expected to be exceeded in terms of a single frequency or concentration and still be considered acceptable in relation to the overall performance of the food safety system. From a practical standpoint the latter approach is the type of decision that has to be used when defining the microbiological limit to be used in conjunction with a MC.

As risk assessors and risk managers explore the potential uses of FSO, PO, and PC concepts, it is most likely that specific applications will be based on risk management decisions derived from an iterative evaluation of the impact of different PO values, both in terms of public health and practical feasibility. Ideally, a fully integrated risk assessment model in combination with sufficient data should make it possible to start at any of the risk management metrics and derive the others (Figure 1). Thus, if a PO is articulated, then the FSO and the corresponding level of public health protection can be calculated. Conversely, one could start with a public health goal (e.g., no more than 1 case of foodborne disease per 1,000,000 servings) and determine the FSO, PO, MC, etc that would provide

the stringency and level of compliance needed at specified points in the food chain to achieve that goal. However, there are specific rules and requirements for moving "forwards" and "backwards" through a risk assessment model. It is critical that risk assessment experts who are familiar with the model should be consulted to ensure proper application and interpretation of the model to risk management applications.

10. Overview of Process

The purpose of establishing metrics such as FSO, PO, and PC is to articulate to stakeholders, in as objective and transparent manner as possible, the stringency that is expected of food safety systems to achieve a desired level of public health protection. Key to understanding this process is that the various metrics are interconnected and ideally integrated so that the establishment of a metric at one point in the food chain can be related through an appropriate risk assessment model to the outcome at another. The process of establishing such metrics can be highly flexible; the process can begin with the establishment of a level of disease control that must be achieved (ALOP), a level of control of a hazard that must be achieved (PO), a required processing outcome at a specific step (PC), a MC, etc. The underlying risk assessment model is then used to relate the metric being considered to the public health protection outcome. This should be done in a manner such that the relative stringency of the system can be considered by the risk manager so that an informed decision can be taken. The steps likely to be needed in this process are:

i. Develop an appropriate risk assessment model for the product of concern.

j. Establish one or more sites along the food chain for this product where a risk management metric would be pertinent and useful for measuring the effective implementation of a food safety program. This can be anywhere along the food chain, including the public health outcome, but in most instances the likely metric will be a PO.

k. Use the risk assessment to determine the impact of different levels of control of the hazard at the points selected as POs to establish the relationship between the food safety system's degree of stringency and the consumers' exposure. Consideration of a range of potential values at that site is beneficial to the subsequent decision-making process.

l. Use the risk assessment in conjunction with data on the present capability and variability of the industry to control the hazard of concern to derive other risk management metrics and outcomes that would be a consequence at each of the levels of control considered.

m. Use the risk assessment in combination with other appropriate statistical and modeling approaches to derive the criteria (i.e., MC, PrC, PoC) that will be used to verify that a level of stringency is being achieved.

n. Evaluate the feasibility of achieving the specific level of stringency being considered including consideration of how to assure that that level of control can be consistently and reliably met.

o. Reach a decision on the specific risk management metrics values to implement and the corresponding verification criteria to ensure continued achievement of that degree of stringency.

p. Implement the risk management criteria and supporting food safety programs.

q. Periodically review the program by comparing verification data against the risk assessment's predictions to evaluate the effectiveness of the initial decision.

This framework follows the principles and guidance in the "*Proposed Draft Principles and Guidelines for the Conduct of Microbiological Risk Management*" to ensure transparency, scientifically sound decisions, and appropriate involvement of stakeholders.

11. Example: *Listeria monocytogenes* in cold smoked salmon

As a technically-based undertaking, the setting of intermediary metrics based on the availability of a QMRA will require the involvement of subject matter experts, risk assessors, risk managers, and risk communicators. It is envisioned that this will involve a multiple step process that entails:

- The establishment a risk assessment team to develop and manipulate the QMRA,
- the interaction of risk assessment team with a risk management team to articulate the impact that different degrees of stringency have on public health outcomes,
- the consideration of different risk management options and scenarios both in terms of feasibility, outcomes, and equivalence,
- the interaction of the risk assessment and risk management teams with appropriate risk communication experts to ensure transparency and effective input from stakeholders regarding all intermediary metrics,
- the taking of a decision(s) by the risk managers regarding the specific values for the intermediary metrics that will be implemented, and
- the implementation and periodic review of the risk management metrics in relation to predicted public health outcomes to ensure continuing achievement of the desired level of public health protection.

This process will require access to substantial expertise in risk assessment, and each application is likely to be unique. Capturing all the possible technical aspects, factors, and details that may have to be considered is well beyond the scope of this document. However, as a means of considering the types of information that may be required, a simplified QMRA for *L. monocytogenes* in smoked salmon was developed. This simplified quantitative risk assessment model was developed for the purpose of providing a reasonably realistic example of calculations leading to various intermediary food safety risk management metrics. The specific product/pathogen pair was selected on the basis of it being a relatively simple product in terms of formulation, processing, manufacturing and marketing. A substantial number of studies have been conducted with this pathogen/product pair, but as expected, there are still uncertainty associated with different aspects of the pathogen and its interaction with the product. The current example was developed for illustrative purposes only since there have been a number of simplifying assumptions. Even though the risk assessment model was purposefully kept simple, the details of the model and corresponding calculations for relating different degrees of stringency with public health outcomes are too complex to include in the current annex. Instead, the QMRA and a more detailed explanatory document have been posted on the JIFSAN Food Safety Risk Analysis Clearinghouse website (http://www.foodrisk.org/index.cfm). The description in the current annex is limited to an overview of the approach, the overall results and lessons learned.

11.1 The Product

Smoked seafood includes a wide variety of products including both smoked finfish and smoked bivalve shellfish. Smoked salmon is the most widely marketed species in many parts of the world. Smoked salmon is manufactured and marketed in two primary forms, cold smoked and hot smoked product. Cold smoked product is the focus of the current example. A generic flow chart for the manufacture and marketing of cold smoked salmon used in the example is depicted in Figure 2.

There is substantial variation among manufacturers in terms of the details and order of the different unit operations. For example, the specific timing of butchering, trimming, skinning, and slicing can vary. The salting process differs markedly between different processors; some use dry salting, others brine injection, and still others submersion in brine.

11.2 The Product and the Pathogen

There are a number of steps within the manufacture of cold-smoked salmon which influence the frequency and extent of *L. monocytogenes* contamination, but there is no distinctly listeriocidal treatment. The typical temperatures used during cold smoking are generally below 32ºC. The drying and exposure to smoke phenolics have been reported to produce some reduction in *L. monocytogenes* in some studies; however, these effects are generally minimal. The prevalence of *L. monocytogenes* on smoke salmon is dependent, in part, on the prevalence of the pathogen on the incoming fish, but the primary factor currently affecting the frequency and extent of *L. monocytogenes* contamination in cold-smoked product is (a) the degree of contamination from the manufacturing environment prior to final packaging and (b) the adequacy of the cold chain during manufacturing, distribution, marketing, and consumption. There are several steps within the manufacturing sequence (e.g., brining, thawing, slicing) where there is a high potential for the transfer of *L. monocytogenes* from one fish to another.

Smoked salmon can typically support the growth of *L. monocytogenes* at refrigeration temperatures. The rate of growth is being primarily dependent on the temperature and duration of storage. The pathogen can reach elevated levels (e.g., $> 10^6$ CFU/g), though in some instances the competing microflora can limit growth to lower maximum values. The purposeful use of a competing microflora in some instance has been used as a control measure. However, it was assumed that the microorganism can reach levels of 10^8 CFU/g.

11.3 Approach for Establishing Risk Metrics

The general approach for establishing food safety risk management metrics used in this example was to:

- Initiate the process by identifying the locations of POs along the food chain that should be established,
- Identify the potential range of values for the one of the PO selected,
- Derive the corresponding values for the other POs using the risk assessment,
- Derive the FSO and corresponding level of protection (LOP) that should be achieved through the application of the corresponding set of POs.
- Derive any appropriate PC and subsequent PrC or PoC that would be needed to achieve the corresponding PO,
- Derive any MC would be needed to verify that the PO was being attained.
- Consider the effectiveness of MC as a control measure or as a means of verifying efficacy of food safety system.

Three locations along the food chain were selected for this example:

- the raw salmon as it enters the manufacturing facility,
- the product immediately after final packaging, and
- the product at the point of sale.

These PO locations were established based on them being clearly identifiable points for all manufacturers and the likelihood that these would be the locations most likely to be used by control authorities and industry alike to verify the effectiveness of a manufacturer's food safety program through inspection and/or testing.

In the development of a QMRA and the subsequent derivation of potential PO values and derived metrics (e.g., PC, MC, FSO), a risk assessment team will typically employ a series of assumptions and/or simplifications. These assumptions and their impact need to be understood by the risk managers for them to make informed decisions using the risk assessment. In the current example, two assumptions that are commonly used in QMRAs were that the concentration of *L. monocytogenes* within lots is log-normally distributed (the log values the concentration of *L. monocytogenes* are normally distributed), and concentration across all lots is also log-normally distributed. These assumptions establish the distributions of *L. monocytogenes* are "unbounded," i.e. there is always the potential for a high concentration value at a low frequency despite the fact that the food safety system is operating as intended. Thus, one of the decisions that the risk managers have to reach is how to "operationalize" a PO, i.e., the percentage of the overall distribution that would exceed the PO and the distribution still considered as meeting the PO. For example, if a PO was "operationalized" at 99% then one would expect that when the food safety system is functioning as intended that less than 1 serving out of 100 would exceed the PO. Selection of such a value would typically require knowledge of the current capability of the industry including the variability within individual facilities and the variability across the industry. Selection of a PO that encompasses the current performance of almost all the industry will result in maintaining the current level of stringency whereas selecting a PO wherein a significant portion of the servings will be greater than the selected PO would require firms to increase the stringency of their food safety systems. The risk assessment team can assist by examining a range of potential PO values and the corresponding impact that the PO values have on public health and the rate of food lot rejections. This type of analysis requires the availability of extensive data on the performance of the segment of the food industry for which the PO is being developed.

The approach taken to derive the three POs in the current example was to arbitrarily establish a series of potential PO values for PO-1 (raw fish entering the cold-smoked salmon manufacturing plant) based on data available in the scientific literature. The corresponding values for the other two POs (i.e., after final packaging and at retail) were then derived using the risk assessment in combination with the conceptual equation of the ICMSF (ICMSF, 2002) and the data available from the FDA/FSIS (2003) and FAO/WHO (2004) risk assessments and the scientific literature. The ICMSF conceptual equation depicts the fact that the ability to achieve a PO (or an FSO) is dependent on the the initial contamination burden (H_o), the sums of the factors that increase extent of contamination either by permitting growth or contamination (ΣI), and the sum of the factors that decrease the level of contamination (ΣR). Thus, a PO will be achieved when:

$$\mathbf{H_o + \Sigma I - \Sigma R \leq PO}$$

As indicated above, the current example starts with the raw fish and moves its way through the manufacturing, distribution, and utilization chain. It would have been alternatively possible to start at another point in the chain (e.g., after final packaging) and derive the other PO values. However, a caution is that there are specific mathematical rules that must be followed when moving "forward" and "backward" through a risk assessment model. Experts in modeling should be routinely consulted when developing and using these models.

5.4 Cold-Smoked Salmon Risk Assessment.

As indicated above, a simple risk assessment model was developed for the purposes of this annex as a means of demonstrating a number of concepts and approaches. While greatly simplified, the model and the data values used were consistent with the scientific literature, prior and ongoing risk assessments for *L. monocytogenes,* and advice obtained from cold-smoked fish production experts. A probabilistic model was developed to demonstrate the impact of considering the variability and uncertainty associated with biological entities and responses, and approaches to dealing with them in the development of food safety risk management metrics. It must be emphasized again that, while the current risk assessment model has attempted to be realistic in terms of approach and output, the model was developed for illustrative purposes only and should be used for that purpose only.

The exposure assessment phase of the risk assessment model was divided into four segments roughly corresponding to the POs and FSO under consideration. This includes (1) the initial frequency and extent of contamination, (2) the changes in contamination levels during the manufacturing of cold-smoked salmon, (3) the changes in contamination levels between final packaging and purchase of the product, and (4) the changes in contamination levels between purchase and time of consumption. The exposure assessment was completed by taking into account the factors affecting the amount of smoked fished consumed, including percentage of population that consumes smoked salmon, frequencies of consumption, and serving sizes. The risk estimates on a risk per serving basis were then obtained by combining the exposure assessment results with the simple exponential dose-response model for the susceptible population that was employed in the FAO/WHO *L. monocytogenes* risk assessment. The information needed to develop the risk assessment and evaluate the impact of different PO values is summarized below. The data need to be acquired in a manner that provides an estimate of the data's variability and uncertainity, and any factors such seasonality or regional differences that would impact the expected results over time.

5.4.1 PO-1: *Listeria monocytogenes* on the Incoming Raw Fish.

Information needed included:

- Sources of raw salmon,
- Frequency and extent of contamination of raw salmon with *L. monocytogenes* at the slaughter facility,
- Methods and conditions (i.e, time and temperature) of transporting raw salmon to cold-smoked salmon manufacturing facility,
- Frequency and extent of contamination when raw salmon enters manufacturing facility,
- Growth characteristics of *L. monocytogenes* in raw salmon, and
- The extent to which contaminated and uncontaminated fish are co-mingled upon or immediately after receipt such that the contamination was evenly distributed across all fish within a production lot. (In the risk assessment, it was assumed that contamination was homogeneously dispersed soon after receipt of raw fish.)

The achievement of PO-1 would be dependent on activities happening largely outside the manufacturing facility:

- Control the initial level of *L. monocytogenes* on the fish prior to slaughter (H_{o-1}),
- Limit increases in *L. monocytogenes* due to growth and further contamination at slaughter and during transport (ΣI_1), and

- Intervention technologies and hygiene programs that reduce the level of contamination (ΣR_1).

5.4.2. PO-2: *Listeria monocytogenes* in Product after Final Packaging

Information needed included:

- The relative extent of contamination of finished product attributable to contamination from the manufacturing environment versus that present on the raw salmon,
- The time and temperature of manufacturing process and environment,
- The growth characteristics of *L. monocytogenes* in cold-smoked salmon at the different phases of manufacturing, and
- The impact of cold-smoking and other processes (e.g., rinsing) that may decrease the levels of *L. monocytogenes* in the product,
- The steps in the process that are likely to disperse *L. monocytogenes* contamination, and
- Inclusion of any bacteriocidal or bacteriostatic control measure that decreases the prevalence of *L. monocytogenes* or its rate of growth.

5.4.3. PO-3. *Listeria monocytogenes* in Cold-smoked Salmon at Point of Sale

Information needed included:

- The temperature and duration of storage during distribution,
- The temperature and duration of storage during marketing, and
- Percentage of product that is shipped and stored frozen until just prior to marketing.

5.4.4. FSO: Level of *Listeria monocytogenes* Present in a Cold-Smoked at the Time of Consumption

Information needed included:

- Percentage of population that consumes the product,
- The range of serving sizes,
- The frequency of consumption,
- The temperature and conditions of storage between purchase and consumption,
- The profile of the population consuming product (e.g., age, immune status, pregnancy), and
- The disposition on any leftovers.

5.4.5. Calculation of the Level of Protection (LOP)

These are the anticipated risk/public health outcomes arising from each of the potential sets of PO values. These are obtained from combining the exposure assessment and the amount of product consumed, and the dose-response relationship. The information needed include are any factors that influence the dose response relationship such as:

- Age of consumers,
- Immune status of the consumers
- Food matrix effects that influence infectivity/virulence of *L. monocytogenes*, and

- The distribution of virulence capacity of the strains of *L. monocytogenes* likely to be encountered in cold-smoked salmon.

Considering a number of different sets of PO values has the distinct advantage of ensuring the risk management decision is made by the risk managers and not *de facto* by the risk assessors. However, this requires that the risk assessment team provide a clear understanding of the details of the risk assessment in a manner that is understandable by the risk managers. After completion of the QMRA, the risk assessment team should be available on an ongoing basis to provide advice to the risk managers and risk communicators. The metrics developed using this framework in the current example are depicted in Table 1.

Table 1. Potential LOP values derived from the risk assessment based on the predicted number of *Listeria moncytogenes* consumed per serving of cold-smoked salmon.

PO-1 [Log(CFU/g)]	PO-2 [Log(CFU/g)]	PO-3 [Log(CFU/g)]	FSO [Log(CFU/g)]	LOP [Log(Probability of a case of listeriosis per serving)]
-3.31[a] (0.01)[a]	-2.14[a]	-1.51[a]	+0.13[a]	-10.11
-2.21 (0.1)	-1.14	-0.51	+1.13	-9.11
-1.21 (1)	-0.14	+0.49	+2.13	-8.11
-0.21 (10)	+0.86	+1.49	+3.13	-7.11
+0.74 (90)	+1.82	+2.44	+4.09	-6.11

a. Mean of the log concentrations of *L. monocytogenes* [Log(CFU/g)]
b. Percentage of raw fish contaminated with *L. monocytogenes*. Contaminated fish were assumed to be contaminated at a level of 1 CFU/g.

6. Selecting the ALOP

The approach taken in the example was to use the risk assessment to explore a range of potential PO values and their derived FSO and LOP vales starting with an initial contamination level on the raw fish and taking into account a series of assumed increases and reductions. As indicated above, this approach was considered to have the advantage of not having the risk assessors make the decision concerning what is the appropriate level of protection (ALOP). In this example it is important to distinguish between a LOP and an ALOP. The LOP is the degree of public health protection that would be achieved if a specific level of control (i.e., stringency) was attained. However, it does not become the ALOP until it has been selected and implemented as the level of stringency that is expected or required of a food safety risk management system.

With the information provided by the risk assessment team, the risk managers would need to evaluate the risk assessment derived "what-if" scenarios to determine the feasibility and impact of the different PO values considered. It is presumed that the risk managers have data available regarding the current capabilities of the industry plus the potential for mitigation. This information would need to be balanced against the public health impact. It is important that the risk managers fully understand the likely impact that setting a specific PO value will have in terms of both public health impact and regulatory outcomes. If, for example, a PO is set at a value that encompasses 99.9% of the current capability of the industry, that would indicate that the current level of stringency is deemed adequate and appropriate. Conversely, if a PO was set at a point that encompasses only 80% of the industry, this would require a substantial increase in stringency once the corresponding LOP

was accepted as the ALOP. The immediate impact of establishing such a PO will mean that the application of other metrics used to verify the PO is being attained (e.g., MC) will result in rejection of a substantial portion of food lots, particularly for manufacturers that consistently produce products containing the hazard at concentrations close to the PO.

The decision to select a specific LOP as the ALOP is typically a complex risk management process that should involve the principles and practices recommended in the Codex Alimentarius Committee on Food Hygiene "*Proposed Draft Principles and Guidelines for the Conduct of Microbiological Risk Management*." As hopefully demonstrated with the above example, the ability to utilize risk assessment tools to link control measures and/or intermediary metrics to public health outcomes can be a highly useful tool for more objectively and transparently taking a decision on an ALOP.

7. Direct Use of a QMRA versus Intermediary Metrics

It is possible to directly incorporate a QMRA into the risk management process such that all acceptable risk management options are incorporated into the risk assessment model. In this approach each control measure is included as a component of the model and the level of risk achieved by the system is directly considered in terms of levels of disease expected. This effectively avoids the need to establish intermediary metrics such as PO, PC, and FSO values by directly incorporating verification criteria (MC, process criteria, product criteria) into the risk assessment model. For example, if a uniform microbiological testing program is being considered to control a foodborne hazard, the ability of the proposed sampling plan to detect unacceptable lots could be directly incorporated into the risk assessment model. This type of an approach was recently used in the risk assessment that was part of the recent international evaluation of the safety of powdered infant formula ("*Enterobacter sakazakii* and *Salmonella* in Powdered Infant Formula" (FAO/WHO, 2006)).

It most likely that the direct use the risk assessment to determine and implement the appropriate control measures would be most applicable to situations where:

- the number of control measures (or risk management options) is limited,
- the segment of the food industry under consideration is highly uniform,
- the number of individual companies in the industry sector is small, and/or
- the risk assessment model is relatively straightforward.

In those cases, the ability to derive control measures from the risk assessment might best be in the hands of a national food safety agency or other competent body that performs the what-if scenarios needed to consider different options proposed. This would be typically used when a single or limited number of control measures would be used across the entire industry and there was a single or limited number of ways for verifying achievement of the selected level of stringency.

The direct use of risk assessment model to implement risk management decisions would be more difficult when:

- the industry is composed of a large number of individual firms,
- there is substantial diversity among the firms (e.g., risk management formulations, size of firms, technologies used to produce product, geographical conditions),
- a substantial portion of the food is imported,
- the companies propose to mitigate that risk by controlling the hazard at different or multiple sites in the food chain, and/or

- there are large differences in the percentage of a food produced by individual companies.

In the last instance, the risk would have to be limited to a "risk per serving basis" because of the small percentage of the total production (and thus overall risk) that would be attributable to any single small firm. When individual manufacturers employ substantially different combinations of control measures to manage a hazard, assessing their ability to achieve required levels of hazard control will likely require a modified version of the risk assessment be made available to consider their particular option(s). This would require that the national food safety agency, the industry, or the individual firm be able to modify the risk assessment to customize it for the individual industry's situation.

In such instances greater implementation flexibility would be achieved by establishing intermediary performance metrics that specify the level and/or frequency of contamination that should not be exceeded at specific locations in the food chain to achieve the desired level of public health protection. By knowing the degree of stringency required through the establishment of the a PO or PC along with the degree of confidence that the control authority requires to ensure that the limit is not exceeded, the industry can then develop the appropriate means for verifying that this risk-based level of pathogen control is attained. This approach also allows control authorities deal with the issues of equivalence that arise when there are both domestic and imported firms providing a food.

8. Alternate Approaches

The current annex describes one example and mentions another briefly. There are a number of other potential approaches for using risk assessment to help establish food safety risk management metrics to link the stringency of a food safety system to its public health outcome. For example, the current example used a probabilistic risk assessment to establish the relationship between the stringency of the food safety system and ultimate exposure of the cold-smoked salmon consumer to *L. monocytogenes*. Alternatively, a deterministic model could have been employed; an approach that offers both advantages and limitations.

The current example started with the consideration of different PO values at selected points in the food chain on the LOP, the selection of one such LOP as the ALOP, and the subsequent derivation of a MC. However, alternative approaches could have started with a consideration of public health outcome (e.g., an incidence of disease), a microbiological criterion, or a processing criterion. For example, one such approach would be to use the risk assessment to determine the exposures anticipated under a HACCP system using agreed upon "best practices." The PO could then be "operationalized" by considering the lots with the highest level of *L. monocytogenes* that would be expected when the best practices are being followed (e.g., set the PO = mean + 3 standard deviation). An MC could then be calculated to ensure that lots that exceed the PO are rejected at a high probability. Another approach could be to determine the distribution of *L. monocytogenes* levels in existing production lots and set a MC on the basis of public health concerns and industry capabilities such that lots with the highest concentration levels would be rejected. The risk assessment could be used to calculate the effective PO at that point in the food chain that the product is subjected to microbiological testing and the resultant FSO and ALOP at point of consumption.

As an evolving area of endeavor, a variety of other new approaches, applications, and techniques will undoubtedly be suggested and tried in the future. As such, it is important that each such risk evaluations be appropriately reviewed for technical accuracy, preferably by risk assessment experts, subject matter experts, and interested stakeholders.

It is impossible to provide guidance that will cover all potential future applications. In such instances, this diversity of approaches requires means for assessing the validity of the metrics

derived. This can be augmented through the principles and guidance provided in the Codex Alimentarius "*Principles and Guidelines for the Conduct of Microbiological Risk Assessment*," and "*Proposed Draft Principles and Guidelines for the Conduct of Microbiological Risk Management*." In particular, the application of principles of transparency and involvement of stakeholders can help ensure that risk assessment techniques to the establishment of food safety performance metrics. A number of national governments have specific requirements for the peer review and involvement of stakeholders in the development and/or review of risk assessments and their application to risk management decision making. A key principle for the conduct of both risk management and risk assessment is the periodic review of decisions and evaluations, a principle that is increasingly being emphasized by national goverments.

9. Verifying Achievement of Food Safety Risk Management Metrics through the Establishment of Microbiological Criteria.

An FSO is not likely to be verified since it reflects the level of control at the time of consumption. Instead, verification of the ability of a food safety risk management system to achieve a specified level of stringency would most likely be at the site of a PO. As discussed in the "*Proposed Draft Principles and Guidelines for the Conduct of Microbiological Risk Management,*" there are several different approaches to verifying compliance with a PO. One approach, when appropriate and practical, is microbiological testing against established microbiological criteria. It is important to note that a MC is distinctly different from a PO; the PO is the value from which the MC can be derived to link its stringency to a specific level of protection.

The traditional use of MC has been as a control measure to test each individual lot of a product to ensure at a specified probability that a lot of a food conforms to an established standard or limit. It is based on the assumption that the examiner has no previous knowledge of the lot. Often termed "lot-by-lot testing" or "within-lot testing," a sampling and testing plan is developed to reject lots, that at a designated probability, that exceed the PO. The other form of MC is to periodically verify that a food safety system is functioning as intended by taking a limited number of samples over time across multiple lots. Referred to as "between-lot testing" or "process control verification testing," this involves limited, periodic testing of multiple lots produced by a single manufacturing facility. This type of microbiological testing is well suited as a verification tool for a facility working under a HACCP program. This type of testing is most effective when based on extensive knowledge of the product and how it was manufactured. For the purposes of the current example, the relationship between MC and PO will be examined only for lot-by-lot testing, i.e., for simplicity it was assumed that every lot was being tested. Standard references are available to describe the differences between the two approaches (ICMSF, 2002).

When a manufacturer or a control agency need to use microbiological testing to determine that a PO is being achieved, they must, of necessity, move from a PO to a MC. This reflects the fact that a PO establishes a decision point between what is considered safe and what is not, whereas a MC establishes the testing scheme to determine if that limit is achieved. In addition to establishing the microbiological limit, the MC also specifies the methods, sampling plans, the type of testing (i.e., attribute (presence/absence) vs. variables (quantitative) testing), decision criteria, and the actions that are to be taken when the limit is exceeded. A detailed consideration of how to use a risk assessment to link a PO to a MC is beyond the scope of the current document. Standard references on the types of microbiological testing programs and the statistical basis for sampling plans are available (ICMSF, 2002; Whiting et al., 2006). Experts in microbiological testing and sampling plans should be consulted when developing an MC.

For the purpose of demonstrating one approach to establishing a MC based on a PO, the development of a MC for a 2-class attribute sampling plan was considered for use in conjunction with PO-3 (PO at retail). A 2-class attribute sampling plan is used in conjunction with presence/absence data or with "binned" quantitative data such as < 1 CFU/g vs. ≥ 1 CFU/g. Presence/absence attribute testing involves taking a specific number of samples (n) of a specific size (s) and testing them independently for the presence of the pathogen using a method that is capable of detecting the pathogen at a specified level (m). A MC includes a term, c, which indicates the number of samples that can be positive and still have the lot considered acceptable. However, the c for an infectious agent such as *L. monocytogenes* is typically set at c = 0 (i.e., any positive sample is sufficient to reject the lot). The overall stringency of the MC (i.e, its microbiological limit) can be set by manipulating the n, m, and c values. The MC also includes a probability that a non-conforming lot will be detected and rejected.

MC values for the three most stringent PO-3 values (Table 1) for the "consumer risks" of 90%, 95% and 99% are provided in Table 2. The information and assumptions used in developing MC values such as these need to be fully articulated to the risk managers who will have to implement such a risk management program. The information needed for the development of the MC include an estimate of the "within-lot" standard deviation and the sensitivity of the testing method being employed. Examples of microbiological criteria for PO-3 are depicted in Table 2.

Table 2. Potential microbiological criteria for PO-3 to verify with a specified degree of confidence that PO-3 is not exceeded.

PO-3 [Log(CFU/g)]	Mean Level of *L. monocytogenes* in a Lot that Just Fails PO-3 [Log(CFU/g)]	Sample Size (g)	Sensitivity of the Method (m) [Log(CFU/g)]	Number of Samples* Required to Achieve Specific Probability of Rejecting the Lot (P_{rej})		
				0.90	0.95	0.99
-1.51	-1.92	100	-2.0	3	3	5
		50	-1.7	11	15	22
-0.51	-0.92	10	-1.0	3	3	5
		5	-0.7	11	15	22
+0.49	+0.08	1	0.0	3	3	5
		0.5	+0.3	11	15	22

*Calculated values round up to the nearest whole sample.

The establishment of a MC based for a 2-class sampling plan is typically based on controlling the "consumer's risk," i.e. ensuring to a high probability that a non-conforming lot would be detected and thus rejected. However, when such a MC is implemented there will be a calculable number of lots that actually meet PO-3 but that would be detected as exceeding the PO based on the detection of *L. monocytogenes* during testing. The extent to which lots that meet the PO are rejected is dependent on the operating characteristics of the sampling plan. Typically, a manufacturer would suffer severe economic consequences if they continued to operate at levels that approach the PO. Often referred to as the "producer's risk," manufacturers typically use a combination of increasing the stringency of their operations and decreasing the variability of their manufacturing process to reduce the level of positive findings (both true and false positives). It is important to note that when a manufacturer implements a higher level of stringency to reduce the "producer's risk" of lot rejection, this adds an additional degree of risk reduction for consumers beyond that which was estimated in setting the original PO and MC.

The direct degree of risk reduction achieved by microbiological testing is a function of the frequency of testing. For example, if testing every lot of food results in 20-fold decrease in relative risk, then testing every tenth lot would be expected to achieve a 2-fold reduction. The occasional random testing of individual lots typically offers little effective risk reduction unless integrated into a HACCP plan with verification control charting being used to predict trends that can be mitigated before a PO is exceeded.

10. Summary

The application of quantitative risk assessment techniques to food hygiene is increasingly allowing the impact of control measures to be more quantitatively linked to food safety outcomes. The current annex provides a limited number of examples of how the embracing of a risk analysis paradigm by Codex Alimentarius can be implemented, at least for food hygiene. However, it is beyond the scope of the annex to outline all potential approaches and applications. Instead, the use of risk assessment techniques to better inform the development, implementation, and review of food hygiene risk management programs will require the ongoing interaction between CCFH and the scientific and risk assessment community both through the involvement of experts in the delegations to CCFH, and through the interaction of CCFH with international organizations that provide scientific advice (e.g., FAO, WHO, ICMSF) and groups that support them (e.g., WHO Collaborating Laboratories).

11. References

ICMSF (International Commission on Microbiological Specifications for Foods). "Microorganisms in Foods 7: Microbiological Testing in Food Safety Management." Kluwer Academic / Plenum Publishers. New York. 2002.

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Whiting, R. C., Rainosek, A., Buchanan, R. L., Miliotis, M., LaBarre, D., Long, W., Ruple, A., and Schaub, S. Determining the Microbiological Criteria for Log Rejection from the Performance Objective or Food Safety Objective. Internat. J. Food Micribiol. 110:263-267. 2006.

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12. Figure Legends

Figure 1. Relationship between the various food safety metrics.

Figure 2. Flow chart for the manufacture of cold-smoked salmon.

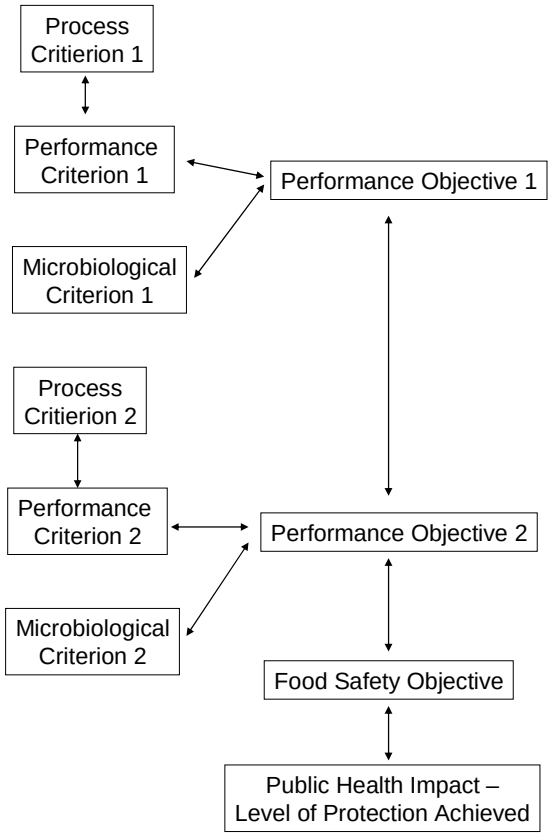
Process Critierion 1
Performance Criterion 1
Performance Objective 1
Microbiological Criterion 1
Process Critierion 2
Performance Criterion 2
Performance Objective 2
Microbiological Criterion 2
Food Safety Objective
Public Health Impact – Level of Protection Achieved

Figure 1.

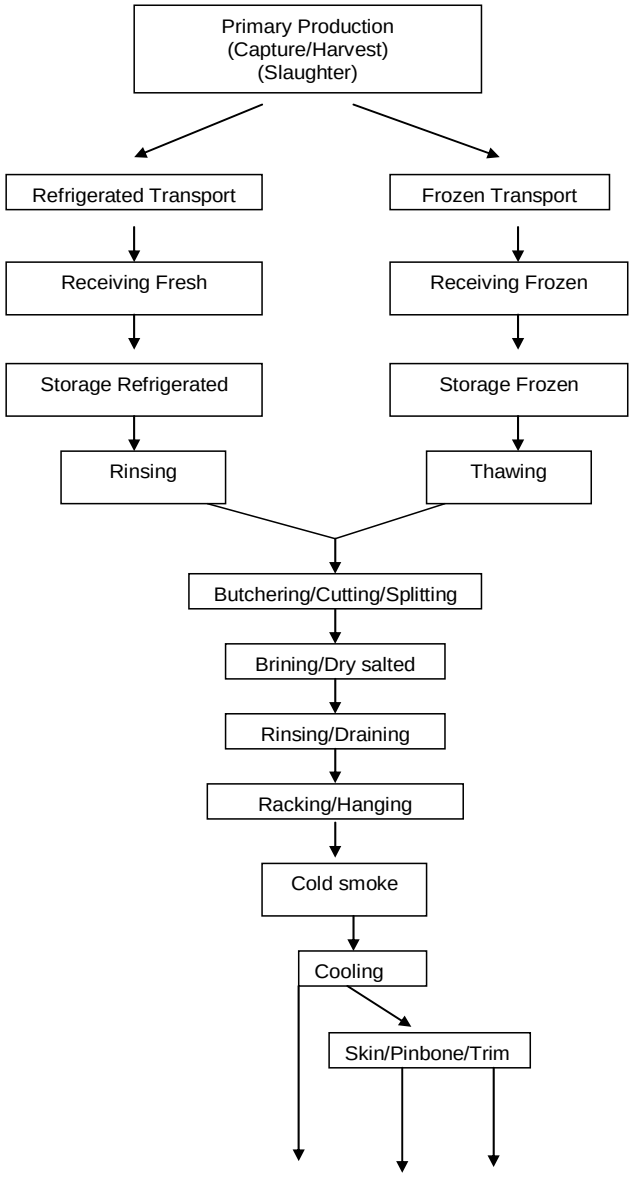
Primary Production
(Capture/Harvest)
(Slaughter)
Refrigerated Transport
Frozen Transport
Receiving Fresh
Receiving Frozen
Storage Refrigerated
Storage Frozen
Rinsing
Thawing
Butchering/Cutting/Splitting
Brining/Dry salted
Rinsing/Draining
Racking/Hanging
Cold smoke
Cooling
Skin/Pinbone/Trim

Figure 2.

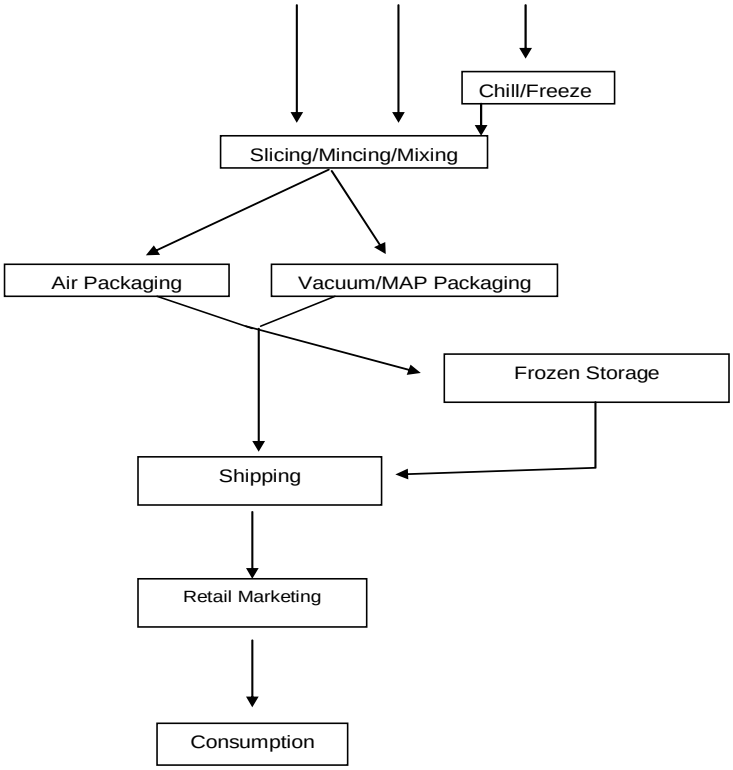

Figure 2. (continued)