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Fuzzy Approach in Evaluation of Operations in Food Production

Abstract: *HACCP (Hazard Analysis Critical Control Points) is a scientifically based set of principles that is designed to prevent food borne illness. This dynamic system uses a combination of food handling procedures, monitoring and record keeping to have food safe. HACCP is based around seven established principles. This paper proposes fuzzy approach in establishing critical limits in process of ensuring food safety.*

Keywords: *HACCP, fuzzy approach*

1. INTRODUCTION

Hazard Analysis and Critical Control Points (**HACCP**) is a systematic preventative approach to food safety that addresses physical, chemical and biological hazards as a means of prevention rather than finished product inspection. HACCP is used in the food industry to identify potential food safety hazards (**H**azard **A**nalysis), so that key actions, known as Critical Control Points **(CCP**'s) can be taken to reduce or eliminate the risk of the hazards being realized. The system is used at all stages of food production and preparation processes. HACCP consists of seven principles. Among others, very important principles are: identification of critical control points and establishing critical limits for each control point. This paper will present fuzzy approach in evaluation of operation in process of food production.

In this paper we suppose the following:

1. We considered separately each process in food processing,
2. The number of production processes is defined according to technological documentation and it is finite
3. The evaluation of production processes is multi-criteria optimization task. Optimization criteria have equal relative importance.
4. The optimization criteria have imprecise values for each production processes. This assertion is based on the fact that relations between production processes critically depend on human activities. This fact is one of main reasons why this problem requires fuzzy system modeling [9]. The values of optimization criteria can be described by discrete fuzzy numbers. The fuzzy approach to treating uncertainties has some advantages over the stochastic approach:
   - Calculating of probability distributions for each stochastic variable requests a lot of evidence,
   - Combining of different uncertainties leads to a complex probability distribution, this results in very complex mathematical expressions.
5. In real problems like the one we have been considering, there are a lot of imprecise data.

This paper is organized in the following way: in Section 2, HACCP is defined. In Section 2, the problem statement of evaluation of each production process is presented. In Section 3, the optimization criteria are defined and they are described by discrete fuzzy numbers. In Section 4, a new procedure for determination of critical limit of each production process is presented. The proposed procedure is illustrated by an example given in Section 5.

2. HACCP AND ISO 22000

Generally HACCP (The **H**azard **A**nalysis **C**ritical **C**ontrol **P**oint system) consists of: preliminary steps, seven established principles and preparation of implementation of HACCP. The core of HACCP is based around seven established principles (defined by Codex Alimentarius Commission, International organization for establishment of standards in food industry):

.**Principle 1**: *Conduct a hazard analysis (HA).* Plants determine the food safety hazards identify the preventive measures the plant can apply to control these hazards.

Principle 2: *Identify critical control points.* A critical control point (CCP) is a point, step, or procedure in a food process at which control can be applied and, as a result, a food safety hazard can be prevented, eliminated, or reduced to an acceptable level. A food safety hazard is any *biological, chemical,* or *physical* property that may cause a food to be unsafe for human consumption.

Principle 3: *Establish critical limits for each critical control point.* A *critical limit* is the maximum or minimum value to which a physical, biological, or chemical hazard must be controlled at a critical control point to prevent, eliminate, or reduce to an acceptable level.

Principle 4: *Establish critical control point monitoring requirements.* Monitoring activities are necessary to ensure that the process is under control at each critical control point. FSIS is requiring that each monitoring procedure and its frequency be listed in the HACCP plan.

Principle 5: *Establish corrective actions.* These are actions to be taken when monitoring indicates a deviation from an established critical limit. The final rule requires a plant's HACCP plan to identify the corrective actions to be taken if a critical limit is not met. Corrective actions are intended to ensure that no product injurious to health or otherwise adulterated as a result of the deviation enters commerce.

Principle 6: *Establish record keeping procedures.* The HACCP regulation requires that all plants maintain certain documents, including its hazard analysis and written HACCP plan, and records documenting the monitoring of critical control points, critical limits, verification activities, and the handling of processing deviations.

Principle 7: *Establish procedures for verifying the HACCP system is working as intended. Validation* ensures that the plans do what they were designed to do; that is, they are successful in ensuring the production of safe product. Verification procedures may include such activities as review of HACCP plans, CCP records, critical limits and microbial sampling and analysis.

ISO 22000 is standard that consists of:

- § Demands necessary for good manufacturing practice,
- § Demands according to Codex Alimentarius's HACCP principles,
- § Demands for management system.

Demands for good manufacturing practice are not listed in the standard, but standard refers to existing good practice. It is clear that HACCP and its seven principles present very important part of ISO 22000.

3. PROBLEM STATEMENT

Mathematical model for evaluation of food processing process is developed under the following assumptions:

1. Each process consists of number of operation. Generally an N operation exists in production processes, which are formally described by group of indexes of operation:

$$\nu = \{1, \ldots, n, \ldots, N\} \quad (1).$$

Number and type of operations are defined in accordance to technological documentation. It could be considered that are unchangeable during distinguish period of time.

2. In each operation (n=1,...,N) one or more critical points could emerged which could produce different effects. In the processes of food production there are physical, biological, or chemical hazard. Formally hazard in operation n (n=1,...,N) could be presented with group of hazard index:

$$\mu^n = \{1^n, ..., m^n, ..., M^n\} \quad (2).$$
(n=1,...,N; m=1,...,M)

Total number of critical points in operation n (n=1,...,N) is defined as M^n. Number and type of hazard are defined by experts according to experience. In this case experts are: manager of technology, and quality managers.

Each critical point could contain different hazards one or more. It is almost impossible to examine influence of each hazard on total hazard and critical limits, so their influence is observed as the sum.

3. Each hazard could be described by number of attributes based upon evaluation criteria are defined. In the general case each hazard $m^n \left(n = 1,.., N;\ m = 1,..., M\right)$ is evaluated in sense of K different criteria which are formally presented with a group of criteria:

$$\kappa = \{1,..., k,..., K\} \quad (3).$$

Number and type of criteria in the sense of estimation of level of the hazard is estimated by experts according to the type of the problem.

In this paper, safety of the food production process is estimated according to two criteria. The first criteria is defined as possibility of hazard and second one is overall safety as result of existence of hazards.

4. As it is known, the optimization criteria can be either of benefit or cost type. Yoon and Hwang [8] define two criteria types:

(a) Benefit optimization criteria are positively correlated with utility or the preferences of decision maker, which means: if the criteria values increase, so does the utility of decision maker,

(a) Cost optimization criteria are negatively correlated with utility or the preferences of decision maker, which means: if the criteria values increase, so does the utility of decision maker. According to classification which is given in [8], both criteria have costly nature.

5. In general, the relative importance of each optimization criterion k $(k \in \kappa)$, $w_k\ (k = 1,..., K)$ is different. Determination of criteria weight is a difficult task which presents a problem to itself. In this paper we started with assumption that both criteria have same importance.

4. MODELING VALUES OF CRITERIA FOR EVALUATION

In this Section, procedure for modeling of two criteria for evaluation of safety of food production process: possibility of hazard and overall safety as result of hazard on specific process are presented.

Based on their experience, experts consider that these to criteria have the greatest importance on safety of food production.

Modeling of values for both criteria is based on theory of fuzzy groups [6,10]. Values are described by discrete fuzzy numbers. We could ask question why we use discrete fuzzy numbers? In this paper principle "***digital thinking***" is used, defined in [2]. Generally this principle could be employed in modeling of values in almost all quantities that exists in managerial problems.

Value of criteria k $\left(k \in \kappa\right)$ for hazard $m^n \left(n = 1,..., N;\ m = 1,..., M\right)$ is described by discrete fuzzy number $\tilde{f}_{m^n k}$. In the next sections procedure of modeling of each considered criteria is presented.

4.1 Possibilities of hazard

If sufficient amount of data exist from data base is could be calculated possibility of hazard emerge. On contrary, if company does not have sufficient data base about types of hazards and frequency of hazards’ appearing (this is case in domestic companies) then experts estimate type of the hazards and possibility of appearance of each hazard.

In this paper, value of considered criteria is described by three linguistic expressions: “small”, “medium” and “great”. They modeled by three discrete fuzzy numbers, $\tilde{M}_1, \tilde{M}_2, \tilde{M}_3$, respectively [5]. For example the linguistic expression "medium" is modeled by discrete fuzzy number $\tilde{M}_2$:

$$\tilde{M}_2 = \left\{ r_j, \mu_{\tilde{M}_2}\left(r_j\right) \right\} \quad (4),$$

where: r_j is a discrete value in the domain of fuzzy number $\tilde{M}_2$. The values of domain are determined by scale of measures, for example "school's" scale of measures. These values are real.

$\mu_{\tilde{M}_2}(r_j)$ is a membership function of fuzzy number $\tilde{M}_2$. In this paper, the discrete fuzzy number $\tilde{M}_2$ can be defined:

$$\tilde{M}_2 = \begin{Bmatrix} (1,0), (1.5,0.25), (2,0.5), (2.5,0.75), (3,1), \\ (3.5,0.75), (4,0.5), (4.5,0.25), (5,0) \end{Bmatrix} \quad (5).$$

Linguistic expression "small" and "great" are modeled by discrete fuzzy numbers $\tilde{M}_1$ and $\tilde{M}_3$, respectively. Let us define these discrete fuzzy numbers:

$$\tilde{M}_1 = \left\{ r_j, \mu_{\tilde{M}_1}(r_j) \right\} \quad (6),$$

$$\tilde{M}_3 = \left\{ r_j, \mu_{\tilde{M}_3}(r_j) \right\} \quad (7).$$

They are obtained by applying simple operations, concentration (Con) and dilation (Dil), respectively, used to modify membership function .Here, we suppose that fuzzy number $\tilde{M}_1$ is concentrated, its membership functions become more concentrated around points with higher membership grades as, in this case:

$\tilde{M}_1 = \text{Con}\,\tilde{M}_2$ and

$$\mu_{\tilde{M}_1}(r_j) = \mu^2_{\tilde{M}_2}(r_j)$$

Dilation has the opposite effect from concentration and is produced by modifying the membership function through the transformation:

$\tilde{M}_1 = \text{Con}\,\tilde{M}_2$ and

$$\mu_{\tilde{M}_3}(r_j) = \mu^{1/2}_{\tilde{M}_2}(r_j)$$

4.2 Importance of consequences resulted by existence of hazard

As it was mentioned earlier consequences $m^n\ (n = 1,..., N;\ m = 1,..., M)$ could appear as the results of biological, chemical and physical hazards. Importance of consequences is different. On the one hand it could be almost neglected; on the other hand it could be very important. In this paper we introduced estimation that importance of each consequence that could be result of potential hazard in process of food production could be described using five linguistic expressions: „very low“, „low“, „medium“, „high“ and „very high“. These linguistic expressions are modeled using five discrete fuzzy numbers, $\tilde{P}_i\ (i = 1,...,5)$, so: $\tilde{P}_i = \left\{ p_s, \mu_{\tilde{P}_i}(p_s) \right\}$

where: p_s is discrete value in the domain of discrete fuzzy number $\tilde{P}_i\ (i = 1,...,5)$. These values are defined on the group of real umbers and belongs to interval [1,9], such as Satty’s scale [4]. Value 1 mark that consequence of specific hazard is neglectable, and value 9 that consequence is extremely high.

$\mu_{\tilde{P}_i}(p_s)$ is a membership function of fuzzy number $\tilde{P}_i\ (i = 1,...,5)$. These values are result of subjective estimation of experts.

5. PROCEDURE FOR HAZARD EVALUATION

Procedure for evaluation of each operation in each process in food production is developed in this paper through following steps:

Step 1. Normalization of values’ of criteria in order to define hazard of operation

$$m^n\ (n = 1,..., N;\ m = 1,..., M).$$

Normalized values of criteria are marked as:

$$\left(\tilde{f}_{m^n k}\right)'.$$

Normalization is procedure for setting value of each criteria in group of real numbers in specific interval [0,1]. In literature we can find different types of normalizations such as: simple normalization, linear, vector etc. [3]. Selection of normalization type presents problem on its own.

In this paper linear normalization is used. Because both criteria have cost character, normalized values of these criteria could be calculated using following analytic equations:

$$\left(f_{m^n k}\right)' = 1 - \frac{f_{m^n k} - f_{m^n k}^{\min}}{f_{m^n k}^{\max}}$$ where is:

$f_{m^n k}\min$ minimal value in domain of fuzzy number $\tilde{f}_{m^n k}$ for k=1,..,K and $\mu_{\tilde{f}_{m^n k}} \neq 0$, $f_{m^n k}\max$ maximal value in domain of fuzzy number $\tilde{f}_{m^n k}$ for k=1,..,K and $\mu_{\tilde{f}_{m^n k}} \neq 0$

Values of distribution function of possibility of normalized fuzzy numbers, $\left(\tilde{f}_{m^n k}\right)'$ could be calculated according to equation:

$$\mu_{\left(\tilde{f}_{m^n k}\right)'}\left(\left(f_{m^n k}\right)'\right) = \mu_{\tilde{f}_{m^n k}}\left(f_{m^n k}\right)$$

Step 2. Evaluation of each hazard $m^n \; (n = 1,..., N; \; m = 1,..., M)$ is marked as $\tilde{O}\left(m^n\right)$ and could be calculated according to following analytic equation:

$$\tilde{O}\left(m^n\right) = \left(\tilde{f}_{m^n 1}\right)' + \left(\tilde{f}_{m^n 2}\right)'$$

Estimated number is also fuzzy number based on rules of fuzzy algebra [6,9,10].

Step 3. Defuzzification of calculated value $\tilde{O}\left(m^n\right)$. In the other words, using defuzzification we get representative scalar of fuzzy number $\tilde{O}\left(m^n\right)$, which is marked $O\left(m^n\right)$. A large number of defuzzification methods could be found in literature [10]. In this paper representative scalars are calculated using moment method [1].

Step 4. Calculated scalar values, $O\left(m^n\right)$ could be grouped in three classes. Each class could be described by linguistic mark, such as: „very low hazard“, „medium hazard“, „extremely high hazard“. Width of class could be defined on many different ways [7]. In this paper width of class is defined using following equation:

$$i = \frac{O\left(m^n\right)_{\max} - O\left(m^n\right)_{\min}}{1 + 3.322 \cdot \log M^n}$$ where is:

$O\left(m^n\right)_{\max}$ maximal values of calculated mark of hazard of specific operation $m^n \; (n = 1,..., N; \; m = 1,..., M)$,

$O\left(m^n\right)_{\min}$ is minimal value of calculated mark of hazard $m^n \; (n = 1,..., N; \; m = 1,..., M)$.

Using this procedure, employees could observe level of hazard of each production process more effectively.

6. NUMERICAL EXAMPLE

Developed model is tested on example of production processes raspberries' and blackberries' processing. Input data for this model are real data from one business environment.

Data input

1. Considered production process consists of six operation which are presented by group of index of operation:

$\nu = \{1,2,3,4,5,6\}$, where are

1- exemption of classified raspberries and blackberries from lager chamber . Packing in PP bags and carton boxes, closing of boxes using tape or packing in large PP bags.
2- metal detecting of packed block and folding in racks u
3- stocking of block in chamber for stock, $T \in \left[-18^0\,C - 20^{0\,C}\right]$ of final product
4-paletization and measurements
5-loading in transport vehicle
6-transport to cooler at $T = -20^0\,C$

2. In each operation of considered process one or more hazards appears which are formally presented by group of hazard indexes:
$\mu^1 = \{1^1, 2^1, 3^1\}$, $\mu^2 = \{1^2\}$, $\mu^3 = \{1^3\}$, $\mu^4 = \{1^4\}$, $\mu^5 = \{1^5\}$ and $\mu^6 = \{1^6\}$
where hazards are defined such as:

1^1-contamination with pathogen microorganisms: echeria coli, staphylococcus aureus, proteus types,

2^1-rest of washing and disinfection material,

3^1-hair, jewelry, peaces of boxes, plastic ...

1^2-peaces of metal,

1^3-development of micro organisms,

1^4-foreign bodies,

1^5-foreign entities, and

1^6-development of micro organisms, ferments and moldiness.

Experts evaluated each hazard according to both criteria. Experts' marks are presented in Table 1.

Table 1 Experts evaluation of hazards which could appear in processing raspberries and blackberries

m^n $(n = 1,\ldots 6;\ m = 1,\ldots 8)$	$\tilde{f}_{m^n 1}$	$\tilde{f}_{m^n 2}$
1^1	$\tilde{M}_2$	$\tilde{P}_3$
2^1	$\tilde{M}_2$	$\tilde{P}_4$
3^1	$\tilde{M}_2$	$\tilde{P}_2$
1^2	$\tilde{M}_3$	$\tilde{P}_5$
1^3	$\tilde{M}_1$	$\tilde{P}_3$
1^4	$\tilde{M}_1$	$\tilde{P}_1$
1^5	$\tilde{M}_2$	$\tilde{P}_1$
1^6	$\tilde{M}_2$	$\tilde{P}_5$

Procedure of definition of marks for each distinguished hazard is presented in following text.

Step 1. Normalized values of criteria in sense of evaluation of hazards are calculated using ( ) equation:

$$\left(\tilde{M}_1\right)' = \begin{Bmatrix} (1,0), (0.9,0.006), (0.8,0.25), (0.7,0.56), (0.6,1), \\ (0.5,0.56), (0.4,0.25), (0.3,0.06), (0.2,0) \end{Bmatrix}$$

$$\left(\tilde{M}_2\right)' = \begin{Bmatrix} (1,0), (0.9,0.25), (0.8,0.5), (0.7,0.75), (0.6,1), \\ (0.5,0.75), (0.4,0.5), (0.3,0.25), (0.2,0) \end{Bmatrix}$$

$$\left(\tilde{M}_3\right)' = \begin{Bmatrix} (1,0), (0.9,0.5), (0.8,0.7), (0.7,0.87), (0.6,1), \\ (0.5,0.87), (0.4,0.7), (0.3,0.5), (0.2,0) \end{Bmatrix}$$

$$\left(\tilde{P}_1\right)' = \{(1,1), (0.83,0.8), (0.67,0.6), (0.5,0.4), (0.33,0.2)\}$$

$$\left(\tilde{P}_2\right)' = \{(1,0.2), (0.8,0.4), (0.6,0.6), (0.4,0.8), (0.2,1)\}$$

$$\left(\tilde{P}_3\right)' = \begin{Bmatrix} (1,0.2), (0.93,0.4), (0.86,0.6), (0.77,0.8), (0.71,1), \\ (0.64,0.8), (0.57,0.6), (0.5,0.4), (0.43,0.2) \end{Bmatrix}$$

$$\left(\tilde{P}_4\right)' = \{(1,0.2), (0.87,0.4), (0.75,0.6), (0.62,0.8), (0.5,1)\}$$

$$\left(\tilde{P}_5\right)' = \{(1,0.2), (0.94,0.4), (0.87,0.6), (0.83,0.8), (0.78,1)\}$$

Step 2. Based on equation (__) each considered hazard described by discrete fuzzy numbers is evaluated by mark. Because a large amount of numbers, these discrete fuzzy numbers are not presented in this paper $\tilde{O}\left(m^n\right)$.

$$\tilde{O}\left(1^1\right) = \{(0.63,0),\ldots,(0.93,0.25),\ldots,(1.31,1),(1.33,0.4),\ldots,(1.9,0.2),\ldots,(2,0)\};\ n_1 = 56$$

$$\tilde{O}\left(2^1\right) = \{(0.7,0),\ldots,(0.9,0.5),\ldots,(1.1,1),\ldots,(1.5,0.2),..(1.75,0),..,(2,0)\};\ n_2 = 45$$

$$\tilde{O}\left(3^1\right) = \{(0.4,0),\ldots,(0.8,1),\ldots(0.9,0.75),\ldots,(1.5,0.4),\ldots,(2,0)\};\ n_3 = 22$$

$$\tilde{O}\left(1^2\right) = \{(0.63,0),\ldots,(0.93,0.25),\ldots,(1.31,1),(1.33,0.4),\ldots,(1.9,0.2),\ldots,(2,0)\};\ n_4 = 55$$

$$\tilde{O}\left(1^3\right)=\{(0.78,0),\ldots,(0.23,0.7),\ldots,(1.38,1),\ldots,(1.9,0.2),\ldots,(2,0)\};\ n_5=44$$
$$\tilde{O}\left(1^4\right)=\{(0.33,0),\ldots,(0.13,0.2),\ldots,(1.6,1),\ldots,(1.7,0.56),\ldots,(2,0)\};\ n_6=41$$
$$\tilde{O}\left(1^5\right)=\{(0.53,0),\ldots,(1.3,0.4),\ldots,(1.6,1),\ldots,(1.9,0.25),\ldots,(2,0)\};\ n_7=28$$
$$\tilde{O}\left(1^6\right)=\{(0.98,0),\ldots,(1.9,0.2),\ldots,(1.38,1),\ldots,(1.9,0.2),\ldots,(2,0)\};\ n_8=43$$

Step 3. Scalar values of fuzzy numbers which present mark of considered hazards are calculated using moment method such as:

$O\left(1^1\right)=1.332$, $O\left(2^1\right)=1.294$,

$O\left(3^1\right)=1.097$, $O\left(1^2\right)=1.407$,

$O\left(1^3\right)=1.323$, $O\left(1^4\right)=1.288$,

$O\left(1^5\right)=1.343$ and $O\left(1^6\right)=1.459$.

Step 4. Systematization of data in classes:

$$i=\frac{1.459-1.079}{1+3.322\cdot\log 8}\approx 0.095$$

Class of mark	Description
[1.079-1.174]	Very low (VL)
[1.174-1.269]	Low (L)
[1.269-1.364]	Medium (M)
[1.364-1.459]	High (H)

Calculated results of evaluation of hazards could be presented by following Table 2.

Table 2 Evaluation of hazard in processing of raspberries and blackberries

$m^n\ (n=1,\ldots 6;\ m=1,\ldots 8)$	Mark
1^1	M
2^1	M
3^1	VL
1^2	H
1^3	M
1^4	M
1^5	M
1^6	H

7. CONCLUSION

In this paper, a new fuzzy model for evaluation of safety of each operation in process of food production is presented. The advantages of developed model according to literal sources are shown, primary, in the more realistic statement of the problem. By developing model, we get evaluation criteria and mark for each operation, separately, respecting more criteria simultaneously. Also, the developed model is flexible according to the possibility of number change, kind of optimization criteria change and also importance of optimization criteria change.

The following conclusion is made:

(i) It is possible to describe the problem of evaluation of safety of food in production process as multi-criteria optimization task by formal language that enables to look for the solution by exact method.

(ii) The uncertainties which exit in the model can be described by discrete fuzzy numbers.

(iii) Importance of estimation of criteria for operation is mostly in increase of safety of the food and safety of the all process. In the other words it significantly decreases influence of possible effects of different hazards in food production. All changes, such as changes in criteria, or their relevance could be easily incorporated in the model.

(iv) The developed methodology gives the possibilities through simulation to get the answer if there would be the result change if the input data change.

(v) The developed methodology is illustrates by numerical example.

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