Department of Grain Science and Industry

Statistical Process Control: Techniques for Feed Manufacturing

Tim Herrman
Extension State Leader
Grain Science and Industry

The application of statistical process control (SPC) during feed manufacturing improves product quality and reduces manufacturing costs. Consequently, quality improvement using SPC offers the feed industry a valuable business strategy. This strategy includes quality planning, analysis, and control to ensure that the quality assurance program contributes positively to cash flow, return on investment, and overall business profitability.

SPC is the application of statistical principles and techniques in all stages of production directed toward the most economical manufacturing of a product. The economic benefits associated with SPC include increased product uniformity, less rework and material waste, increased production and plant operating efficiency, increased customer satisfaction resulting in repeat business, less money invested in finished product inspection, and fewer product recalls. These financial benefits should exceed the costs of implementing an SPC quality program, thus resulting in a positive return on investment.

Quality costs are often categorized as follows:

- *Prevention Costs*, or the costs of doing something right the first time.
- *Appraisal Costs*, or the costs associated with measuring, evaluating, or auditing products or services.
- *Internal Failure Costs*, which are costs resulting from a product failing to meet quality requirements.
- *External Failure Costs*, which are costs resulting from a product failing to meet customer expectations.

The application of SPC usually does not increase prevention and appraisal costs; rather, it is a way to better utilize existing data to reduce internal and external failure costs. Examples presented in this bulletin highlight internal and external failure costs and how those can be reduced through the application of SPC tools.

SPC Application

Feed manufacturing primarily is a batch manufacturing process. The adaptation of SPC may be difficult at first, particularly if only a few batches of a ration are manufactured each week. To assist feed manufacturers in incorporating SPC in their quality program, a list of potential control points by cost center are presented below:

Receiving: Incoming ingredient moisture content, protein content, temperature, and bulk density.

Grinding: Particle size, grinding rate (tons/hr), and kWh electrical usage per ton.

Batching: Batches per hour, target weight versus actual weight (may be collected via automated systems or production records).

Conditioning: Mash moisture content and temperature before and after the conditioner.

Pelleting: Pellet durability, tons per hour, kilowatt hour per ton, pellet temperature post die, finished pellet moisture content, and pellet temperature post cooler.

Bagging: Bag weight.

Feed Product: Moisture and protein content.

SPC Tools

Four of the major SPC tools presented in this publication include the frequency histogram, control chart, Pareto chart, and the cause and effect diagram.

The **frequency histogram** shows how a process is operating in a summary format. It helps answer four important questions:

- Is there a normal distribution for the process or products?
- Where is the process centered?
- Is the process capable of meeting the engineering or product specification?
- What is the economic loss associated with not meeting product specifications?

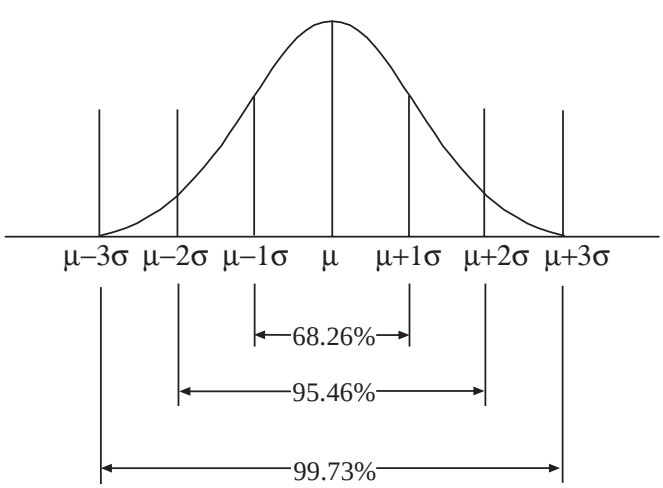
The frequency histogram does not show when the variation occurred nor does it diagnose why the variation occurred. To answer the question "When did the variability occur?" one applies the control chart.

The **control chart** is popular in many industries for the following reasons:

- Control charts are a proven technique for improving productivity.
- Control charts are effective in defect prevention.
- Control charts prevent unnecessary process adjustments.
- Control charts provide diagnostic information.
- Control charts provide information about process capability.

The application of the control chart relies on the Central Limit Theorem. This theorem states that variation naturally occurs in a population (no two things are alike). A large group of the population (processes, analyses, etc.) cluster around the middle and form what is referred to as a bell shaped curve (Figure 1). Descriptive statistics used to explain the population include the mean (average of the population) and the standard deviation. Three standard deviations to each side of the mean (average) explain 99.7 percent of the variation in a population.

Figure 1. *Bell shaped curve displaying the population mean (μ) and standard deviation (σ)*



The **Pareto chart** and the **cause and effect diagram** (fishbone chart) are problem solving techniques that augment the frequency histogram and control chart. The Pareto chart helps to prioritize customer complaints using a frequency histogram format. The fishbone chart assists in pinpointing the cause of the problem by focusing on the sources of potential variation (material, machine, methods, personnel, and environment).

Procedures for Developing a Frequency Histogram

Step 1. Collect samples or measurements during processing. Sample collection requires the application of sampling (MF-2036 *Sampling: Procedures for Feed*) and evaluation (MF-2037 *Evaluating Feed Components and Finished Feeds*) techniques that enable a representative characterization of the population.

Step 2. Find and mark the largest and smallest number in the data set.

Step 3. Calculate the range (difference between the largest and smallest values) of the measurements.

Step 4. Determine the intervals for the frequency histogram. The interval is calculated by dividing the range by the number of intervals (divide by 7 when there are fewer than 50 data points; divide by 10 when there are more than 50 data points). Either round up or down to arrive at a value that is easy to plot (e.g., 2.47 could be rounded to 2.5, or 1.03 can be rounded to 1, etc.).

Step 5. Assign boundaries and midpoints.

Step 6. Determine the frequency of occurrences within each interval.

Step 7. Prepare a frequency histogram.

Example 1:

A feed mill reported the following protein contents for the past 32 loads of soybean meal.

42.38	42.87	42.73	42.87	42.72	44.10	43.56	42.83
43.63	43.59	42.99	43.15	42.78	43.27	44.30	43.36
44.39	42.98	43.48	43.11	42.57	42.10	41.78	43.93
43.10	43.85	43.06	43.05	42.80	42.73	42.33	43.01

Step 1. Collect and evaluate the sample of soybean meal.

Step 2. Find and mark largest (44.39) and smallest (41.78) values.

Step 3. Calculate range: 44.39 - 41.78 = 2.61

Step 4. Determine interval width: 2.61÷ 7 = .37

Note: The data set consists of fewer than 50 measurements; therefore, seven intervals were selected. The interval width of .37 is then rounded off to 0.4 to facilitate plotting the frequency histogram.

Step 5. Assign boundaries and midpoints.

The beginning boundary is 41.7; this is based on the smallest value in the data set which was 41.78. The midpoint is equivalent to the lower boundary value (41.7) plus half the interval width which equals 0.2 percent protein. The columns for midpoint, interval width, and boundaries are completed in the Frequency Histogram Worksheet (Figure 2).

Step 6. Tally occurrences within each boundary and calculate frequency (Figure 2). Perform this activity by placing a 1 in the appropriate tally column for each of the values located in Step 1 (e.g., for the first measure 42.38, place a 1 in the second row in the tally column. The frequency column is calculated by adding all the 1's in the tally column by row, dividing by the total measures (n = 32) and multiplying by 100 (e.g., row one frequency is calculated as follows: 1 ÷ 32 = .031, .031 x 100 = 3.1).

Step 7. Finally, plot the frequency histogram in the space below the worksheet (Figure 2).

Interpretation of Frequency Histogram

The results of the bar graph communicate several important pieces of information:

- The distribution appears normal.
- The protein content of the different lots is centered at 43.1 percent.
- More than 50 percent of the soybean meal had a protein content greater than 42.9 percent.

The guaranteed minimum protein content was 42 percent, and all feed rations were based on this protein level. Therefore, an opportunity exists to reformulate rations for different protein levels in soybean meal.

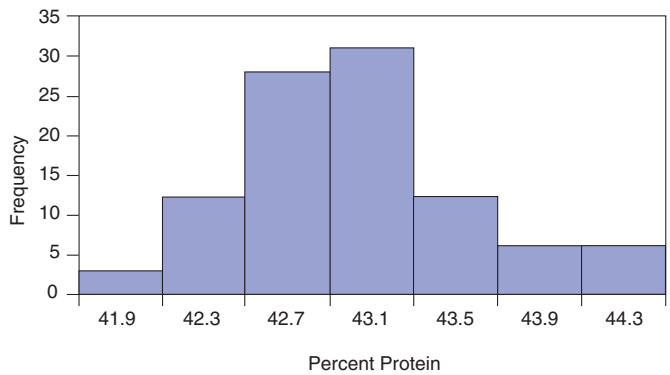
Refer to the cause and effect diagram for ways to improve the process and improve corporate profitability.

Using Frequency Histograms for Economic Analysis

In a second example, complete feed was analyzed for protein content to estimate the variation in the finished feed and to calculate costs associated with over-fortifying feed protein content. The following 28 data points were used to prepare a frequency histogram and estimate the cost of over-fortifying feed to ensure that the minimum label content was provided. The label protein content was 17.0, the feed mill had an 18 percent protein target, approximately 650 tons of this feed was manufactured per month, and the cost of over-fortifying finished feed by 1 percent protein was assumed to be $5.60 per ton. (Note: See bulletin MF-2506 *Sampling: Statistical and Economic Analysis* for procedures to calculate the value of 1 percent protein.)

Figure 2. *Frequency Histogram Worksheet*
Attribute or Process: Soybean Meal Protein Content

Midpoint	Interval	Boundaries	Tally	Frequency
41.90	0.4	41.70-42.09	1	3.1
42.30	0.4	42.10-42.49	1111	12.5
42.70	0.4	42.50-42.89	111111111	28.1
43.10	0.4	42.90-43.29	1111111111	31.2
43.50	0.4	43.30-43.69	1111	12.5
43.90	0.4	43.70-44.09	11	6.2
44.30	0.4	44.10-44.49	11	6.2



Example 2:

17.47	17.95	18.91	18.87	18.35	18.44	18.71
18.60	18.80	18.84	19.41	18.82	18.19	18.75
19.01	18.27	18.60	19.46	18.08	18.24	17.73
18.40	19.26	18.64	19.46	19.23	18.53	18.12

The equation used to calculate the cost of over-fortifying feed is calculated for each bar above the target protein level of 18 percent. No deduction was taken for feed falling below 18 percent since the label protein content was 17 percent.

Values were calculated as follows:

(Frequency) x (% protein over target) x (protein cost) x (tons/month)

.179 frequency x .15 protein x $5.60 x 650 tons = $97.73

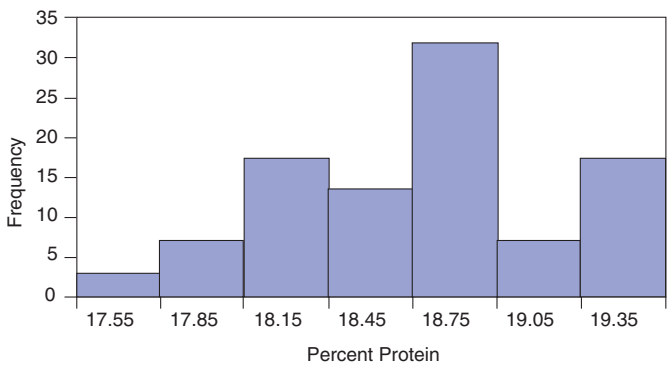
The total cost per month for over-fortifying this one feed was $2,369.

Figure 3. *Frequency Histogram Worksheet*
Economic Analysis of Feed Containing Protein Overfortification

Midpoint	Interval	Boundaries	Tally	Frequency	Economic Analysis
17.55	.3	17.40-17.69	1	3.6	$0.00
17.85	.3	17.70-17.99	11	7.1	$0.00
18.15	.3	18.00-18.29	11111	17.9	$97.00
18.45	.3	18.30-18.59	1111	14.3	$243.00
18.75	.3	18.60-18.89	111111111	32.1	$876.00
19.05	.3	18.90-19.19	11	7.1	$271.00
19.35	.3	19.20-19.49	11111	17.9	$880.00

Table 1. Factors for Control Limits

n	A2	D4	d2
2	1.880	3.268	1.128
3	1.023	2.574	1.693
4	0.729	2.282	2.059
5	0.577	2.114	2.326
6	0.483	2.004	2.534



The total savings potential or opportunity cost associated with over-fortifying protein content in this feed ration is $1,557 per month or $18,684 per year.

Procedures for Developing a Control Chart

Step 1. Collect samples or measurements during processing. This is similar to Step 1 for the frequency histogram. In some cases, multiple measurements for a particular process are collected, such as when monitoring bag weight or tracking conditioned mash temperature.

Step 2. Perform preliminary calculations with the data set. If there are multiple measurements (subsamples), calculate the average and the range of these measurements. Next, calculate the overall sum and average for these values.

Step 3. Calculate the control limits (upper control limit UCL_x and lower control limit LCL_x) for the mean and the upper control limit for the range (UCL_R). These control limits are set at three standard deviations. A simplified method for calculating control limits involves the use of Table 1, which presents factors for calculating control limits. The A2 column provides a list of factors used to calculate the UCL_x and LCL_x for data sets with subsamples (Example 3). The D4 column is used to calculate the UCL_R. The d2 column is used to calculate the UCL_x and LCL_x for data sets that contain only one measurement per sampling (Example 4).

Example 3. Bag Weight

Step 1. Collect sample data; in this example 5 bags for 20 lots of feed.

						Mean	Range
1)	40.00	40.20	40.05	40.00	40.10	40.07	0.20
2)	40.10	40.17	40.15	40.20	40.00	40.12	0.20
3)	39.90	39.95	39.95	40.05	40.00	39.97	0.15
4)	40.05	40.10	40.10	40.05	40.03	40.07	0.07
5)	40.00	40.10	40.10	40.05	40.10	40.07	0.10
6)	40.25	40.15	40.25	40.15	40.15	40.19	0.10
7)	40.30	40.10	40.10	40.30	40.30	40.22	0.20
8)	40.05	40.10	40.05	40.05	40.25	40.10	0.20
9)	40.10	40.10	40.10	40.20	40.20	40.14	0.10
10)	40.10	40.10	40.05	40.20	40.05	40.10	0.15
11)	40.30	40.20	40.15	40.05	40.05	40.15	0.25
12)	40.15	40.30	40.15	40.20	40.20	40.20	0.15
13)	40.00	40.05	40.05	40.05	40.00	40.03	0.05
14)	40.10	40.10	40.04	40.25	40.25	40.15	0.15
15)	40.00	40.10	40.10	40.10	40.00	40.06	0.10
16)	40.12	40.10	40.10	40.40	40.00	40.14	0.40
17)	40.12	40.27	40.25	40.10	40.15	40.18	0.17
18)	40.10	40.10	40.00	40.20	40.10	40.10	0.20
19)	40.30	40.20	40.15	40.15	40.20	40.20	0.15
20)	40.15	40.30	40.10	40.20	40.15	40.16	0.20
					Total	802.42	3.29
					Avg	40.12	0.16

Step 2. Calculate the averages and range for the subsamples. Then calculate the sum for the mean and range columns (802.42 and 3.29, respectively) and calculate the average by dividing the sum by the number of samples (n = 20) which results in values of 40.12 and 0.16, respectively.

Step 3. Calculate the upper and lower control limit for the range control chart. Select the factor from Table 1 under the column titled D4. (Note: The complete

table is published by the American Society for Quality Control.) In this example, select the value from the row n=5, since there are five measurements for each sample collection period (the select value is 2.114). The upper control limit is derived by multiplying D4 by the average range R:

$$UCL_R = 2.114 \times 0.1645$$
$$UCL_R = 0.348$$

Calculate the upper (UCL_x) and lower control (LCL_x) limits for the averages. Using Table 1, identify the value A2 based on the number (n=5) of measurements per sampling period.

Multiply A2 by the average range, then add and subtract this value from the average mean to arrive at the upper and lower control limits.

A2 times R = 0.577 x 0.1645 = 0.0949

$$UCL_x = 40.121 + 0.0949 = 40.21$$
$$LCL_x = 40.121 - 0.0949 = 40.03$$

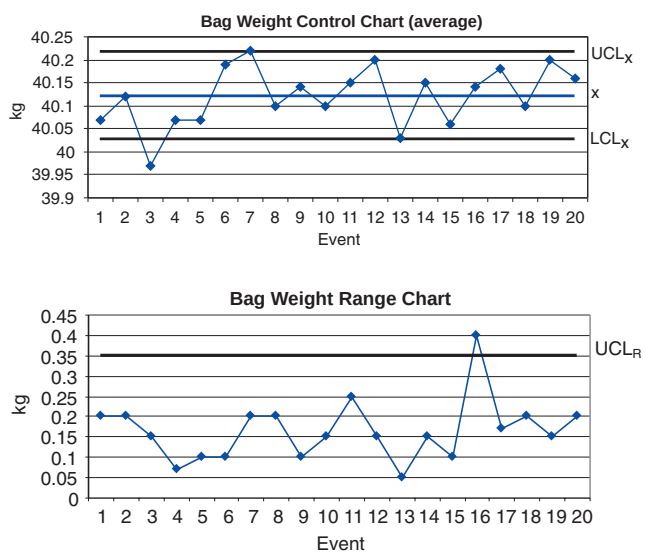
Step 4. Plot the data on the control chart (Figure 4).

Interpretation of the Control Chart

In Example 3, the following interpretations are included:

- The bag weight data resulted in fairly narrow upper and lower control limits; this indicates that little product is given away.
- The lower control limit of 40.03 kg indicates that there is little likelihood of under filling bags and shorting customers of product when the bagging process is under control.

Figure 4. *Control chart for average and range values*



- Bag weight measurements occur in nearly equal proportions above and below the mean.
- The process, while appearing to perform well, is out of control.

The control chart differentiates between normal population variation and variation due to an assignable cause. Normal variation typically occurs within upper and lower control limits. The UCL_x and LCL_x were plus and minus three standard deviations from the mean. (Note: Three standard deviations from the mean accounts for 99.7 percent of the variation in a population.)

Thus, there is a low probability (3 in 1,000) that a measurement will fall outside the control limits due to random chance.

For the bag weight control chart (Figure 4), the third event in the average control chart occurred below the lower control limit. Thus, the process was out of control. The cause could be due to failure to calibrate the bagging scale or, perhaps, an error by the operator. The cause and effect diagram can be used to help identify the problem, the control chart only lets us know when the event occurred. Looking at the range control chart in Example 3 (Figure 4) the 16th event resulted in an average range value that was above the upper control limit, again, indicating the process was out of control.

Additional Rules for Interpretation

In addition to assessing if points occur outside the control limits, it is important to detect whether non-random patterns of data occur within the control limits. Specifically, if seven consecutive data points occur all above or below the mean (even if they are within the control limits), it is correct to conclude that the process is out of control. To help understand why, consider the probability that you will get heads if you flip a coin; it is 50 percent. Now, what is the probability of flipping two heads in a row? The answer is 50 percent times 50 percent (0.5 x 0.5) or 25 percent. Carrying this calculation through seven times results in a probability of less than 1 percent of getting heads seven times in a row. At this point, we reject the possibility that this event occurred through random change.

Similar to the coin illustration, the possibility of having seven consecutive measurements in ascending or descending order also is unlikely unless there is a change in the process. Thus, if either of these events occur, the process is considered out of control.

Example 4. Individual and Range Control Charts for Finished Feed Protein Content

Step 1. Collect sample data. In this example, the value represents finished feed protein content. There are 28 total measurements.

Batch Number	Protein Content	Moving Range
1	17.47	
2	17.95	.48
3	18.91	.96
4	18.87	.04
5	18.35	.52
6	18.44	.09
7	18.71	.27
8	18.60	.11
9	18.80	.20
10	18.84	.04
11	19.41	.57
12	18.82	.59
13	18.19	.63
14	18.75	.56
15	19.01	.26
16	18.27	.74
17	18.60	.33
18	19.46	.86
19	18.48	.98
20	18.24	.16
21	17.73	.51
22	18.40	.67
23	19.26	.86
24	18.64	.62
25	19.46	.82
26	19.23	.23
27	18.53	.70
28	18.12	.41
Total	521.54	13.21
	x =18.62	MR=0.489

Step 2. Calculate the moving range for each pair of data; note the range between two measures is calculated as a positive value. Then summarize the values and calculate the mean and moving range average. Notice that the average (x) is calculated by dividing the total (521.54) by 28 and the moving range (MR) total (13.21) is divided by 27 since there are only 27 moving range values.

Step 3. Calculate the upper control limit for the range chart. Select the factor from Table 1 under the column titled D4. In this example, select the value from the row n=2 which is the smallest value in the table, since there is one measurement per event. The upper control limit is derived by multiplying D4 by the average range R:

$UCL_R = 3.268 \times 0.489$

$UCL_R = 1.6$

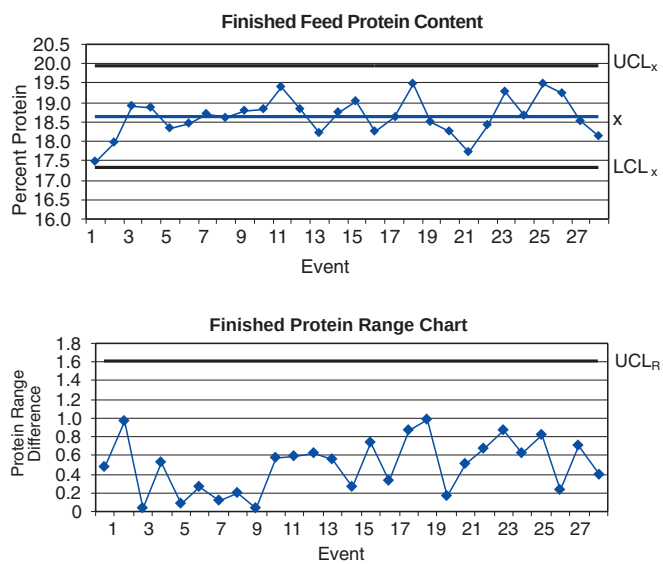
Calculate the upper and lower control limits for the average control chart. Divide the moving range average by 1.128 (d2), multiply by three (the desired number of standard deviations) and then add and subtract this value from the average mean.

$UCL = x + 3(MR/d2)$

$LCL = x - 3(MR/d2)$

Where x = mean of all lots

Figure 5. *Finished Feed Protein Content*



For this example, the calculations for UCL and LCL are as follows:

$UCL = 18.62 + 3(.489/1.128) = 19.92$

$LCL = 18.62 - 3(.489/1.128) = 17.31$

Step 4. Plot the data on the control chart (Figure 5).

Procedures for Developing a Pareto Chart

A Pareto chart is a special type of frequency histogram that records the most frequent problem as the first bar, the next most frequent problem as the next bar, and so on. This procedure helps prioritize problem solving activities.

Steps for developing a Pareto chart are as follows:

Step 1. Categorize the type of complaint: e.g., moldy feed pellets, too many fines, etc.

Step 2. List the most serious defect first under the defect column, followed by the second, etc.

Step 3. Report the number of occurrences for each incident in the frequency column.

Figure 6. *Worksheet for Pareto Chart: Pelletized Feed*

Defect	Number of Complaints	Cumulative Complaints	Cumulative Percentage
Fines	10	10	42%
Foreign Material	8	18	75%
Low Fat	4	22	92%
Bugs	1	23	96%
Color	1	24	100%

Step 4. Complete the cumulative complaints column by adding, in succession, the number of complaints.

Step 5. Calculate the cumulative frequency by dividing the cumulative complaints by the total number (n = 24) of complaints.

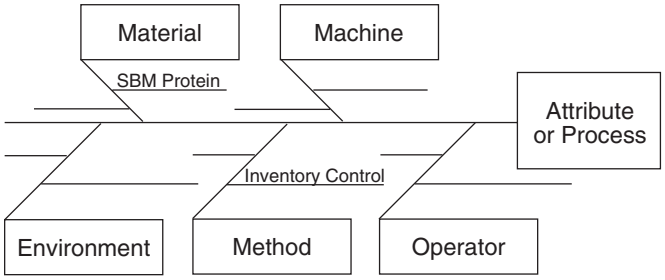
Step 6. Plot the results.

Process Improvement Using a Cause and Effect Diagram

The cause and effect diagram shows in picture or graph form how causes relate to the stated effect or to one another. Also referred to as a fishbone diagram, the main causes or "bones" of the fishbone are:

- Material
- Machine
- Environment
- Method
- Operator

Figure 7. *Cause and Effect Diagram (Fishbone Chart)*



For example, suppose finished product protein content is found to fluctuate by 2 percent. While in most cases the product meets label requirements for nutrient content, management is concerned about giving away protein, which is the same as giving away money. To address this problem, a team of employees, including the production supervisor, quality assurance manager, receiving technician, and lab technician, meet to solve the problem. They use the cause and effect diagram as a guide to discuss the source and solution to the problem. It is discovered that a wide range in soybean meal protein content occurs between lots. The soybean meal protein content is not identified in the warehouse, therefore, it is treated as having the same protein content by production personnel. The team decides to reformulate rations based on 1 percent soybean meal protein increments and identify the protein content of different lots of soybean meal in the warehouse. Therefore, the plant production personnel can match feed rations with the appropriate soybean meal content. The variation in finished product protein content ceases and the company reports a substantial profit increase during the next business quarter.

Summary

Statistical process control (SPC) finds many applications in the feed manufacturing industry. Examples illustrating the application of four SPC tools (frequency histogram, control chart, Pareto chart, and cause and effect diagram) are presented in this bulletin. Additionally, a list of other ways in which SPC may be applied to control the process and improve product uniformity are presented in the bulletin. SPC relies on the application of statistical principles and procedures to improve product quality and profitability. The benefits derived from SPC in the areas of reduced internal and external failures should offset any additional costs incurred from sample collection, testing, and data analysis.

This, and other information, is available
from the Department of Grain Science at
www.oznet.ksu.edu/grsiext,
or by contacting Tim Herrman,
Extension State Leader
E-mail: tjh@wheat.ksu.edu
Telephone: (785) 532-4080

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

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