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Integrating statistical process control to monitor and improve carcasses quality in a poultry slaughterhouse implementing a HACCP system

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ABSTRACT

In meat slaughterhouses, the enumeration of certain microorganisms as microbiological quality indicators is very important for verifying effectiveness of the Good Hygiene Practices (GHP) and Hazard Analysis Critical Control Points (HACCP) systems. Microbiological testing of final products as part of the HACCP verifying process may provide information that a process is in control. The aim of this work was to exploit the data from a poultry slaughterhouse implementing HACCP and demonstrate an alternative approach to the conventional statistical analysis using the principles of the Six Sigma quality. The data collected on Total Viable, Total Coliforms and *Staphylococcus aureus* counts were used to construct control charts (X bar–R control chart) and perform process capability analysis. Based on X bar–R control charts, the process was in a statistical control state but this before its automation was not capable since process capability and process performance indices were below 1.00, indicating the production of poultry carcasses with poor microbiological quality. After process automation, the indices were much higher than 2.00, indicating that the process was capable of producing poultry carcasses within the specification limits.

1. Introduction

Six Sigma was first established by Motorola, Inc. aiming at continuous quality improvement. Six Sigma is the quality level of 3.4 defects per million (DPM) (Mitra, 2008). It is based on a structured approach to solving problems. This structure involves five steps: Define, Measure, Analyze, Improve and Control (DMAIC). The DMAIC process is generic and applicable to all domains. Each step of this process includes tools enabling users to focus on problems and assess the relevance of the results obtained (Brook, 2010). The first step is the definition of the problem followed by the measurement step. The aim of this step is to measure the current performance (baseline) of the process. Then, the causes of the problem are identified and their effects on process performance are quantified through the analysis of the process. This will allow the development, selection and implementation of the best solutions (process improvement). The final step involves statistical process control (SPC) to assure that the solutions or improvements found will be sustained (Brook, 2010; Montgomery, 2009).

Control charts and process capability analysis are tools of the Measure, Analyze and Control phases of the DMAIC process. Control charts are constructed to determine whether or not the process is in a statistical control state and establish control limits for monitoring the process in the future. Process capability reflects the process performance when this is in a statistical control state. Process capability analysis estimates the process mean, process standard deviation, relative frequency distribution of the quality characteristic and proportion of the non conforming products (Mitra, 2008).

Although the use of control charts relative to microbiological quality in food industry is infrequent (Augustin & Minvielle, 2008), such tools can be easily implemented in a Hazard Analysis Critical Control Point (HACCP) system for verifying process control (Giese, 1999; Hayes, Scallan, & Wong, 1997; Murphy, Osaili, Beard, Marcy, & Duncan, 2005). Integrating SPC into a HACCP plan, it may improve its effectiveness toward preventing food hazards. HACCP application certainly influences the microbiological quality of carcasses. Control charts could be used for quantifying process output and investigating whether or not this can remain within statistically defined control limits. In addition, control charts can indicate the beginning of a process shift, which could potentially lead to a safety hazard (Hurst, 2002).

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Slaughterhouses implementing a HACCP system collect a huge amount of data on the microbiological quality of carcasses, as a part of their system monitoring. The data can be used to evaluate and improve process performance relative to carcasses microbiological quality. However, such data is usually left unexploited. Following a previous report (Tsola, Drosinos, & Zoiopoulos, 2008) the aim of the present study was to exemplify through a practical example how microbiological data can be handled to perform process capability analysis and construct control charts.

2. Materials and methods

2.1. Terms used in the manuscript

TVC: Total Viable Counts.

TCOL: Total Coliforms.

SA: *Staphylococcus aureus*.

Subgroup: Each subgroup is referred to three different carcasses sampled on a single visit (sample size = 3).

n: Total number of subgroups sampled. It is the number of visits performed over a ten weeks period ($n = 10$).

X_{mean}: Subgroup mean. It is the average of three measurements corresponding to three different carcasses sampled on a single visit. Each carcass was sampled at the beginning, at the middle and at the end of the slaughter process to take into account variation of the counts.

R: Range of the measurements for each subgroup. It was calculated based on the following equation: $measurement_{max} - measurement_{min}$.

X bar–R control charts: Use of X_{mean} and R to construct control charts when the sample size is relatively small (equal or less than 10; here is 3).

$CL_{X\ bar\ or\ R}$: Center line of the corresponding control chart.

$UCL_{X\ bar\ or\ R}$: Upper control limit of the corresponding control chart.

$LCL_{X\ bar\ or\ R}$: Low control limit of the corresponding control chart.

ARL: Average Run Length. It shows, for a given situation, how long, on the average, successive points will be plotted on the control chart before the detection of a point outside the control limits as a function of the products quality in terms of TVC, TCOL or SA concentration ($\log_{10}$ cfu/g).

OC curve: Operating Characteristic curve. It describes the probability of not detecting a process which is in an out of control state as a function of the products quality in terms of TVC, TCOL or SA concentration ($\log_{10}$ cfu/g).

USL: Upper specification limit. It is the greatest amount in which a process or product is within the acceptable performance limits.

Target: Carcass of acceptable microbiological quality.

Short term and long term variation of the process: Six Sigma theory assumes that the process mean will shift over time and that the variation observed in a sample of data at a point of time (short term variation) will deteriorate over the long run (long term variation).

CpK: Process capability index adjusted for the effect of a non-centered to the target distribution. It is referred to short term performance. It shows the potential of a process to be capable of, i.e. producing conforming products or not.

CpU: Upper process capability index used when only one specification limit exists, i.e. USL. It is referred to short term performance.

PpK: Process performance index adjusted for the effect of a non-centered to the target distribution. It is referred to long term performance. It shows the actual performance of a process.

PPU: Upper process performance index used when only one specification limit exists, i.e. USL. It is referred to long term performance.

k: Scaled distance. It is a measure of deviation of the process mean from the target. It is referred to long term performance and should be <1.00.

DPM: Number of defects expressed per million. It is referred to short term performance. It is the poultry carcasses that do not meet the specifications (e.g. TVC, TCOL or SA exceeding the USL).

PPM: Same as before except that it is referred to long term performance.

Sigma level: It is the distance between the mean of a normally distributed process and the specification limit (here the USL) expressed in units of standard deviations. If its value is high, e.g. 6, then the process performance is high, meaning that virtually all poultry carcasses produced will be within the specification limits, i.e. carcasses with acceptable microbiological quality. The desired situation (Case I) is the Sigma level to be greater than 3σ because in case of shifts in the process mean and/or standard deviation, which are undesirable indicating an out of control condition, there is no waste since conforming products (quality characteristic of interest inside the USL) are still produced. The other situations are the Sigma level to be equal to 3σ, indicating that any shift in the process leads to an out of control condition and production of non conforming products (Case II), and the Sigma level to be less than 3σ (undesirable condition). In this case although the process could be in control non conforming products are produced. Hence, the process is performed poorly producing products that do not meet the specifications. When shifts in the process occur the problem becomes much worse (Case III) (Besterfield, 2000).

$\mu_{process}$: Process mean. It measures the process location.

$\sigma_{process}$: Process standard deviation. It reflects the variability of the process.

2.2. Data collected

The primary data are based on a previous work (Tsola et al., 2008) conducted at a large scale poultry slaughterhouse implementing a HACCP system. The methodology followed for data collection is described by Tsola et al. (2008). The differences before and after automation of the poultry processing line are presented in Table 1. The poultry carcass samples collected were subjected to microbiological analysis determining TVC, TCOL and SA. Verification of slaughter process can be carried out by examining carcasses at the end of the slaughter line or after chilling (Bolton, Doherty, & Sheridan, 2001; Lenahan, O'Brien, Kinsella, Sweeney, & Sheridan, 2010). Therefore, the data used in the present study was those collected after carcass chilling. Control charts and process capability analysis were done for each microbiological parameter studied before and after process automation.

2.3. Control charts

X bar–R control charts were constructed using TVC, TCOL and SA counts. For each sample, the X_{mean} and R were calculated. A control chart constitutes of the CL, UCL and LCL. Any data point exceeding the control limits indicates process which is in an out of control state. When someone, however, deals with microbiological data then any data point below the LCL does not show an out of control situation because low numbers of microorganisms are desirable, i.e. products of better microbiological quality. Therefore, the LCL can be skipped (Anonymous, 2006).

For the X bar control chart: