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THE APPLICATION OF FMEA AND PARETO ANALYSIS METHODS IN THE PROCESS OF INDUSTRIAL BREAD MAKING IN ROMANIA

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Abstract: *Zero defects or nearly zero faulty products production process represents a new and important concern towards quality control of production systems. The requirement of a pertinent statistical control is important for identifying and monitoring defects, the main source of defects that occur in industrial bread making process. The current study was focused on applying two analysis methods Failure Mode and Effects Analyses, abbreviated FMEA and Pareto. Analysis concerning two technological stages that were considered as having a major impact on the quality of the final products. It was observed that the percent of nonconformities decreased in a significant manner – from 30% in 2018 to 5% in 2019 by applying the FMEA analysis. Also, the Pareto diagram showed that the application of several corrective measurements conducted to important decreases of Risk Priority Number from 288 to 128 and the severity decreased from 8 to 5 in the mixing process and from 128 to 81 for the baking process.*

Key words: *FMEA, Pareto, bread making, industrial process, effectiveness.*

1. Introduction

The bread making process represents one of the main industrial branches in developed countries, being able to ensure the required quantities of products. Novel food technologies are based on the revaluation of new ingredients with beneficial potential in order to satisfy the requirements of the contemporary consumer – gluten free, functional products, sanogenous products, diet products and ready-to-eat products [7].

Quality control processes [5], [14] in industrial bread making processes are developed through an identification of the weak points that cause lack of quality of the final products and increase the failure

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rate as well as the resulted waste. This industrial area is often affected by the fact that the statistical control process is not considered a viable method for preventing non-conformities of final products that usually results in waste, cost increase and quality depreciation [3].

It is essential to point out that there are certain quality requirements that characterize individual bread varieties so as to be acceptable for the final consumer regardless of their diet and nutritional habits, the most obvious and straight forward examples being the hard and crunchy crust of the French baguette and the soft core of toast bread [4]. The complexity of the interaction of ingredients completed by their quality, quantity and processing technology also influences the final product quality.

The industrial bread making process on automated production lines with commercial dough mixers raised several problems that are reflected in final product quality – decrease of product porosity. It was observed that the resulted dough was irregular and a sticky consistency was obtained. A high quantity of dough with unsatisfactory attributes was considered waste and costs of production raised.

The use of the tunnel oven for the industrial process also caused product nonconformities – it was observed that the final products were undercooked (e.g. the bread crust was too light as compared to the standard attributes). A higher number of unbaked products led to a higher production cost.

A possible reason for the occurrence of nonconformities could be: the use of low quality flour, the flour gluten is weak, insufficient dosage of flour, inappropriate ratio of flour and water, inadequate baking temperature for dough baking. Taking into account the results of the work conducted by [12] a possible reason for the occurrence of the defects could be: the cells shrinking of bread sides cells, the composition of the dough and the bread during the baking and the cooling.

By analysing and considering the average of flaws during the bread making process, it was noted that the percentage of defects ranged between 11.5% and 18%.

The purpose of this work is to identify the reason of the occurrence of nonconformities and to apply the Failure Mode and Effect Analysis Method (FMEA) and the Pareto analysis. The results of the research are going to contribute to the decrease in the number of nonconformities related to dough mixing and baking and to reduce this number to an acceptable one [5], [14].

2. Materials and Methods

The research was conducted in two bread making factories in Romania. The effect Analysis Method (FMEA) was applied for the mixing and baking technological processes and each failure mode got a numeric score that quantifies: a) likelihood that the failure will occur, b) likelihood that the failure will not be detected, and c) the amount of harm or damage the failure mode may cause to the equipment. Table 1 shows the correlation between the numerical values of risk assessment.

With regard to the values comprised in Table 1, the following formula for calculating the Risk Priority Number (RPN) can be used:

$$RPN = S \cdot O \cdot D \quad (1)$$

where:
S is the severity;
O – the occurrence;
D – the detection (S x O are considered critically).

Data obtained were analysed by using ARIS Six Sigma Software. The limits considered were explained in Table 2.

Correlation between numerical values of risk assessment Table 1

<table>
<tr><th>Rank</th><th>Severity</th><th>Explanation</th></tr>
<tr><td>1</td><td>minor fault extremely unlikely</td><td>consumer may not notice</td></tr>
<tr><td>2</td><td rowspan="2">system performance is slightly affected, it can very rarely occur, it could be detected with a careful monitoring process</td><td rowspan="2">slight dissatisfaction of consumer</td></tr>
<tr><td>3</td></tr>
<tr><td>4</td><td rowspan="3">the retrogression of the system, can cause inconvenience, a certain amount of waste and equipment deterioration</td><td rowspan="3">noticeable by consumers</td></tr>
<tr><td>5</td></tr>
<tr><td>6</td></tr>
<tr><td>7</td><td rowspan="2">major deterioration of equipments, high rate of nonconformities, severe damage, disruptions of process</td><td rowspan="2">high disagreement of consumer</td></tr>
<tr><td>8</td></tr>
<tr><td>9</td><td>process endangered, significant disruptions, low probability of prevention</td><td>consumer safety threatened</td></tr>
<tr><td>10</td><td>almost certain failure</td><td>Consumer endangered</td></tr>
</table>

*values are expressed as failure per unit

Range of limits considered Table 2

Range	Probability of failure	Measurement
1 … 10	failure is unlikely or very low	insignificant
10…100	moderate to high	moderately significant
>100	very high, failure is imminent	very significant

3. Results and discussions

In Table 3 the FMEA diagram for the industrial bread making process is presented thus highlighting the steps considered relevant for controlling and monitoring the final product quality.

The Failure Mode and Effects Analysis (FMEA) can anticipate and prevent problems and help companies achieve high reliability in products and processes within considerably shorter development times, and within budget, being an optimal and adequate method for improving products quality through statistical control [2], [13].

Products analysed in the diagram from Table 3 were obtained during a week 24.05.2019-31.05.2019 in two factories from Romania. The results were compared and analysed using the FMEA diagram and corrective measures were implemented in order to decrease the occurrence rate of the nonconformities.

The highest values of the RPN were obtained for two process steps – mixing and baking, being considered the most relevant steps that contribute to the high failure rate. The dough mixer was not handled adequately following the parameters that the final product was supposed to accomplish. According to

Davidson, there are a series of processes that occur during the mixing of the dough - dispersion of all the ingredients and blending into a homogeneous mass, hydration of the flour, emulsification of the fats and water, development of the gluten formed by the proteins in the flour and activation of leavening agents [6], [8], [10]. The tunnel oven must ensure a proper baking area for products to turn from dough into bread. In the current study, several charges of product were baked defective and finally were considered waste because the physicochemical and sensory attributes were unsatisfactory according to standard recommendations. Table 3 shows the FMEA diagram applied for the industrial bread making process.

The RPN value was higher than the maximum accepted value for the processes mentioned above – 288 for mixing and 225 for baking. As compared to other processes, the values were the highest, the obtained values for intermediate processes were situated in the range between 2 and 96. Baking and mixing were considered very significant with a very high probability of failure. The severity (SEV) of the mixing process was considered to be 8, and the occurrence (OCU) and detection (DET) to reach 6. This fact means that there is a considerable probability to cause serious damage to the technological process. The baking process got a score of 9 for severity (SEV), 5 for occurrence (OCU) and 5 for detection (DET). As compared to the mixing process, the severity was higher, but the probability of occurrence and detection was lower. It was also noticed that during the baking process, the samples were placed too close to one another, with a distance of 1 cm between them and the steam dispenser had serious dysfunctionalities regarding steam distribution throughout the inside of the oven.

Regarding the other steps in the technological process, the severity ranged between 2 and 6, a particularly remarkable fact being that the occurrence and detection rate were significantly diminished with a superior value of 4 meaning that there is a high probability that with recurrent control, the existing problem can be detected and eliminated or kept under control [1], [9], 11].

The Pareto chart was also elaborated for the values obtained before applying the corrective actions. In Figure 1, it can be noticed that dough mixing and baking processes attained RPM values between 250 and 300. Percentually, the values reach 100% for dough mixing and 80% for baking. It can be observed that the other steps in industrial bread making reach values of about 40% (as measured in percents) and a RPN under 100.

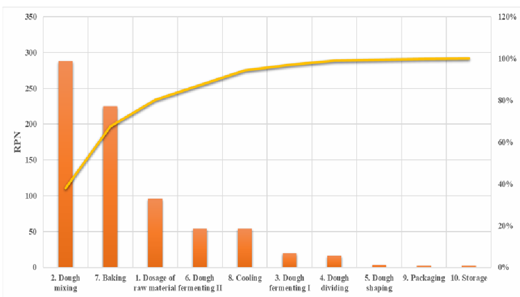

Fig. 1. *The pareto diagram for the technological process prior to corrective actions*

FMEA diagram applied to the industrial bread making process Table 3

Process stage	**1. Dosage of raw material**	**2. Dough mixing**	**3.Dough fermenting I**	**4. Dough dividing**	**5. Dough shaping**
Failure mode	Faulty dosage of raw and auxiliary materials	Inadequate mixing process due to inefficient speed and time adjustment	Inadequate conditions for fermenting	The mass of dough is not properly divided according to the type of product	Irregular dough shapes
Failure cause	Uncalibrated scales used	Mixing and kneading are carried out according to wrong parameters	Fermentation parameters are unsuitable and not properly adjusted	The dough pieces are too large and have irregular shapes; the weight of the pieces does not correspond to the technological specifications	Dough shaper is not properly adjusted according to the desired shape of the final product
Failure effect	The quantity of raw and auxiliary materials is inaccurate and does not correspond to the technological indications	Mixed dough is sticky and lacks in consistency; obtained product shape, lower volume, undeveloped porosity, thin core, salt grain feel during a sting and core elasticity	Bread does not reach the proper volume and gaseous phase	The quantity of dough inserted in the dividing machine is too high and is not in accordance to the capacity of the machine	Different shapes of final dough pieces
Severity	6	8	5	4	3
Occurrence	4	6	2	2	1
Detection	4	6	2	2	1
Risk Priority Number (RPN)	96	288	20	16	3
Corrective actions	Replacing fault scales and rescaling measuring equipment	Adjustment of dough mixer parameters, dividing the dough in portions in order to correspond to the capacity of the mixer	Adjustment of the conditions before fermentation	Correction of the quantity of dough inserted by dividing the large mass into smaller masses	Correction of the shaping parameters
Risk Priority Number after correction	12	128		4	1

Table 3 *(continuance)*

Process stage	**6.Dough fermenting II**	**7.Baking**	**8. Cooling**	**9. Packaging**	**10. Storage**
Failure mode	Inappropiate conditions for fermenting	Pale colour of the products, thin crumb, weak porosity, weak elasticity	Time of cooling (too short)	Unfinished packed products	Storage temperature is too low (2-4°C)
Failure cause	The conditions for fermentation are inadequate	Tunnel oven temperature not properly adjusted, steam distribuitor not working, dough pieces are placed too close to one another	Inappropiate time	The thermal equipment does not seal the bags enough	The thermostat of the storage area is not working properly
Failure effect	The volume of the bread is affected, the shape is not well developed	Bread crust is too pale, the colour is opaque, the middle is sticky and not enough baked, the gluten newtork is not developed	Development of mould on the surface of the product	Difficult handling and possible contamination	Several packed products develop sweat on the surface
Severity	6	9	6	2	2
Occurrence	3	5	3	1	1
Detection	3	5	3	1	1
Risk Priority Number (RPN)	54	225	54	2	2
Corrective actions	Correction of the condition before fermentation	Adjustment of the functions of the oven according to the process indications and the type of product	Consideration of the cooling time	Extending the sealing time for the bags	Repairing the thermostat in order to ensure optimal temperature
Risk Priority Number after correction	24	81	24	2	2

As a corrective action for dough mixing the adjustment of the parameters was considered according to the loading capacity and the desired attributes of the formed dough.

By adjusting the parameters, the efficiency of the mixing process was significantly improved and the quality of the dough was according to the requirements.

The veracity of the adjusted equipment provides dough with adequate quality properties with no defects and improved characteristics that correspond to the specifications. RPN decreased from 288 to 128 and the severity decreased from 8 to 5.

In Figure 2, the Pareto chart after corrections is represented. It can be observed that the RPN decreased to 128 for the mixing process and to 81 for the baking process. Meanwhile, as a resulting positive aspect, the number of nonconformities was reduced and the obtained products successfully abided by the physicochemical and quality demands.

Also, substantial energy reductions were noticed due to the fact that the equipment was working properly and dysfunctionalities were eliminated. The number of nonconformities was considerably diminished, in accordance with the proper organization of the factory and the adequateness of the technological specifications required for the industrial bread making process.

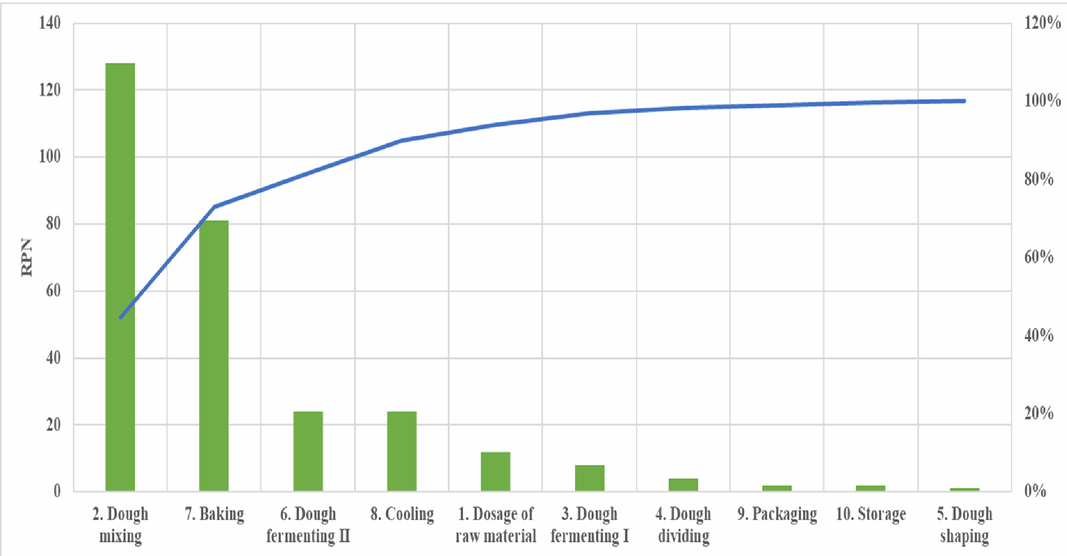

Fig. 2. The *Pareto diagram for the technological process prior to corrective actions*

In connection with this aspect, corrective measurements were also applied to the baking process. The person authorized for maintenance was trained in order to be able to adjust the tunnel oven parameters in accordance with the required standards. With regard to the functionality of the tunnel oven, a specialized inspection was performed and the dysfunctionalities were fixed.

Figure 3 represents an analysis of annual nonconforming products reported since 2011. It can be remarked that the percentage of nonconformities was between 35% and 30% until 2018. The number of nonconformities decreased as an effect of the corrective activities developed and improvements implemented.

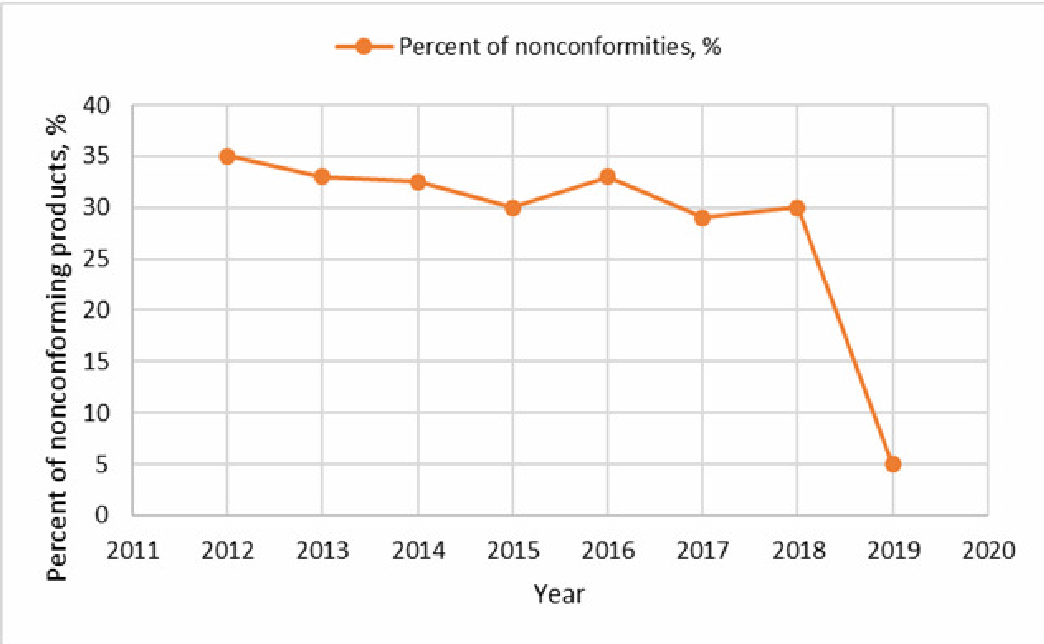

Fig. 3. *Percentage of nonconformities reported per year since 2011*

4. Conclusions

The current experimental research leads to successful results that offer new perspectives on using statistical analysis for improving industrial processes.

By applying the Failure Mode and Effect Analysis Method (FMEA) and the Pareto Analysis, the weak points in the technological flow were identified and corrective actions were implemented.

The study applies the FMEA method to an industrial scale bread making company, in which technological parameters and equipment have an important influence on the final product quality.

It was noticed that two of the industrial bread making stages had a significant influence concerning the final product – the mixing process and the baking process.

The malfunctioning of the equipment in both cases and the failure in accomplishing the standard and technical specification contributed in equal proportion to an increase in nonconforming products and waste quantity. The resulted products could not be redirected to other industries in order to be processed because the core had an increased moisture and weak porosity.

The FMEA and the Pareto analysis contributed to the relevant identification of weak points in the technological flow, thus applying corrective measurements and restoring the desired accurateness of the bread making process.

Either of the methods used in this study is an excellent method for industrial companies to use in order to establish process control and improve the quality management system for producing high quality products that fulfil consumer expectations and requirements.

Also, the amount of waste resulted from the industrial technological process is radically diminished and thus efficiency could reach a high rate.

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