Combined HACCP and TOPSIS-based approach to prioritize risks in the salmon manufacturing process: a case study

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Abstract: The food safety risk assessment is defined by the Codex Alimentarius Commission as the scientific evaluation of known or potential adverse health effects resulting from human exposure to food-borne hazards. Nowadays, the implementation of a systematic and disciplined risk assessment approach in the food safety field is recognized to be a powerful tool for carrying out science-based analyses and for reaching sound consistent solutions to food safety problems. With this recognition, a combined Hazard Analysis and Critical Control Point (HACCP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)-based approach is proposed in the present paper to prioritize risks of the salmon manufacturing process of a real Sicilian industry. Specifically, the hazard analysis is firstly performed within the HACCP implementation to develop and evaluate a list of potential biological, chemical and physical hazards which may be introduced, increased or controlled at each step of the investigated manufacturing process. Then, the TOPSIS method is used to rank risks arising from contamination hazards previously identified and evaluated against two differently weighted criteria, namely the frequency of Occurrence (O) and the Severity (S). The proposed structured and semi-quantitative risk assessment approach perfectly matches with the current need highlighted by the regulatory Authorities to rank food safety risks so as to prioritize regulatory controls.

Keywords: Risk prioritization; HACCP; Fishing industry; TOPSIS.

1. Introduction and literature review

Nowadays, risk analysis is more and more considered as a powerful tool on the basis of which taking science-based decisions in the food safety context with the aim of promoting ongoing improvements in the public health. Within the food safety field, risk analysis is used to quantify risks caused by food-borne hazards to human health and to identify, assess and implement appropriate measures of intervention to control such risks (Butler, 2008). According to the Regulation EC No 178/2002 (Regulation EC No 178, 2002), the food safety risk analysis can be seen as a structured decision-making system comprised of three highly interrelated components, namely risk management, risk assessment and risk communication. As concerns the risk assessment which the present paper is focused on, in 1991 the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) have jointly recommended the incorporation of its principles into the decision-making process of the Codex Alimentarius Commission (CAC) (FAO/WHO, 2006). In this regard, CAC defines the food safety risk assessment as the scientific evaluation of known or potential adverse health effects resulting from human exposure to biological, chemical or physical food-borne hazards (FAO/WHO, 1997).

Generally speaking, the risk assessment consists of three main steps, namely the hazard identification, the exposure assessment, and the risk characterization (FAO/WHO, 1995; FDA, 2013; Oscar, 2012). As concerns the hazard identification, it is often considered as the most important step of the risk assessment because an unidentified hazard in the early stages of the production process can cause devastating effects in later stages. The identification of biological, chemical or physical food-borne hazards is in common with the Hazard Analysis and Critical Control Point (HACCP) system traditionally implemented by food producers and processors as a comprehensive approach to the food control (Regulation EC No 852, 2004; ISO 22000, 2005). Asserted by the National Advisory Committee for Microbiological Criteria for Foods (NACMCF) as the first principle of the HACCP plan development, the hazard analysis actually comprises two stages, namely the hazard identification and the hazard evaluation. The hazard identification aims at developing a list of potential chemical, biological and physical hazards which may be introduced, increased, or controlled at each step of the production process under investigation. The hazard evaluation aims at characterizing each identified potential hazard by the related Occurrence (O) and Severity (S). Specifically, O stands for the probability/frequency of occurrence of the hazard whereas S represents the level of damage as a consequence of the hazard occurrence.

Therefore, the hazard analysis to be conducted as the first principle of HACCP refers to the process of collecting and evaluating information on each hazard associated with the food under consideration to look at the conditions that may cause the hazard to be present or to increase and to decide which hazards must be addressed in the HACCP plan (Oscar, 2012; National Advisory Committee for Microbiological Criteria for Foods, 1998). However, none specification is supplied by the technical literature as concerns the way how such a collection and evaluation of hazards' information need to be performed (Oyarzabal, 2015). With this recognition, the present paper proposes a structured and semi-quantitative risk assessment approach based on HACCP and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Hwang and Yoon, 1981) to address the prioritization of risks arising from food-borne hazards. Referring to a real smoked salmon manufacturing process, the hazard analysis is firstly performed to identify hazards which are of such significance to cause injury or illness if not effectively controlled. Then, the TOPSIS method is used to rank risks arising from the occurrence of food-borne hazards previously listed. In this regard, two differently weighted evaluation criteria are taken into account to characterize hazards, namely the related frequency of Occurrence (O) and Severity (S).

To the best of the authors' knowledge, this is the first attempt in the literature of using the TOPSIS method for the food safety risk assessment. Actually, the main part of the existing literature proposes the Failure Mode and Effects Analysis (FMEA) (IEC 60812, 2006) to deal with such an issue. In (Ozilgen, 2012) the risk assessment of a confectionary manufacturing process is performed by FMEA, and potential failure modes, their effects and causes are identified in the process flow. Then, the Risk Priority Number (RPN) related to each processing stage is computed and stages finally ranked on the basis of their contribution to the risk. Referring to two medium-size bakeries located in Poland, Trafialek and Kolanowski (2014) propose a combined HACCP and FMEA approach for the identification of high and critical risks in HACCP areas of verification and recordkeeping. One more time, Xiaochuan and Qiang (2015) integrate FMEA into HACCP to analyze potential failure modes and RPNs of meat products. Obtained results are then used to formulate the HACCP plan of meat products. Varzakas (2011) and Arvanitoyannis and Varzakas (2008; 2009) use FMEA for the risk assessment of pastry processing, snails industry and salmon processing respectively, and carry out a comparison between ISO 22000 (2005) and HACCP. Varzakas and Arvanitoyannis (2007) combine FMEA and preliminary hazard analysis together with Fault Tree Analysis (FTA) (Curcurù et al. 2013) for the risk assessment of a corn curl processing plant. Kurt and Özilgen (2013) approach the criticality assessment of manufacturing processes of six widely consumed dairy products in Turkey by means of the traditional RPN method. Sixty-seven process' hazards are identified and the related RPNs computed to identify the risk level of each hazard.

The remainder of the paper is organized as follows. The TOPSIS method is described in Section 2 whereas the application case is presented in Section 3. Section 4 reports a brief discussion about the main strengths of the proposed approach in respect to the extant body of literature and final conclusions are drawn in Section 5.

2. Overview on the TOPSIS method

The traditional TOPSIS method was firstly proposed by Hwang and Yoon (1981) and further developed by Hwang et al. (1993) as a Multi-Criteria Decision Making (MCDM) technique by means of which ranking alternatives on the basis of their ratings against diverse qualitative and/or qualitative criteria opportunely weighted. TOPSIS has been widely applied in the literature because of its ability to deal with different decision problems addressed to the ranking of alternatives even in uncertain environments and/or in the presence of multiple decision makers (Aiello et. al, 2009; Awasthi et al., 2010; Zeydan et al., 2011; Carpitella et al., 2016a; 2016b). The method is grounded upon the concept of distances between each alternative and the positive (Azimuth) and the negative ideal (Nadir) solutions. Therefore, the best alternative among those under investigation is that characterized by the shortest distance from the Azimuth and the greatest distance from the Nadir.

The implementation of TOPSIS consists of the following steps.

1. Collection of scores g_{ij} of each alternative i (with i=1,…,n) against each criterion j (with j=1,…,k). Elements g_{ij} constitute the so called decision matrix.

2. Definition of the importance weight of each criterion j, i.e. w_j.

3. Computation of the weighted and normalized decision matrix where the generic element u_{ij} is (Eq. 1):

$$u_{ij} = w_j \cdot z_{ij}, \forall i, \forall j \tag{1}$$

where z_{ij} is the rating of the alternative i under the criterion j normalized by the equation (2):

$$z_{ij} = \frac{g_{ij}}{\sqrt{\sum_i g_{ij}^2}} \forall i, \forall j \tag{2}$$

4. Identification of the positive and negative ideal solutions A^+ (Eq. 3) and A^- (Eq. 4) respectively:

$$A^+ = \{u_1^+,....,u_k^+\} = \\ = \left\{ \left(\max_i u_{ij} \mid j \in I' \right), \left(\min_i u_{ij} \mid j \in I'' \right) \right\} \quad (3)$$

$$A^- = \{u_1^-,....,u_k^-\} = \\ = \left\{ \left(\min_i u_{ij} \mid j \in I' \right), \left(\max_i u_{ij} \mid j \in I'' \right) \right\} \quad (4)$$

where I' refers to benefit criteria and I'' to the cost criteria.

5. Computation of distances S_i^+ and S_i^- of each alternative i from A^+ (Eq. 5) and A^- (Eq. 6) respectively.

$$S_i^+ = \sqrt{\sum_j (u_{ij} - u_j^+)^2}, \forall i \quad (5)$$

$$S_i^- = \sqrt{\sum_j (u_{ij} - u_j^-)^2}, \forall i \quad (6)$$

6. Computation of the closeness coefficient C_i (Eq. 7), with $0 \le C_i \le 1$.

$$C_i = \frac{S_i^-}{S_i^- + S_i^+}, \forall i \quad (7)$$

7. Ranking of alternatives on the basis of the obtained closeness coefficients, namely if $C_i > C_m$ then the alternative i has to preferred to the alternative m.

3. Case study

The combined HACCP and TOPSIS-based approach to prioritize risks is here applied to the smoked salmon manufacturing process of Sicily Food, a Sicilian industry which has been operating in the fishing sector for many years as a division of the Mancuso Group. Sicily Food commercializes its products in Italy and in foreign markets both with their own brands and private labels as well. With the aim of assuring quality and safe finished products, the company pays particular attention to the selection of raw materials and to the control of the manufacturing process. In this regard, suppliers are from Alaska, Norway and Scotland, and a dedicated productive structure of 4800 m^2 over an area of 16000 m^2 was opened in Sicily in 2013 according to the highest standards of safety. Environmental and productive process parameters, products' specifications and rules regarding the staff are certified by the British Retail Consortium (BRC) and the International Food Standard (IFS).

The smoked salmon manufacturing process begins with the receiving of frozen salmons and ends with the distribution of finished products to customers (Figure 1).

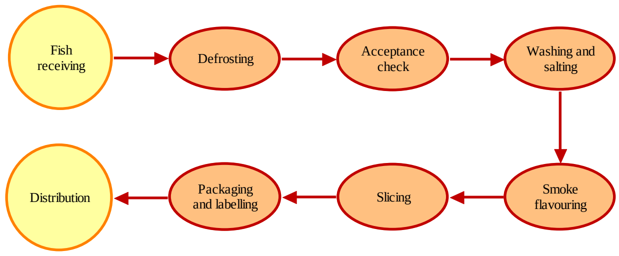

Figure 1: Process flow diagram

Stages of the salmon manufacturing process are detailed in the following.

– Fish receiving and defrosting: received fillets of frozen salmons are firstly defrosted into appropriate rooms where the temperature is opportunely monitored.

– Acceptance check: once defrosted, the temperature, the weight and the integrity of salmons' fillets packages are checked. Then, a sample of the received lot is sent to the laboratory for the microbiological testing and to verify the presence of foreign bodies. The microbiological testing includes the post-mortem pH monitoring. For pH values greater than 7, the whole lot is rejected and sent back to the supplier.

– Washing and salting: such a stage is performed into a specific room which is sanitized every three hours to avoid the fish contamination by the listeria monocytogenes bacterium. The temperature is kept beneath the 7°C and salmons are manually placed on steel shelves where they are checked to ensure the absence of residual scales and impurities due to the filleting process. Then, fishes are washed with water and finally salted.

– Smoke flavouring: washed and salted salmons' fillets are placed on appropriate trolleys and introduced into particular ovens where the humidity and the temperature are opportunely monitored. Generally speaking, there are two types of smoke flavouring processes, namely the so-called hot smoked salmon that takes place at temperatures of about the 70°C, and the cold one which uses a temperature between 25°C and 30°C. The company makes a cold smoke flavouring process which makes use of beechwood and lasts for 15-18 hours. As the hot smoked salmon process, the cold one applied on farmed fishes and together with appropriate hygienic conditions assures safety and quality products.

– Slicing: such a stage starts with the automated skin removal and carries on with a manual removal of residual skin and bones. Then, fillets are sent to a slicer machine which produces slices having a thickness of 1.5 mm, and trays of different size and weight are manually prepared.

– Packaging and labelling: salmons' trays are weighed by a specific machine and vacuum packed to avoid air bubbles and thus the development of bacteria.

Packages are labelled to include information such as expiration date, lot number, etc. A further laboratory check is performed on samples of finished products before the distribution.

As aforementioned, assuring the quality and the safety of products is the main goal of Sicily Food. To such an aim, all lots are monitored during all stages of the manufacturing process by the extraction of samples which are sent to the laboratory for the microbiological testing. As required by the HACCP, the organization also performs the hazard analysis of the smoked salmon manufacturing process with the aim of identifying known and potential hazards that may have an adverse effect on the human health. Table 1 synthesizes the identified hazards and the process stage they are connected to apart from the analysis of suppliers which is directly performed by salmon suppliers before sending the fish to Sicily Food.

Table 1: Identified hazards

Process phase	Hazards
Fish receiving	Aeromonas Hydrophila
	Heavy metal (Hg, Cd, Pb)
	Salmonella SPP
Smoke flavouring	Benzopyrene and other polycyclic aromatic hydrocarbons
Fish receiving and Packaging	Parasites
All phases	Allergens
	Foreign bodies, metals, glass, stones
	Plastic foreign bodies
	Listeria Monocytogenes
Analysis of suppliers	Staphylococcal enterotoxins
	Formaldehyde
	Residues of medicinal products
	PBC and PCDD

The main part of hazards reported in Table 1 is specifically regulated in order to contribute to the protection of public health and establish harmonized safety criteria on the acceptability of food, in particular as regards the presence of certain pathogenic micro-organisms. For instance, the Commission Regulations EC No 2073/2005 (Commission Regulation EC No 2073, 2005) and No 1881/2006 (Commission Regulation EC No 1881, 2006) need to be complied for the listeria monocytogenes whereas the benzopyrene is regulated by the Commission Regulation EC 835/2011 (Commission Regulation EC 835, 2011).

Starting from the necessity recognized by the Sicily Food to implement a systematic risk assessment approach, the next prioritization of hazards reported in Table 1 is performed by using the proposed TOPSIS method. Actually, the hazard analysis as the first principle of HACCP does not represent the main focus of the present paper which is instead addressed to the proposal of a semi-quantitative and structured method to prioritize the identified food-borne hazards on the basis of ratings expressed by the organization HACCP team. Therefore, the TOPSIS method is applied to rank risks related to their occurrence and severity. On the TOPSIS point of view, identified hazards reported in Table 1 hence represent the alternatives to be ranked on the basis of their evaluations against criteria, namely the occurrence O and the severity S. In particular, a four-point scale is used for the first criterion whereas the severity is assessed on a five-point scale. Both scales are characterized by a decreasing preference versus, namely the smaller the rating, the smaller the probability of occurrence and the severity. Ratings of alternatives against criteria (i.e. g_{ij}) are reported in Table 2 and then normalized by the equation (2). As concerns criteria, they are assumed equally weighted, i.e. $w_O = w_S = 0.5$. The elements u_{ij} of the weighted and normalized decision matrix (Table 3) are then computed by the equation (1) whereas equations (3) and (4) are used to compute the positive and negative ideal solutions (i.e. A^+ and A^- respectively) synthesized in Table 4.

Table 2: Hazards' ratings against criteria O and S

Hazards	O	S
Aeromonas Hydrophila	1	2
Heavy metal (Hg, Cd, Pb)	1	4
Salmonella SPP	1	3
Benzopyrene and other polycyclic aromatic hydrocarbons	2	5
Parasites	1	1
Allergens	1	3
Foreign bodies, metals, glass, stones	1	3
Plastic foreign bodies	2	1
Listeria Monocytogenes	4	4
Staphylococcal enterotoxins	1	3
Formaldehyde	1	2
Residues of medicinal products	1	3
PCB and PCDD	1	4

Table 3: Weighted and normalized matrix

Hazards	O	S
Aeromonas Hydrophila	0.0857	0.0884
Heavy metal (Hg, Cd, Pb)	0.0857	0.1768
Salmonella SPP	0.0857	0.1326
Benzopyrene and other polycyclic aromatic hydrocarbons	0.1715	0.2210
Parasites	0.0857	0.0442
Allergens	0.0857	0.1326
Foreign bodies, metals, glass, stones	0.0857	0.1326
Plastic foreign bodies	0.1715	0.0442
Listeria Monocytogenes	0.3430	0.1768
Staphylococcal enterotoxins	0.0857	0.1326
Formaldehyde	0.0857	0.0884
Residues of medicinal products	0.0857	0.1326
PCB and PCDD	0.0857	0.1768

Table 4: Ideal solutions

Hazards	O	S
A^+	0.0857	0.0442
A^-	0.3430	0.2210

On the basis of computed closeness coefficients (Eq. 7), the following Table 5 synthesizes the final ranking results. On the basis of the performed analysis, the most dangerous hazard is the listeria monocytogenes. Actually, such a bacterium causes the listeriosis, a disease particularly dangerous for pregnant women, immune-compromised patients, children and elderly. The bacterium can be present both in raw and smoked fishes, it survives to refrigerator temperatures and it particularly proliferates between 30°C and 38°C. As a consequence, the temperature is monitored during all stages of the process and it is maintained between 10°C and 12°C, and opportune hygienic measures for personnel are taken as well. Then, the second position is taken by the benzopyrene and the other polycyclic aromatic hydrocarbons released during the smoke flavouring stage of salmons. Therefore, the listeria monocytogenes, the benzopyrene and the other polycyclic aromatic hydrocarbons result to be the most critical hazards which must be addressed into the HACCP plan.

Table 5: Ranking of risks

Hazards	C_i
Listeria Monocytogenes	0.1325
Benzopyrene and other polycyclic aromatic hydrocarbons	0.4661
Heavy metal (Hg, Cd, Pb)	0.6632
PCB and PCDD	0.6632
Plastic foreign bodies	0.7418
Allergens	0.7547
Foreign bodies, metals, glass, stones	0.7547
Staphylococcal enterotoxins	0.7547
Residues of medicinal products	0.7547
Salmonella SPP	0.7547
Aeromonas Hydrophila	0.8675
Formaldehyde	0.8675
Parasites	1

In the light of the obtained results, the organization decides to undertake the following preventive measures.

- Further agreements with suppliers about the microbiological testing to be performed to ensure the integrity of raw materials.
- Specific hygienic measures designed to reduce external contaminations. During the manufacturing process, such measures concern tools, machineries as well as the personnel which are obliged to wear appropriate coveralls according to the adopted standards.
- Microbiological testing based on systematic sampling to more accurately monitoring all those hazards that cannot be visually detected such as the heavy metal contamination which may occur during the salmons' aquaculture into oceanic cages.

4. Discussion

As emphasized in the manual (FAO/WHO, 2005), traditional food safety systems are recognized as "inadequate to cope with the complex, persistent pervasive and evolving array of food safety issues existing today." To the contrary, "modern food safety systems need to be science-based to effectively cope with, and respond to, the wide range of food safety challenges." As a concept, a science-based approach to food safety is not completely new. What is new is the use of science-based approaches within the risk analysis framework fairly recently introduced in the food safety field to effectively manage, evaluate and communicate risks. Actually, science-based results may support Decision Makers (DMs) to minimize the occurrence of food-borne hazards, to reduce and manage risks, and to improve the outcomes of decision-making.

However, food safety hazards potentially occurring in whatever manufacturing environment are generally numerous so that setting priorities among them is fundamental to enable informed decision-making and resource allocation. With this recognition, the proposed TOPSIS-based approach represents a structured way to set priorities among food-borne hazards. As mentioned in Section 1, the extant body of literature on such an issue is mainly focused on the proposal of the traditional FMECA by means of which food-borne hazards are ranked on the basis of related RPNs. Nevertheless, the general use of the RPN method has been widely criticized to have several shortcomings (Certa et al., 2017a; Certa et al., 2017b; Liu et al., 2013) some of which are listed below.

- RPNs' parameters (i.e. O, S and Detection D) are equally weighted.
- Different combinations of O, S, and D may produce exactly the same value of RPN, but their hidden risk implications may be totally different.
- The mathematical formula for calculating RPN has been debated, because there is no rationale in obtaining the RPN as a product of the risk factors O, S and D.

The TOPSIS method allows at differently weighting criteria on the basis of the DM perceptions. The latter makes able a better management of the information available on the decision-making problem to be dealt.

5. Conclusions

The hazard analysis is the first principle of the Hazard Analysis and Critical Control Point (HACCP) system commonly implemented by food producers and processors as a comprehensive approach to the food safety control. It is defined as the process of collecting and evaluating information on each known or potential hazard associated with the food under consideration. However, none specification is supplied by the technical literature about the way how such a collection and evaluation of hazards' information need to be performed.

With this recognition, a structured and semi-quantitative risk assessment approach based on HACCP and TOPSIS was proposed in the present paper to prioritize risks arising from food-borne hazards of a real smoked salmon manufacturing process. Specifically, the hazard analysis was firstly performed to identify hazards which could be of such significance to cause injury or illness if not effectively controlled. Then, the TOPSIS method was used to rank risks arising from the occurrence of food-borne hazards previously listed. To the prioritization aim, hazards were evaluated against two differently weighted evaluation criteria, namely the frequency of Occurrence (O) and the Severity (S). The proposed approach classified the listeria monocytogenes, the benzopyrene and the other polycyclic aromatic hydrocarbons released during the smoke flavouring stage as the most critical hazards on which paying attention to assure safety and quality finished products. On the basis of the obtained results, the subject's company decided the more appropriate measures to be undertaken to minimize the impact of the aforementioned hazards on the investigated manufacturing process.

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