Statistical process control procedure for controlling moisture content in tobacco

ARUP RANJAN MUKHOPADHYAY
SQC & OR Unit, Indian Statistical Institute, Calcutta, India

ABSTRACT *Moisture content percentage (MC%) in tobacco is a very important quality characteristic. High cut-out or the presence of a lot of moisture in tobacco leads to moldy tobacco—a problem with considerable implications from the standpoint that thrashed tobacco may lie in the stock for up to 3 years before cigarette making. The presence of low moisture in tobacco also leads to unfavorable conditions for cigarette making, although the problem is not as severe as the presence of high moisture in tobacco. This study describes how the variation in moisture content in tobacco was reduced, resulting in a substantial reduction of high cut-out percentage from 20.33 to 1.62% in an Indian tobacco leaf thrashing unit. Since overseas customers from the UK are very particular about not accepting a lot of high cut-out percentage, the study narrates a success story in the procedure of statistical process control implementation for moisture control in tobacco. The statistical techniques used for the purpose are: paired t-test and CUSUM control chart for routine bias correction of moisture measuring instruments and X-MR chart for controlling MC% on a regular basis.*

Introduction

As far as tobacco processing is concerned the presence of the right amount of moisture is very crucial. The amount of moisture present in tobacco should be neither too high nor too low. While too high a moisture content results in moldy tobacco, too low a moisture content results in lack of cohesiveness, an unfavorable condition for further processing for manufacturing cigarettes.

The study was conducted in an Indian tobacco leaf thrashing unit. It exports around 70% of what it produces. The thrashed tobacco leaves may remain packed for up to 3 years after being packed. Since moist tobacco leaf is susceptible to the growth of molds, high cut-out % or high moisture content percentage (MC%) is not at all acceptable, particularly to overseas customers. Naturally, it leads to customer dissatisfaction.

The process

There are two portions in a tobacco leaf. One is called stem or butt and the other is called lamina or tip. Leaf thrashing is a sequential process of separating out stems or butts from laminas or tips.

There is a stage called exit LRD (lamina redryer). This stage is just prior to the last

Table 1. *Specification*

Customer	Customer-specified sampling procedure at packing stage	Target	Tolerance
ITL (overseas)	$\frac{1}{2}$ inch diameter auger is to be used. Two auger samples from two diagonally opposite corners are to be mixed for one composite sample. Samples are to be collected from every alternate pack or case, i.e. 50% of the order quantity	12.5	SD $\leq$ 0.5
BAT (overseas)	1 inch diameter auger is to be used. One auger sample is to be taken from one corner of a pack or case. Samples are to be collected from every fourth pack or case, i.e. 25% of the order quantity.	12.5	$\pm$1%
ITD (Indian)	1 inch diameter auger is to be used. One auger sample is to be taken from one corner of a pack or case. Samples are to be collected from every fifth pack or case, i.e. 20% of the order quantity.	11.5 for Top or Medium grade	$\pm$1%
ITD (Indian)	1 inch diameter auger is to be used. One auger sample is to be taken from one corner of a pack or case. Samples are to be collected from every fifth pack or case, i.e. 20% of the order quantity	11.0 Low grade	$\pm$1%

stage of packing or case formation. An instrument called TM-55 is used for measuring the moisture content of tobacco at exit LRD. Adjustment of steam is done by the exit LRD operator based on TM-55 moisture reading. It displays digitally the moisture content of the tobacco that passes through the conveyor.

The *Trim* or the bias of the TM-55 needs correction at times. At present, the *Trim* correction of TM-55 generally takes place against MC% based on oven. Note that:

$$\text{MC\% by oven method} = \frac{(\text{Moist wt of 10 g sample} - \text{Oven dry wt of the sample})\ 100}{\text{Moist wt of 10 g sample}}$$

where oven drying takes place at 100°C for 15 hours. The advantage of the oven is reported to be its close repeatability of results if the same sample is retested.

Sometimes, *Trim* correction of TM-55 takes place against MC% estimated by another instrument known as IAA (Infra Alyser). The advantage of IAA is that while the cycle time of the oven method is about 18 hours, that of IAA is merely 15 minutes. However, the repeatability of IAA is reported to be not as good as the oven.

The problem

(1) At present, *Trim* correction of TM-55 at exit LRD takes place routinely for every grade change and sometimes while running a particular grade. It is to be noted that there exist plenty of grades for a customer and grades are dependent on input material. The existing practice calls for very frequent *Trim* correction at TM-55 based on no scientific methodology.

(2) If the *Trim* correction of the TM-55 instrument does not take place properly then naturally the process control in the form of steam adjustment based on TM-55 instrument readings cannot be proper. The problem is further compounded because of:

- Correcting *Trim* sometimes against oven and sometimes against IAA. The importance of *Trim* correction based on a single instrument can hardly be overemphasized.

- Not knowing what will be the target value of moisture content at exit LRD to meet the customer-specified requirement at packing by taking into consideration the drop in moisture content between exit LRD and packing.
- Non-existence of control limits for MC% based on the inherent variation of the process. Needless to mention that this results in frequent inadvertent process adjustment or steam adjustment leading to errors in the form of taking corrective action when it is uncalled for and not taking corrective action when it is called for.

Objective of the study

(1) To suggest a scientific methodology based on statistical principles for *Trim* or bias correction of the TM-55 instrument meant for measuring moisture content at exit LRD. This is the first and foremost requirement since moisture in tobacco is to be controlled based on instantaneous TM-55 readings.
(2) To set the target value of moisture content at exit LRD based on the drop in moisture content between exit LRD and packing.
(3) To suggest a statistical process control (SPC) procedure for moisture content in tobacco at the exit LRD so that the customer's requirements are met while packing.

Approach

(1) Since IAA measures the moisture content of tobacco much faster than oven, for day-to-day *Trim* correction of TM-55, IAA should be the basis instead of oven. Of course, for this purpose it has to be routinely established first that IAA is corrected for its bias (if any) against the oven result, technically considered to be the most authentic among the three measuring equipments—TM-55, IAA and OVEN. The CUSUM control chart is thought to be used for *Trim* correction of TM-55 against IAA subsequent to checking the bias of IAA against the oven results based on *t*-test for pair-wise differences. One very crucial point to note here is that although the existing practice of *Trim* correction of TM-55 takes place for every grade change, the decision regarding *Trim* change should be taken seeing the difference between TM-55 result and IAA result of the same sample. If the difference, or more precisely the cumulative difference, is statistically significant, *Trim* correction should be carried out, otherwise, no *Trim* correction will be called for. So, the yardstick for *Trim* correction at TM-55 should be periodic cumulative difference between the TM-55 and IAA result—not the grade change. This message is thought to be communicated loud and clear contrary to the popular perception of grade change as a primary criterion for *Trim* correction. *Trim* correction is the joint responsibility of the concerned Shift Manager and Quality Control Manager.
(2) Target moisture content at exit LRD is to be decided based on the correlation between exit LRD moisture content (oven method) after drop. One-to-one correspondence between exit LRD sample and packing sample has to be ensured from the time lag based on the conveyor speed. Regression analysis is thought to be useful here. Once the target value at the exit LRD is established it is the responsibility of the production people to achieve that.
(3) Since at a particular time only one moisture content value will be available at exit LRD TM-55, inherent variation is to be estimated through the moving range (MR) control chart method after ensuring that the process is stable and in control. For day-to-day steam control to correct MC%, control chart for individual measurements

Table 2. *Estimate of inherent variation*

Characteristic	No. observations	Average MR	$\hat{\sigma}$
(TM-55 − IAA) MC%	217	0.5613	0.4976
TM-55 MC%	26	0.456	0.40

Table 3. *Range of MC%*

Characteristic	Minimum value	Maximum value
MC% at exit LRD	11.0	13.1
Packed MC%	10.9	13.3

of moisture control is thought to be appropriate. The steam control is to be done by the concerned exit LRD operator based on control chart indications. Maintenance of the control chart should be the responsibility of the exit LRD operator.

Estimating inherent variation

Based upon the data collected from 5 to 10 July 1999 on MC% of the same sample by exit LRD TM-55 and IAA at approximately half-hour intervals, inherent variation of the difference between TM-55 and IAA results (TM-55 − IAA) and TM-55 results as such is estimated by the MR method. The moving ranges are calculated for two successive observations. The findings are given in Table 2.

The X-MR chart for exit LRD TM-55 MC% under controlled conditions is provided in the Appendix.

Estimating drop in moisture between exit LRD and packing

Regression analysis yielded the following equation:

$$\text{Moisture content \% at exit LRD} = -1.3222 + 1.1671 * \text{Packed MC\% by oven method} \quad (1)$$

The correlation coefficient is found to be 0.85 for 18 pairs of observations. This equation is valid for the ranges shown in Table 3.

Comparing 3¼-hour oven results with 15-hour oven results

Since *Trim* correction at exit LRD TM-55 will take place against IAA subsequent to the bias correction of IAA against oven results, it is quite natural to see whether there exists any significant difference between 3¼-hour oven results at 110°C temperature and 15-hour oven results at 100°C temperature. Subjecting the same sample to two treatments yielded the observations shown in Table 4.

$$n = 20,\ \bar{d} = -0.04,\ S_d = 0.1667$$

$$t_0 = \frac{\bar{d}}{S_d}\sqrt{n} = -1.07$$

Since, $t_{0.025,19} = 2.093$, it is concluded that no significant difference exists between 3¼-hour oven results (at 110°C) and 15-hour oven results (at 100°C). So, for day-to-day bias

Table 4. *Oven results*

Sample No.	$3\frac{1}{4}$-hours MC%	15 hours MC%	$(3\frac{1}{4}$–15) hours MC% (d_i)
1	13.1	13.3	−0.2
2	13.0	13.0	0.0
3	11.8	12.0	−0.2
4	12.0	12.1	−0.1
5	11.9	12.0	−0.1
6	12.5	12.8	−0.3
7	12.5	12.4	0.1
8	12.8	12.8	0.0
9	12.5	12.6	−0.1
10	12.3	12.5	−0.2
11	13.1	12.9	0.2
12	12.6	12.5	0.1
13	13.1	12.8	0.3
14	13.3	13.2	0.1
15	12.8	13.1	−0.3
16	13.2	13.1	0.1
17	13.0	13.2	−0.2
18	12.9	12.9	0.0
19	12.6	12.7	−0.1
20	12.9	12.8	0.1

correction purpose of IAA it is better to follow the $3\frac{1}{4}$-hour oven method since it is quicker in nature. It may be worth noting here that this finding is contrary to the popular belief is the factory that the 15-hour oven method yields more authentic results. This belief if strengthened further by the stated need of the overseas customers about measuring MC% of packing or case by the 15-hour oven method.

Bias correction procedure to be followed at IAA

In order to correct the *Trim* of TM-55 at exit LRD against IAA in an effective manner, it must be ensured on a day-to-day basis that IAA does not have any bias against oven results. This can be done in the following manner:

(1) Every day take nine IAA readings from nine different samples collected from exit LRD at 5-minute intervals.
(2) Take the corresponding $3\frac{1}{4}$-hour oven readings (MC%) of the above samples.
(3) Find out the differences between IAA and oven (IAA − $3\frac{1}{4}$-oven) MC%.
(4) Find out the average ($\bar{d}$) and standard deviation (SD) of these differences.
(5) Compute $t_0 = (\bar{d}\sqrt{n})/\hat{\sigma}_d = 3\bar{d}/\hat{\sigma}_d$. Note that $\bar{d}$ may be positive or negative.
(6) If the magnitude of t_0 is greater than 1.860 ($t_{0.05,8}$), correct—$\bar{d}$ amount of bias. Otherwise, do not correct any bias for IAA.

Trim correction procedure to be followed at exit LRD TM-55

Every hour sample will be collected and tested using exit LRD TM-55. The observed MC% will be recorded and the same sample sent to the quality control laboratory for IAA testing. The difference between the TM-55 reading and IAA reading will be obtained. The decision

regarding *Trim* change will be taken on the basis of the CUSUM control chart, the method of construction of which is described in the following:

(1) SD of (TM-55 − IAA) MC% has been estimated as 0.50.
(2) $K = \text{SD}/2 = 0.25$, where K = reference value.
(3) $H = 2d\sigma^{*}\tan\theta = 2(10)(0.50)^{*}\tan 14^{\circ} = 2.50$ where H = decision interval. The optimum values of d and θ are chosen for detecting a shift of 1σ corresponding to average run length (ARL) of 500 when process is in control.
(4) X_i = (TM-55 − IAA) MC% has to be calculated first at the ith time point. Then $S_H(i)$ and $S_L(i)$ shall be calculated based on the following formulae:

$$S_H(i) = \text{Max}\{0, X_i - 0.25 + S_H(i-1)\}$$

$$S_L(i) = \text{Max}\{0, -X_i - 0.25 + S_L(i-1)\}$$

where, $S_H(0) = 0 = S_L(0)$

(5) Whenever any $S_H(i)$ or $S_L(i)$ is more than $H = 2.50$, conclude that *Trim* correction is necessary.
(6) *Amount of Trim*: Suppose, $S_H(i)$ is greater than 2.50 for some i. Consider the corresponding X_i values wherefrom all the $S_H(i)$ values are greater than zero but not greater than 2.50. *Trim* shall be the negative of the average of those X_i values. Similarly, it is to proceed when $S_L(i)$ is greater than 2.50.
(7) Adjust the *Trim* and start the CUSUM control chart afresh with $i = 1$ and $S_H(0) = 0 = S_L(0)$.

Table 5. *Table recording format for implementing CUSUM control chart to adjust* Trim *at exit LRD TM-55 (H = 2.50)*

Date	Shift	(i)	MC% by TM-55	MC% by IAA	X_i = (TM-55 − IAA) MC%	$S_H(i)$	$S_L(i)$	Remarks (if any)

It is to be noted that the exit LRD MC% set points are determined from *equation* (1) and the control limits are 2σ limits instead of the usual 3σ limits. Since control chart for individual observations is not as sensitive as the $\bar{X}$-chart for detecting process shift, 2σ control limits are used.

Table 6. *Control limits for implementing individual control chart at exit LRD to control MC% measured by TM-55 at every 15-minute interval*

Packed MC% target	Exit LRD MC% set point	Exit LRD lower control limit (LCL)	Exit LRD upper control limit (UCL)
12.5	13.3	12.5	14.1
11.5	12.1	11.3	12.9
11.0	11.5	10.7	12.3

The concerned exit LRD operators were given training by highlighting that *steam adjustment* should take place if any point falls beyond the control limits. Otherwise, *no steam adjustment* should be there. There is a clear-cut guideline contrary to the present inept and arbitrary adjustment of steam.

Comparison of pack MC% measured by the oven method (15-hour at 100°C) before and after implementation

It is to be noted that as per the customer's (ITL's) specified requirement, the 15-hour oven method is followed instead of the 3¼-hour oven method for measuring moisture content.

It is to be noted that high cut-out percentage implies proportion of packs for which MC% is above 13.1 and low cut-out percentage implies proportion of packs for which MC% is below 11.1%.

Table 7. *Results of implementation*

	Before implementation		After implementation	
Class interval	Tally mark	Frequency	Tally mark	Frequency
10.95–11.45	𝍸	5	|	1
11.45–11.95	𝍸|||	14	𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸	50
11.95–12.45	𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸||||	59	𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸||||	54
12.45–12.95	𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸||	62	𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸|||	43
12.95–13.45	𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸	40	|||	3
13.45–13.95	𝍸𝍸||	12		
13.95–14.45	||	2		
Total:		194 packs		151 packs

Characteristics	Before implementation	After implementation
$\bar{X}$	12.62	12.19
σ_{n-1}	0.575	0.426
High cut-out %	20.33	1.62
Low cut-out %	0.41	0.52

Appendix: X-MR chart for moisture content % measured by exit LRD TM-55

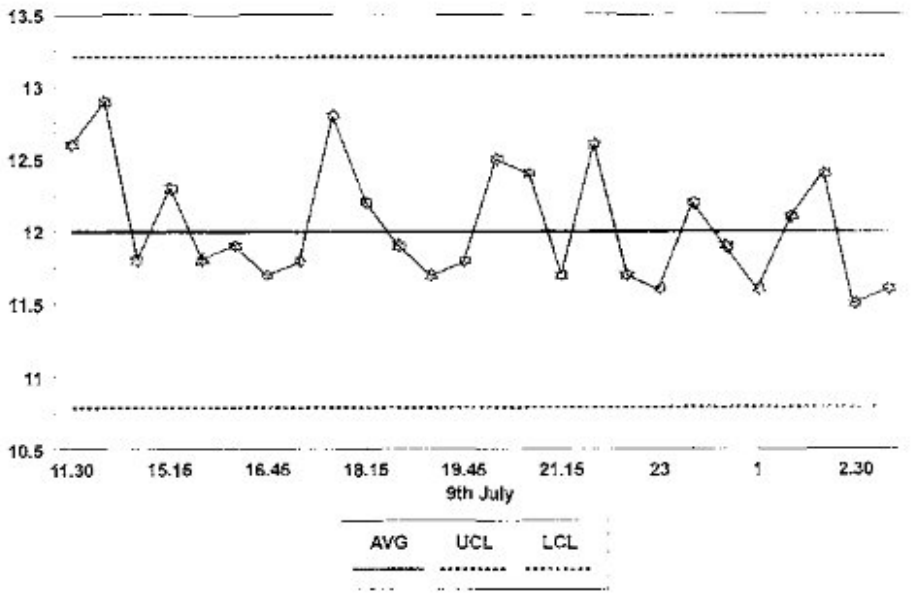

Figure A1. *TM-55 moisture reading.*

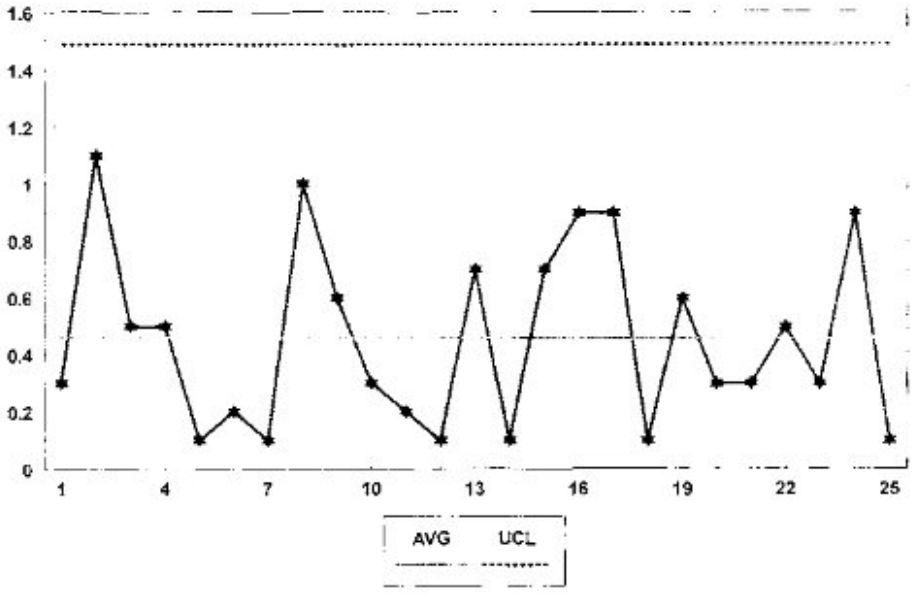

Figure A2. *Moving range.*