Developing Control Measures to Reduce Variation in Weight of Packed Cement Bags

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The performance of the packing process at a cement plant was found to be unsatisfactory because of the high variability of the weight of the cement bags, resulting in violation of the specification. Violation of upper specification will lead to loss of profit, whereas bags below lower specification will lead to customer dissatisfaction. This article demonstrates the use of a variety of quality improvement tools to help resolve these issues.

The first step in the study was to confirm the extent of nonconformance as perceived by the management. Next, planned data were analyzed using analysis of variance techniques based on a mixed-effect, cross-nested model, to identify the possible sources of variation such as nozzles, shifts, and days of operation. The process capability was then estimated using *Clements' method.* Finally, the stochastic nature and economic factors (*manufacturing cost, selling price,* and *cost of repacking*) of production were taken into account to derive the optimum economic setting of the packing process. Implementations of the findings brought down the percentage off-specification by an amount of 39% along with a considerable reduction in variability. In the long run, this would lead to consistent production of a larger number of cement bags, along with better assurance to the customer. The additional sales value is expected to be about $249,000 annually.

Keywords Clement's method; Economic setting; Setting and control scheme.

INTRODUCTION

Product

The contribution made by cement to the development of modern civilization is evidenced by innumerable ways in which it is being used. Over the years, the cement industry has grown in India and is now poised for a big expansion.

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Ordinary Portland cement (OPC) is used for all types of construction and concrete products. It is a standard product with high strength and great durability, and is suitable for a multitude of jobs ranging from side walls to sky scrappers. This cement develops a high strength in its early stages and continues to grow stronger with the passage of time.

An Indian cement manufacturer distributes the finished product to different customers in India and abroad in bags, each having a target weight of 50 kg. The packing and loading of packed bags in trucks and wagons are mostly done by automatic machines. The quality characteristic of a packed bag is its weight, with the specification of 50 ± 0.5 kg.

The Packing Process

OPC is produced by mixing calcareous and argillaceous and/or other silica, alumina, or iron oxide-bearing materials, burning them at clinkering temperature, and grinding the resultant clinker.

From the grinding mills, the cement is stored in silos first and then it is delivered through rotary feeder by means of screw conveyors and bucket elevators to the *stationary packing machines* having four spouts (or nozzles). After inserting an empty gunny bag in position with respect to a nozzle by an operator, the following functions are performed:

1. A bag holder cylinder extends and holds the empty bag in position on the filler pipe.
2. A slide valve cylinder fully extends and releases the filling cross-section.
3. The ram of a weigh scale stop cylinder goes to midposition and releases in this way the weighing system.
4. The filling impeller starts running and commences filling.

The filled-up gunny bags are weighed and discharged from the packing machine to a conveyor. From this conveyor, the cement bags are further transported by a belt conveyor to the railway wagon or road truck.

Problem

For quite sometime, the performance of the packing process was found to be unsatisfactory because of high variability of weights of the bags and resulting in violation of the specification. From past experience, the management believed the extent of off-specification was around 70 to 75%. Violation of upper specification will lead to loss of profit, whereas bags below lower specification will lead to customer dissatisfaction. This study was therefore undertaken to reduce the variability and the production of off-specification bags.

THE ANALYSIS

A Preliminary Study

To obtain a preliminary idea about the existing status of the problem, three steps were followed.

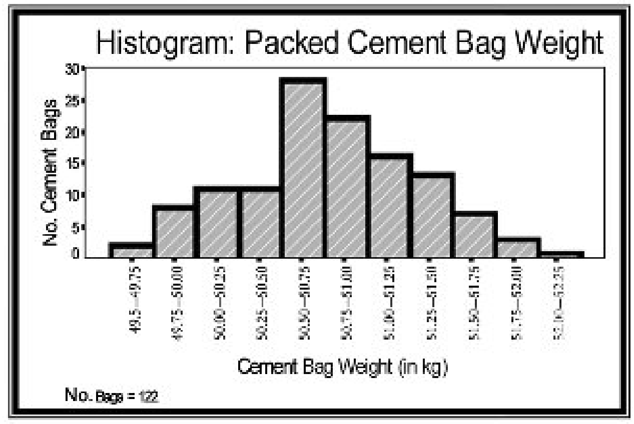
Step 1. Studying the Existing Process Control System

Generally, the weights of 10 to 15 bags were being checked randomly in each shift without recording the nozzle number. In case of a very high or low weight, the inspector tried to locate the nozzle creating problems and did the corresponding weight adjustment. The nozzles were cleaned after every shift by air.

Step 2. Studying the Existing Database System

Data on weight of packed cement bags were collected and the performance of the packing process was measured through histogram.

The process average and standard deviation were 50.8 kg and 0.526 kg, respectively. The nonconforming products in terms of excess and short weights (*as compared with the specification*) were estimated as 74.3 and 0%, respectively. The previous performance was expected to be normal, but this skewed nature was observed due to repeated and intentional adjustments of the process on the higher side by the operators to avoid underweight of cement bags.



Step 3. Conducting a Brainstorming Session

A brainstorming session was held in the factory to identify the possible causes of packing process variation. The detailed cause-and-effect diagram is shown in Appendix A.

Identifying Sources of Variation—Data Collection and Analysis

In this phase of study, the overall variation in the weight of packed cement bags and the magnitude of variation due to different sources such as days, shifts, and nozzles were assessed. In each of the two shifts A and B, two observations were collected from each of the four nozzles at the same time. This process of data collection was continued for 6 days.

The collected data were subjected to mixed effect (nozzle and shift:fixed; day:random) cross-nested analysis of variance (ANOVA) for the different sources of variation as identified from technical considerations. The following linear statistical model for this design was adopted:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_{k(j)} + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik(j)} + \varepsilon_{(ijk)1}$$
$$i = 1(1)4;\ j = 1(1)6; k = 1,2 \text{ and } l = 1,2$$

where μ is overall average; α_i is effect of ith nozzle; β_j is effect of jth day; $\gamma_{k(j)}$ is effect of kth shift within jth level of day; $(\alpha\beta)_{ij}$ is nozzle × day interaction; $(\alpha\gamma)_{ik(j)}$ is nozzle × shift(day) interaction; $\varepsilon_{(ijk)l}$ is random error distributed as NID (0, σ^2); and Y_{ijkl} is an individual observation on packed cement bag weight.

Because the original data cannot be provided to the readers because of confidentiality requirements of the client organization, we only describe the conclusions obtained through ANOVA undertaken.

The following observations were made from the ANOVA:

1. The inherent variability of the packing process was estimated as 0.251 kg (about 14% of the total variation explained by the process).
2. The process performance of packing with respect to packed cement bag weight was measured through two important indices C_p and C_{pk}, using Clements' method (Clements, 1989 for nonnormal distribution (tested through Shapiro & Wilks' W statistic).

USL	50.5 kg
LSL	49.5 kg
T (Process Target)	50 kg
$\overline{X}$ (Process Average)	50.8 kg
s (inherent variability)	0.251 kg
U_p (Estimated 99.865 percentile)	51.49602
L_p (Estimated 0.135 percentile)	50.13496
M (Estimated Median)	50.79

where L'_p is standardized 0.135 percentile $\approx$2.64955, U'_p is standardized 99.865 percentile $\approx$2.77299, and M' is standardized median ≈ -0.009. These obtained using Clement's table.

Then,

$$L_p = \overline{X} - s.L_{p'};U_p = \overline{X} + s.U_{p'},M = \overline{X} + s.M' \quad \text{and}$$
$$C_p = (USL - LSL)/(U_p - L_p);$$
$$C_{p1} = (M - LSL)/(M - L_p) \text{ and}$$
$$C_{pu} = (USL - M)/(U_p - M)$$

Therefore,

$$C_p = \frac{USL - LSL}{U_p - L_p} \cong 0.73$$
$$C_{p_k} = \min(C_{P_L}, C_{P_U}) = -0.40$$

It was found that the inherent variability of the process, measured by C_p (73%), was not satisfactory. The C_{pk} (40%) was also used and found to be highly unsatisfactory.

3. The results of the ANOVA are summarized in this paragraph. There was no significant difference among the four nozzles. But there existed significant variation between two shifts of a day. Thus, workmanship of operators could not be considered as identical. Also, there existed significant variation between days, shifts within day, and nozzle–day interaction. The significance of interactions revealed that all nozzles were not behaving uniformly on different days and at different time points of a shift.
4. In conclusion, it was the change of nozzle setting, at different time points, which was the most significant cause for this high-process variability. The optimum interval between nozzle settings was established from this analysis.

Most Economic Adjustment in Packing Machine

After deriving the optimum interval for adjustment, an economic analysis was undertaken for selecting the most favorable value for individual-filling bag weights (Bisgaard, Hunter, and Pallesen, 1984; Nelson, 1978). Now, if the filling process operates in a state of statistical control, the statistical distribution of filled bag weight is expected to have a normal distribution. In this study, the data on bag weight were subjected to test for normality assumption, the details of which are given in Appendix B. The test result indicates the generation of a normally distributed process in the long run. Given this result, the stochastic nature and economic factors of production were taken into account to achieve the most profitable operating policy.

Let T be the target value for the filling process, and x be the observed value of packed bag weight with an inherent process variance σ^2. Then, $x \sim N(T, \sigma^2)$.

Suppose, S = selling price of a good unit of packed cement per bag (i.e., satisfying $LSL \leq x \leq USL$), and M is manufacturing cost per unit of measure of cement (in kg), and R is cost of repacking per bag, if $x < LSL$. Then, the net income per bag of cement is

$$I = \begin{cases} S - R & , \quad \text{if } x < LSL \\ S & , \quad \text{if } LSL \leq x \leq USL \\ S - M(x - USL), & \text{if } x > USL \end{cases}$$

The expected net income is

$$E(I) = (S - R)\int_{-\infty}^{LSL} f(x)dx + S\int_{LSL}^{USL} f(x)dx + USL\int_{USL}^{\infty} [S - M(x - USL)] \cdot f(x)dx$$

where $f(x)$ is the p.d.f. of $N(T, \sigma^2)$.

The optimal value of T (say, T^*) is the solution to

$$\frac{dE(I)}{dT} = 0$$
$$\Rightarrow \frac{M\sigma}{R} = \frac{\phi[(L - T)/\sigma]}{1 - \Phi[(U - T)/\sigma]}$$

(see Appendix C for the previous deduction)

Here, in this study, $L = 49.5\,\text{kg}$, $U = 50.5\,\text{kg}$, $\sigma = 0.251$ kg, and $M/R = 0.0458$.

Therefore, solving for optimal T, we find from the previous equation that $T^* = 50.3$ kg. Hence, the economically optimum average-packed cement bag weight for packing process should be 50.3 kg.

Note: The expected percentage off-specification with respect to upper specification (i.e., 50.5 kg) and considering $\mu_F = 50.3\,\text{kg}$ and $\sigma_F = 0.251\,\text{kg}$ was found as 21%.

RECOMMENDATIONS AND CONCLUSIONS

Process Setup and Control Procedures

In situations where the initial setting plays a pivotal role, the following setting approval scheme for operators and supervisors at shop floor level of the filling process is recommended. The procedure is purely based on the experience and the type of production process, with a focus on introducing stringent control while setting a process.

1. **Setting Procedure:** At any time point, collect four filled-up gunny bags from four different nozzles. Estimate the average weight of four bags (μ_F).

   Then, set the process with average-filled weight (μ_F) and start full-scale production, provided that the next few sets of filled-bag weight readings coming out of the filling process are within the band $\mu_F \pm 1.5(\sigma_F/\sqrt{4})$.

   Here, if $\mu_F = 50.3\,\text{kg}$ and $\sigma_F = 0.251\,\text{kg}$ (inherent variability of the process), then

   $$\mu_F \pm 1.5(\sigma_F/\sqrt{4}) \equiv (50.1125, 50.4875)$$

   In view of the previous setting, a process control scheme is suggested next.
2. **Control Procedure:** For patrol control, pick up four filled bags every 2 hours from four different nozzles and weigh them. Find out the average weight of four bags (μ_{F4}, say). If this average is within the control limits ($\mu_{F4} \pm 3(\sigma_F/\sqrt{4})$), allow the process to continue. If not, take necessary action.

Expected Benefit

The expected cost benefit, if the optimal process setting (*as found in this study*) is implemented, was computed on the basis of the following information, as provided by the factory management.

Given:

1. Average daily production: 32,000 bags
2. 1 Year = 300 working days
3. Selling price: \$52/ton

	Before study	After study
Overall process average (kg)	50.8	50.3 (economic setting)
Average saving in weight per bag (kg)	0.5	
Average yearly savings (tons)	$0.5 \times 32 \times 300 = 4,800$	
Expected annual sales value (\$)	$4,800 \times 52 \cong \$249,600$	

Recommendation

- The most economic process setting for a packed cement bag was found to be 50.3 kg. Weight of packed bags should be observed on a two-per-hour basis and plotted on a control chart to decide when the process level should be adjusted for setting. The necessary instructions for setting and control of the filling process must be handed over to the operators at the shop floor.
- The online cleaning of the packer machine, especially the weight box and knife edges, should be done at regular intervals, preferably three to four times per shift.
- A robust process design study is recommended for further reducing the inherent variability and then adjusting the process average to the desired level with minimum impact on variability.

Implementation

Implementations of the previous suggestions brought down the percentage off-specification from 74 to 35%. In addition, there was a considerable reduction in variability. It may be noted that this 35% off-specification has been kept on the higher side to eliminate any chance of lower-weight bags reaching the customer.

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Prasun Das is a faculty member in the SQC & OR Unit of Indian Statistical Institute (ISI), Kolkata. He received his master's degree in technology with specialties in quality, reliability, and operations research from ISI. His responsibilities are consultancy work in various industries, including service sectors, teaching, and applied research in the field of quality control, quality management, and operations research. He is also engaged in interdisciplinary project studies. He has published many papers in various national and international journals during the last 12 years.

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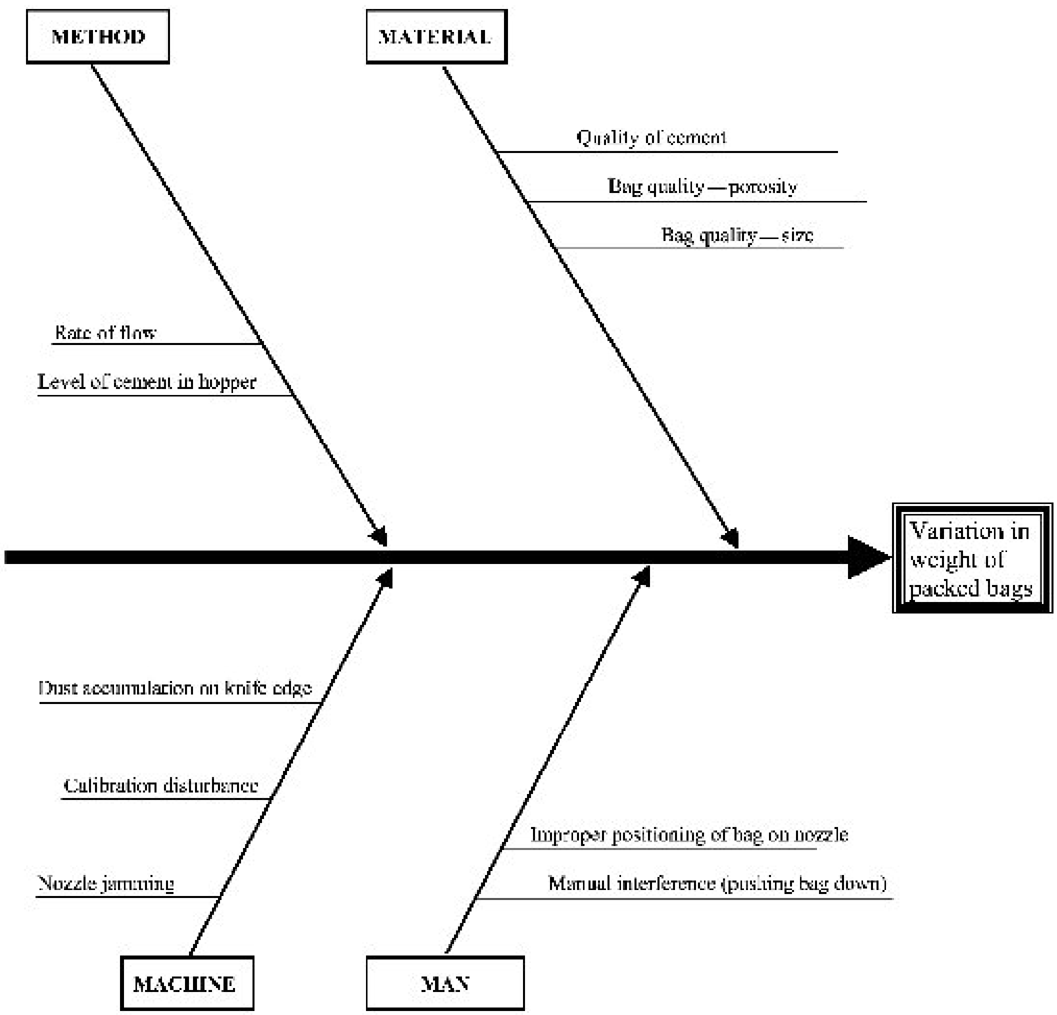
APPENDIX A



Cause-and-effect diagram for weight variation of cement bag.

APPENDIX B

Lack of fit test for normality

Sl. no.	General rule	Actual data analysis	
Step 1	Calculate $\overline{x}$ and s for n data values.	$\overline{x} = 50.783$, $s = 0.526$	
Step 2	Divide the x-scale into 10 zones	≤ 50.109	
	that would have equal frequencies	50.109–50.340	
	(each containing 10% of the x-values)	50.340–50.507	
	for a perfect normal curve. These zones are:	50.507–50.650	
		50.650–50.783	
		50.783–50.916	
		50.916–51.059	
		51.059–51.226	
		51.226–51.457	
		≥ 51.457	
Step 3	Count the number of values occurring in	*Data interval*	*Frequency*
	each of these 10 zones. Calculate the	≤ 50.109	10
	standard deviation ($s_f = \sigma_{n-1}$) of these	50.109–50.340	11
	frequencies and divide by $\sqrt{n}$.	50.340–50.507	11
		50.507–50.650	28
		50.650–50.783	0
		50.783–50.916	22
		50.916–51.059	0
		51.059–51.226	16
		51.226–51.457	13
		≥ 51.457	11
Step 4	Some useful percentage points of $s_f/\sqrt{n}$ are 10%: 0.365, 5%: 0.395, 2.5%: 0.422, 1%: 0.453, 0.5%: 0.475, 0.1%: 0.520.	$s_f = 8.6126$ $s_f/\sqrt{n} = 0.779$	

Values exceeding these criteria may indicate significant discrepancies from normality, and the distribution of the data values should be carefully examined to diagnose the nature of the nonnormality.

APPENDIX C

Assume, $x \sim N(T, \sigma^2)$.

Then, the net income per bag of cement is

$$I = \begin{cases} S - R & , \text{ if } x < LSL \\ S & , \text{ if } LSL \leq x \leq USL \\ S - M(x - USL), & \text{ if } x > USL \end{cases}$$

where S is selling price of a good unit of packed cement per bag (i.e., $LSL \leq x \leq USL$); m is manufacturing cost per unit of measure of cement (in kg); and is cost of repacking per bag, if $x < LSL$.

The expected net income is

$$\begin{aligned} E(I) =& (S-R)\int_{-\infty}^{LSL} f(x)dx + S\int_{LSL}^{USL} f(x)dx \\ &+ USL\int_{USL}^{\infty}[S - M(x - USL)]\cdot f(x)dx \\ =& (S-R)\cdot\Phi\left(\frac{L-T}{\sigma}\right) + S\left[\Phi\left(\frac{U-T}{\sigma}\right)\right. \\ &\left.-\Phi\left(\frac{L-T}{\sigma}\right)\right] + (S+MU)\left[1-\Phi\left(\frac{U-T}{\sigma}\right)\right] \\ &-M\left\{T\left[1-\Phi\left(\frac{U-T}{\sigma}\right)\right] + \sigma\cdot\phi\left(\frac{U-T}{\sigma}\right)\right\} \\ =& (S+MU-MT) - R\cdot\Phi\left(\frac{L-T}{\sigma}\right) \\ &+ M(T-U)\cdot\Phi\left(\frac{U-T}{\sigma}\right) - M\cdot\sigma\cdot\phi\left(\frac{U-T}{\sigma}\right) \end{aligned}$$

where $f(x)$ is the p.d.f of $N(T, \sigma^2)$.

$$\begin{aligned} \frac{dE(I)}{dT} =& -M + \frac{R}{\sigma}\cdot\phi\left(\frac{L-T}{\sigma}\right) + M\cdot\Phi\left(\frac{U-T}{\sigma}\right) \\ &- \frac{MT}{\sigma}\cdot\phi\left(\frac{U-T}{\sigma}\right) + \frac{MU}{\sigma}\cdot\phi\left(\frac{U-T}{\sigma}\right) \\ &- \frac{M(U-T)}{\sigma}\cdot\phi\left(\frac{U-T}{\sigma}\right) \\ =& -M\left[1-\Phi\left(\frac{U-T}{\sigma}\right)\right] + \frac{R}{\sigma}\cdot\phi\left(\frac{L-T}{\sigma}\right) \end{aligned}$$