Chair's Message
by Nancy Beltis

In 1990, I was serving my second year as Membership Chair when I received a call from Steve Bailey, who was then Chair. Steve started the conversation by saying “Do I recall that you volunteered to be Newsletter Editor?” I quickly searched my memory knowing that I would definitely remember that. I responded “No, but...” That was all Steve needed to hear.

As Newsletter Editor, I interacted with the Division Council and membership. It was a challenging and rewarding role.

I think Larry Sue had a similar experience. Larry sat next to me at lunch at the 1993 Fall Technical Conference. Our newsletter editor had announced that he was taking an assignment in Australia and would be leaving the country within a month. Before the end of the conference, Larry agreed to become the new Editor.

As Larry moves on to work on the 1996 Fall Technical Conference, I want to thank him for his time as Newsletter Editor.

I would like to welcome Janice Shade as the new Newsletter Editor. She will be working closely with our new Acquisitions Coordinator, Falguni Sharma, to publish basic tools and mini-paper columns that will provide you with techniques to use in your work.

This newsletter has been the primary source of communication with members. Through the newsletter, we have been able to provide you with information about Division activities as well as technical papers. The newsletter has largely been a one-way communication: us to you. How can you give us information and ideas?

The Officers and Regional Councilors receive calls throughout the year from Statistics Division members as well as non-Division ASQC members. They typically have been referred by ASQC headquarters with a statistical question. We have started a process to track these questions. These could be used to determine topics for basic tools and mini-paper columns. However, as you can imagine, this is not the most effective means of obtaining information. If we received calls from a large portion of our membership on a regular basis, we would not be able to handle the volume. Plus, we might not have the expertise to answer all the questions. That takes us to a new option for ASQC members.

All members, for a $10.00 fee, can obtain access to the ASQC bulletin board service. There is currently a place on this system that Wayne Fischer established to ask statistical questions. These questions can then be answered by other bulletin board participants. The Statistics Division, under the coordination of Mark Kiel, will also have a separate area focusing on our Division activities. Mark is beginning to work with the system administrators to set up the Division area. Through the newsletter, he will keep you informed of what is available.

We will continue to obtain information from the booth at AQI and membership surveys. Bob Mitchell, our Membership Chair, has been working on a tactical plan to assess membership needs. A survey was put together to measure member satisfaction. We want to identify areas of need and opportunities for continuous improvement. The survey will be conducted on a quarterly basis by the Regional Councilors. If you receive a call from your Regional Councilor, spend 5 minutes with them and let them know what the Division can do to help you be more effective.

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This is my last issue serving as the editor of the Statistics Division Newsletter. I have enjoyed my tenure working with the various officers and committee chairs of the division. The members of the council are dedicated to serving the division and we are fortunate to have their leadership. Thanks to Nancy Belunis for providing me this opportunity to serve. Thanks to the many who responded to my plea for articles and papers. Those of you who would like to submit Mini-Papers and Basic Tools for consideration to be published in future editions of the newsletter need to contact the new editor.

Serving in various capacities in the division is a great way to increase your opportunities for networking, sharing your talents, and give to your profession. Give some thought to the various vacancies and positions that are advertised and notify the officers of your interest. They will benefit from your participation and so will you.

Relieving me of the responsibility of editor will permit me to focus as the local chair of the 1996 Fall Technical Conference. The 1996 FTC will be held in Scottsdale, Arizona, at the Radisson Resort. If you have never heard of Scottsdale, it is in the valley of the sun in the Phoenix Metropolitan area. October is right at the beginning of our peak tourist season so plan to come and enjoy some recreation along with the conference. Give yourself some extra days to visit some of our popular spots such as the Grand Canyon, or enjoy some great golfing.

Janice Shade has accepted the position to serve as the new editor of the Statistics Division Newsletter and will produce the Winter, 1996 issue. Janice works for Nabisco in New Jersey. Please give her your support. Janice has written an incoming editor's message found elsewhere in this newsletter. Please note that her computer support is IBM PC whereas mine was Macintosh.

Larry

VISION
- Our customers' needs will be continuously anticipated and met.
- Our members will be proud to be a part of the Division.
- Our Division's operations will be a model for other organizations.
- We will be a widely influential authority on scientific approaches to quality and productivity improvement.

MISSION
- Promote statistical thinking for quality and productivity improvement.
- Serve ASQC, business, industry, academia and government as a resource for effective use of statistical methods for quality and productivity improvement.
- Provide a focal point within ASQC for problem-driven development and effective use of new statistical methods.
- Support the growth and development of Division members.

STRATEGY
- Our primary customers are Statistics Division members. Other key customers are:
  - Management,
  - Users and potential users of statistical methods for quality and productivity improvement,
  - Educators of the above customers.
- Our orientation to customers is customer focused.
- Our markets, within which we intend to offer products, are weighted as follows: greatest weight on intermediate statistical methods, nearly as much weight on basic methods, and much less weight on advanced methods.
- Our primary products are educational services.

PRINCIPLES
- Focus on a few key things.
- Balance short-term and long-term efforts.
- Recognize that we exist for our customers.
- Value diversity (including geographical and occupational) of our membership.
- Be proactive.
- View statistics from the broad view of quality management.
- Apply statistical thinking ourselves (that is, practice what we preach).
- Uphold professional ethics.
- Continuously improve.
Meet Your New Editor

by Janice Shade

Many thanks to Larry for all the work he has done on the newsletter. We wish him continued success as the Local Chair of the 1996 Fall Technical Conference.

The newsletter is not only a vehicle for communication, but is also a medium for instruction. With the assistance of the Acquisitions Coordinator, Falguni Sharma, we will continue to provide Basic Tools Papers, Mini Papers and other writings which can be applied to your day-to-day activities.

Papers can be submitted with one hard copy and one copy on a 3-1/2" diskette. Since I use Microsoft Word for Windows, the files should be sent in either Microsoft Word, ASCII Text File, or WordPerfect. Figures should be properly identified and labeled.

In the coming months, tell me how we are doing. Tell me what you like or dislike. Tell me what changes you would like to make. Tell me what mini paper or basic tools articles interest you. Tell me. Tell me. Tell me. (Gee, I think a slogan is born!) △

1996 Fall Technical Conference Call for Papers

Call for papers is currently in process for the 40th Fall Technical Conference to be held in Scottsdale, Arizona. The conference will be hosted by the Phoenix section at the Radisson Resort in Scottsdale, Arizona, on October 23-25, 1996. The theme is “Leveraging Data For The Quality Transformation.”

The conference is co-sponsored by the Chemical and Process Industries Division of ASQC, the Statistics Division of ASQC, and the Section on Physical and Engineering Sciences of ASA.

Papers are presented in three parallel sessions: Statistics, Quality Control, or Tutorial/Case Study.

Request detailed submission instructions, preferably by e-mail, from:

Jacob Van Bowen, Chair, Mathematics and Computer Science
212 Jepson Hall, University of Richmond, Richmond, VA 23173
e-mail: JVBOYEN@URVAX.URICH.EDU or by phone (804) 289-8081

Necip Doganaksoy  GE Corp. R&D
PO Box 8, K14G43
Schenectady, NY 12301
e-mail: doganaksoy@crd.ge.com or by phone (518) 387-5319

Sharon Fronheiser  Eastman Kodak Co.
151 Mill Hollow Crossing, Rochester, NY 14626
c-mail: KP40.2340110KODAK.O.KODAK.COM or by phone (716) 588-2014

The submission process started on August 1, 1995, and concludes on Jan. 19, 1996. Papers should be strongly justified by application to a problem in quality control, or the chemical, physical, or engineering sciences. The mathematical level of papers may range from none to that of the Journal of Quality Technology or that of Technometrics.
Introduction

This paper extends the discussion concerning the EWMA initiated by Dr. Donald J. Wheeler (1) in the previous issue of the Statistics Division Newsletter, Vol 15, No. 4, Summer 1995, pp 6-13. The data will be the same as that used by Dr. Wheeler. The point of view with respect to the EWMA will be different.

The EWMA Algorithm:

Consider a sequence of observed values

\[ Y_1, Y_2, Y_3, ..., Y_t \]

There are two common and equivalent algebraic expressions for the EWMA, that is,

\[ \text{EWMA} = \lambda Y_t + (1 - \lambda) \text{EWMA}_{t-1} \quad \text{where} \quad \lambda = \lambda - 1 \]

\[ \text{EWMA} = Y_{t+1} = Y_t + \lambda e_t \quad \text{where} \quad e_t = Y_t - \text{EWMA}_t \]

The EWMA parameter \( \lambda \) must lie in the interval \( 0 < \lambda \leq 1 \).

The first expression for the EWMA given above is read, “The smoothed value of the response at time \( t \) equals lambda times today’s observation plus theta times yesterday’s smoothed value. This expression identifies the EWMA at time \( t \) as a weighted average of the today’s new observation \( Y_t \) and the most recent EWMA, that is, the one available at time \( t-1 \). The second expression, sometimes called the ‘plotting equation’ (2), is perhaps the more familiar in quality control circles.

This expression is read, “Tomorrow’s predicted value equals today’s predicted value plus lambda times today’s error.” As we will soon see, the EWMA can be used as a forecast under certain conditions. For plotting convenience, the EWMA is often placed one time unit ahead of \( Y_t \). An alternative graphical method for obtaining the EWMA can be found in S. W. Roberts’ seminal paper (3) in Vol. 1 of Technometrics. In practice, graphical estimates do just fine.

Dr. Wheeler’s paper (1) uses \( \text{EWMA}_{t-1} \) for the EWMA and \( \alpha \) for the parameter value. As Dr. Wheeler notes, the

\[ \text{Var}(\hat{Y}_{t+1}) = [1 - (1 - \lambda)^2] \lambda(2 - \lambda) \sigma^2 \]

which quickly becomes

\[ \text{Var}(\hat{Y}_{t+1}) = \frac{\lambda(2-\lambda)}{\lambda} \sigma^2 \]

as \( t \) increases.

The Shewhart Model

The model that underlies the Shewhart, Cusum and EWMA control charts for variables data is simply:

\[ Y_t = \eta + m_t \]

where \( \eta \), the expected value of the observations \( E(Y_t) \), is a constant and where the \( m_t \) are Gaussian white noise disturbances or measurements, that is, the \( m_t \) -> NID(0,\( \sigma^2 \)).
Warning

Under Shewhart model (the mean and variance are both constant and the errors are independent) the EWMA is NOT a forecast. Under these Shewhart conditions the forecast for the next observation (or average) is always $\mu_0$, the chart's center line. Plotted on a Shewart chart and under the Shewhart model conditions the EWMA is retrospective. It smooths the time trace. By reducing the role of noise the EWMA helps the eye see (pardon the mixed sound and sight metaphor) what the process level may have been. It can be useful in identifying assignable causes.

Which chart is best?

The EWMA chart is simple to construct once a Shewhart chart is in hand. The plotting equation makes it easy to position the EWMA along with the Shewhart $Y_t$ and to judge the EWMA performance against its own control limits set at $\mu_0 \pm 3\mu_0/\sigma_y$. In the context of the probability of sequences of independent events, when $\lambda = 0.4$ the EWMA uses the historical data almost identically to that of the combined Western Electric rules (4). With $\lambda = 0.4$ the control limits for the EWMA are exactly half those of the $Y_t$.

Much work has been done investigating which charting procedure is "best". In these exercises it is usual to set up an initiating 'null' hypothesis $H_0$: $\mu = \mu_0$ and an alternative hypothesis $H_1$: $\mu = \mu_0 + \delta$ where $\delta$ is some fixed constant. The alternative hypothesis imagines the mean to move as a ratchet to some new fixed value and stay there. Simulations are often required to determine individual run lengths under varying values for $\delta$ and $\sigma$. Although run length distributions are quite long tailed, the average number of observations required to reject $H_0$ when $H_1$ is true, the ARL (average run length), becomes the essential measure of the usefulness of the charting procedure. The chart with the shortest ARL is preferred. Costs for being off target, for making process adjustments and for data collection are often added to these studies. The distributions of the run lengths are usually badly skewed and extensive computer simulations are often required to determine the ARL. In general, one finds that the Cusum chart is preferred over the Shewhart for values of $\delta \leq \sigma$. The EWMA chart "wins" and more generally "loses" in these contests depending on the choice of $\delta$, $\lambda$ and the costs.

Why bother with the EWMA?

The model underlying all that has been mentioned above declares that $Y_t = \eta_t + m_t$ where $\eta_t$ is a CONSTANT and that the "errors" $m_t$ are normal, INDEPENDENT, with zero mean and constant variance $\sigma^2$. This model is often not matched by reality. The key question becomes, "Is there some alternative model that might in many situations be more appropriate and, if so, would it be useful and robust to alternatives, including those of constant mean and independent errors?" The answer to this question is, "Yes," and we will find the resulting model and statistic to be the EWMA. The essential issue is not that the EWMA statistic and its chart are "complex", but rather that the Shewhart model may often be too restrictive.

The Alternative Model

Required now are two models, one for the mean and another for the errors, with both models reflecting the passage of time $t$, thus

$$Y_t = \eta_t + c_t .$$

Models for $\eta_t$ might be that of a linear or low order time trend, or something cyclic, or a function of some observable external factor $X_t$, or even something dynamic and characterized by an 'autoregressive' model equivalent to a first or second order differential equation. For the errors $c_t$ one could postulate 'moving average' models each identifying unique autocorrelation patterns. Combinations of models for $\eta_t$ and $c_t$ would also be possible. Nor need we be confined to 'stationary' models, that is, those that over time provide observations with a constant variance. Many environments are "non-stationary" and characterized by unlimited changes in both level and variance. Non-stationary processes are quite common. To experience a non-stationary process, the next time you actually run a piece of machinery, say drive your car, leave it alone entirely for a few moments. Replicate and see how varied in location and variability each time path of observations will be. (If you are in your car, good luck.)

Continued on page 6
What would be useful in the industrial practice of statistics is a model that is not only easy to apply but robust to many of the alternative models for performance that might be proposed. That model is the EWMA.

Checking Assumptions:
To repeat, the essential mathematical assumptions that underlie Shewhart methodologies are those of a CONSTANT mean and INDEPENDENT constant variance errors. The crucial assumption is that of independence. The simple multiplicative law of probability must work. Each $Y_t$ should not in any way be conditional upon previous values. Before establishing a Shewhart chart for observations $Y_t$ one should check for the independence of time sequenced data. The fundamental assumption of independence can of course be guaranteed by random sampling.

As an exercise in detecting non-independence consider the data given in Dr. Wheeler's mini-paper.

<table>
<thead>
<tr>
<th>Table 1: Fifty Camshaft Bearing Diameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 46 52 42 49</td>
</tr>
<tr>
<td>51 50 46 43 50</td>
</tr>
<tr>
<td>50.5 52 42 42 49.5</td>
</tr>
<tr>
<td>49 52.5 43 45 51</td>
</tr>
<tr>
<td>50 51 45 49 50</td>
</tr>
<tr>
<td>43 52 46 50 52</td>
</tr>
<tr>
<td>42 50 42 51 50</td>
</tr>
<tr>
<td>45 49 44 52 48</td>
</tr>
<tr>
<td>47 54 43 54 49.5</td>
</tr>
<tr>
<td>49 51 46 51 49</td>
</tr>
</tbody>
</table>

These data are read down, with $Y_1 = 50, Y_2 = 51, ..., Y_{49} = 49.5, Y_{50} = 49$. The independence of these data across time can be checked by estimating their lag autocorrelation coefficients $\rho_k$, $k = 1, 2, \ldots$. If the observations are time independent their autocorrelations should equal zero. (Many software programs compute autocorrelation coefficients although they may vary slightly in the actual computing algorithm employed.) The first ten lag autocorrelation coefficients for the data are displayed in Table 2.

<table>
<thead>
<tr>
<th>Table 2: Estimates of autocorrelation coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_1 = 0.74$ $r_6 = -0.02$</td>
</tr>
<tr>
<td>$r_2 = 0.55$ $r_7 = -0.09$</td>
</tr>
<tr>
<td>$r_3 = 0.34$ $r_8 = -0.23$</td>
</tr>
<tr>
<td>$r_4 = 0.24$ $r_9 = -0.23$</td>
</tr>
<tr>
<td>$r_5 = 0.13$ $r_{10} = -0.34$</td>
</tr>
</tbody>
</table>

Under the hypothesis that all the $\rho_k = 0$ the approximate standard error of an $r_k$ is

$$\text{StdErr}(r_k) = 1/\sqrt{n}.$$  

(More generally, the $\text{StdErr}(r_k) = \sqrt{1 + 2\rho_{k+1}/n}$.) Thus, an approximate 95% confidence interval for $r_1$ is given by $r_1 \pm 2/\sqrt{n}$ or $0.74 \pm 0.29$. Placing numerical nuances aside (slightly different ways of computing $r_k$ and determining standard errors) it is clear in this example that the estimates $r_k$ do not support the assumption of independence.

(Although it is beyond the scope of this mini-paper, the autocorrelation pattern in this instance suggests that the $Y_t$ are stationary and can be characterized by a 1st order autoregressive model (an AR(1) model) with parameter $\theta \approx 0.75$. But as we shall soon see the EWMA will do quite well.)
Consequences of non-independence

One immediate consequence of our discovery of positive autocorrelation is its influence on the use of the moving range statistic to provide an estimate of $\sigma$ when single sequentially recorded observations are in hand. When adjacent observations are positively correlated their differences will be suppressed by their natural tendency to be much alike, high observations followed by highs, and lows by lows. The standard deviation $\sigma_Y$ will thus be underestimated and the associated control limits thus influenced. The opposite effect occurs when observations are negatively autocorrelated, with highs followed by lows, etc..

The point being raised here is not that employing the Shewhart methodology in this instance is wrong, but rather that it may be losing its efficiency as a learning and monitoring tool. "All models are wrong, some are more useful than others."

The Variogram

George Box suggests (3), (4) that a check on the adequacy of the assumption of constant mean, independence and constant variance, and more generally a check of the assumption that the data are from a stationary process, is provided by the variogram. If the assumptions are valid then producing alternative time series by taking pairs of observations 1 interval apart, or 2, 3 or $m$ apart, should make no difference in the expectation of statistics obtained from these differences. Box computes the standardized variogram

$$G_m = \frac{\text{Var}(Y_{t+m} - Y_t)}{\text{Var}(Y_{t+1} - Y_t)}.$$ 

If the data are independent with constant mean and variance the ratio $G_m = 1$ whatever the choice of $m$. If the $Y_t$ come from a stationary process (a process with ultimate constant variance) $G_m$ will increase at first but soon becomes a constant. If the $Y_t$ are from a non-stationary process (a process whose level and variance can grow without limit) then $G_m$ will continually increase. If $G_m$ increases as a straight line the model is uniquely that of the EWMA.

In quality control circles a simple alternative to computing $G_m$ would be to employ the familiar moving range computation for the standard deviation. Here the absolute value of the differences $Y_{t+1} - Y_t$ is averaged and then divided by $d_2 = 1.128$ to provide an estimate of $\sigma_Y$. The absolute values of the quantities $Y_{t+m} - Y_t$ are now computed for different values of $m$, averaged and divided by $d_2$ to provide additional estimates of $\sigma_Y$. Table 3 gives the results of these computations for the data in Table 1.

<table>
<thead>
<tr>
<th>Separation</th>
<th>Moving Range</th>
<th>$\sigma_{Y_m}$</th>
<th>$(\sigma_{Y_m})^2$</th>
<th>$G(m) = (\sigma_{Y_m})^2/(\sigma_{Y_1})^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m$</td>
<td>$\text{Avg}<em>{Y</em>{t+m}} - Y_t$</td>
<td>AR/$d_2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.082</td>
<td>1.845</td>
<td>3.466</td>
<td>1.000</td>
</tr>
<tr>
<td>2</td>
<td>2.594</td>
<td>2.299</td>
<td>5.287</td>
<td>1.552</td>
</tr>
<tr>
<td>3</td>
<td>3.255</td>
<td>2.886</td>
<td>8.329</td>
<td>2.445</td>
</tr>
<tr>
<td>4</td>
<td>3.391</td>
<td>3.006</td>
<td>9.039</td>
<td>2.654</td>
</tr>
<tr>
<td>5</td>
<td>3.689</td>
<td>3.270</td>
<td>10.695</td>
<td>3.140</td>
</tr>
<tr>
<td>6</td>
<td>4.045</td>
<td>3.586</td>
<td>12.862</td>
<td>3.776</td>
</tr>
<tr>
<td>7</td>
<td>4.209</td>
<td>3.732</td>
<td>13.925</td>
<td>4.088</td>
</tr>
<tr>
<td>8</td>
<td>4.393</td>
<td>3.894</td>
<td>15.166</td>
<td>4.453</td>
</tr>
<tr>
<td>9</td>
<td>4.793</td>
<td>4.249</td>
<td>18.053</td>
<td>5.300</td>
</tr>
</tbody>
</table>

Continued on page 8
Figure 1 suggests that the plot of $G(m)$ versus $m$ is an increasing straight line. We can conclude now that a reasonable model appropriate for the data is the EWMA. An estimate of $\lambda$ can be obtained from the slope of this line. Since the line must pass through the point $G(m) = 1$ and $m = 1$ the slope is quickly obtained by computing

$$b = \frac{\sum xy}{\sum x^2}$$

where $x = (m-1)$ and $y = [G(m) - 1]$. Thus $b = 155.913/285 = 0.547$. An estimate of $\lambda$ is obtained by solving the equation $b = \lambda^2/[1 - (1 - \lambda)^2]$. An iterative solution gives $\lambda = 0.76$. A fitted model that well represents the camshaft data is the EWMA:

$$\hat{Y}_{t+1} = \hat{Y}_t + 0.76(Y_t - \hat{Y}_t) = 0.76Y_t + 0.24\hat{Y}_t.$$

**Employing the fitted EWMA**

Let the target value for the camshaft diameters $\tau = 50$, and the first prediction $\hat{Y}_1 = 50$, then employing the fitted EWMA model gives the predicted values and errors displayed in Table 4. If the EWMA were used as a forecast to control the process then a considerable reduction in variability seems possible, from $\sum(Y_t - \tau)^2 = 775.00$ to $\sum(Y_t - \hat{Y}_t)^2 = \sum e^2_t = 312.47$.

<table>
<thead>
<tr>
<th>$t$</th>
<th>$Y_t$</th>
<th>$\hat{Y}_{t+1}$</th>
<th>$e_t$</th>
<th>$t$</th>
<th>$Y_t$</th>
<th>$\hat{Y}_{t+1}$</th>
<th>$e_t$</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>50.0</td>
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<td>46.0</td>
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<td>50.0</td>
<td>1.000</td>
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<td>42.0</td>
<td>45.649</td>
<td>-3.649</td>
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<tr>
<td>3</td>
<td>50.5</td>
<td>50.76</td>
<td>-0.260</td>
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<td>44.0</td>
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<td>-1.562</td>
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<td>-0.730</td>
</tr>
<tr>
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<td>0.625</td>
<td>30</td>
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<td>-6.850</td>
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<td>42.0</td>
<td>45.322</td>
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<td>45.0</td>
<td>42.228</td>
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<td>49.0</td>
<td>46.384</td>
<td>2.616</td>
<td>35</td>
<td>49.0</td>
<td>44.335</td>
<td>4.665</td>
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<td>11</td>
<td>46.0</td>
<td>48.372</td>
<td>-2.372</td>
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<td>50.0</td>
<td>47.880</td>
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<tr>
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<td>50.0</td>
<td>46.569</td>
<td>3.431</td>
<td>37</td>
<td>51.0</td>
<td>50.638</td>
<td>1.362</td>
</tr>
</tbody>
</table>

**Table 4: Observations, Predicted values and Errors**

Continued on page 9
Table 5 compares the autocorrelations of the original observations with those of the residuals $e_t$ left over after fitting the EWMA. The residuals suggest independence and thus support the use of the EWMA as a reasonable model and a useful forecaster of process performance.

**Taking Active Control:**

Under the Shewhart model the forecast of the next and all subsequent observations is always $\hat{\tau}$. Hopefully, or implicitly, $\hat{\tau} = \tau$. A quality control operator then uses the Shewhart chart to graphically perform a hypothesis test to determine whether a significant departure from hypothesis has occurred. Only then is action allowed on behalf of the process. Action usually consists of the identification and possible elimination of some special cause. This is not control in the usual sense of the word but monitoring, that is, being attentive to a process but taking action only when unusual events occur.

If one wishes to control a process then one must be willing to forecast where the process will be in the next instance of time. Thus, should a forecast fall too distant from a target $\tau = 50$. Suppose the full consequences of taking a corrective action can be accomplished within the next time interval. Let $X_t$ be the current setting of the controlling factor and $\hat{Y}_{t+1}$ the forecast. Then by making the change $x_t = X_{t+1} - X_t$ one can exactly compensate for the discrepancy $z_t = Y_{t+1} - \tau$. Thus, to bring the process back to $\tau$ one sets $g x_t = -z_t$ where $g$ is the "units adjuster" or "gain". (In Table 6, to match the measurements the corrections have been rounded to the nearest 0.5). The initial setting of the controlling factor $X_1 = 0$ and the first forecast $Y_1 = \tau = 50$. Table 6 contains two data traces: 1) the original observations $Y_t$ and 2) the new observations $Y_{c,t}$ that will be observed once control action has been taken. The changes $x_t$ to bring the process on target and the actual setting of $X_t$ are also displayed. Since the final setting $X_t$ equals the sum of the $x_t$ the EWMA used as forecast for active control becomes identical to a process under pure integral control.
### Table 6: The Controlled Process

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Control to 50.0, x(t) = 5.5, X(t) = 5.5

| 7 | 42.0     | 47.5   | 50.0 | -2.5 | -1.9     | -2.0     |
| 8 | 45.0     | 50.5   | 48.0 | 2.5  | 1.9      | 2.0      |
| 9 | 47.0     | 52.5   | 50.0 | 2.5  | 1.9      | 2.0      |
|10 | 49.0     | 54.5   | 52.0 | 2.5  | 1.9      | 2.0      |

Control to 50.0, x(t) = -4.0, X(t) = 1.5

|11 | 46.0     | 47.5   | 50.0 | -2.5 | -1.90    | -2.0     |
|12 | 50.0     | 51.5   | 48.0 | 3.5  | 2.66     | 2.5      |
|13 | 52.0     | 55.5   | 50.5 | 3.0  | 2.28     | 2.5      |

Control to 50.0, x(t) = -3.0, X(t) = -1.5

|14 | 52.5     | 51     | 50.0 | 1.0  | 0.76     | 1.0      |
|15 | 51.0     | 49.5   | 51.0 | -1.5 | -1.14    | -1.0     |
|16 | 52.0     | 50.5   | 50.0 | 0.5  | 0.38     | 0.5      |
|17 | 50.0     | 48.5   | 50.5 | -2.0 | -1.52    | -1.5     |
|18 | 49.0     | 47.5   | 49.0 | -1.5 | -1.14    | -1.0     |
|19 | 54.0     | 52.5   | 48.0 | 4.5  | 3.42     | 3.5      |
|20 | 51.0     | 49.5   | 51.5 | -2.0 | -1.52    | -1.5     |
|21 | 52.0     | 50.5   | 50.0 | 0.5  | 0.38     | 0.5      |
|22 | 46.0     | 44.5   | 50.5 | -6.0 | -4.56    | -4.5     |

Control to 50.0, x(t) = 4.0, X(t) = 2.5

|23 | 42.0     | 44.5   | 50.0 | -5.5 | -4.18    | -4.0     |

Control to 50.0, x(t) = 4.0, X(t) = 6.5

|24 | 43.0     | 49.5   | 50.0 | -0.5 | -0.38    | -0.5     |
|25 | 45.0     | 51.5   | 49.5 | 2.0  | 1.52     | 1.5      |
|26 | 46.0     | 52.5   | 51.0 | 1.5  | 1.14     | 1.0      |
|27 | 42.0     | 48.5   | 52.0 | -3.5 | -2.66    | -2.5     |
|28 | 44.0     | 50.5   | 49.5 | 1.0  | 0.76     | 1.0      |
|29 | 43.0     | 49.5   | 50.5 | -1.0 | -0.76    | -1.0     |
|30 | 46.0     | 52.5   | 49.5 | 3.0  | 2.28     | 2.5      |
|31 | 42.0     | 48.5   | 52.0 | -3.5 | -2.66    | -2.5     |
|32 | 43.0     | 49.5   | 49.5 | 0.0  | 0.00     | 0.0      |
|33 | 42.0     | 48.5   | 49.5 | -1.0 | -0.76    | -0.1     |
|34 | 45.0     | 51.5   | 48.5 | 3.0  | 2.28     | 2.5      |
|35 | 49.0     | 55.5   | 51.0 | 4.5  | 3.42     | 3.5      |

Continued on page 11
Control to 50.0, \( x(t) = -4.5, \ X(t) = 2.0 \)

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A Manual Adjustment Chart

On page 601 of the text *Statistics for Experimenters* by Box, Hunter and Hunter (7) there is an illustration of a manual adjustment chart constructed for a situation such as this one. Another much more recent reference to the same methodology is by George Box (8). A plot of both the original and the controlled observations is displayed in Figure 2. Clearly, the variability of \( Y_{c,t} \) about \( t \) is much less than that of the original observations \( Y_t \).

![Figure 2: Camshaft Diameters Original & Controlled Obs.](image-url)
Summation

The EWMA can be strongly recommended as a useful tool for industrial quality control personnel. It is first of all easy to plot, a happy circumstance that reduces worries about computations on the production floor. When employed under the Shewhart model of constant mean, constant variance and independent errors, it acts retrospectively, smoothing the historical time trace and enabling the investigator to sense alternative paths for the mean that are not pre-specified. The search for assignable causes is often enhanced by review of the time trace of the EWMA. The EWMA can be displayed on a Shewhart chart and used with its own control limits.

The EWMA also plays an important role in the active control of industrial processes. Whenever a data trace $Y_t$ (and the successive $Y_t$ can be individual observations or other statistics) demonstrate autocorrelation the EWMA can provide an opportunity to reduce variability about target. The EWMA is able to forecast by viewing recent time history through a narrow window and by down weighing older observations. It is thus an appropriate statistic to employ when a process is non-stationary, requiring no specific model for the mean. It can also be used as a useful approximate forecast for many postulated dynamic models for the mean. When the EWMA is used actively to keep a process on target Shewhart charts should also be placed on the control acts $x_t$ to uncover shocks that required unusual control actions. Shewhart procedures and those of the EWMA are complementary. Used in active control the EWMA provides results identical to the integral control procedures employed by mechanical, chemical and electrical control engineers. Finally, the EWMA is easy to simulate using a spreadsheet program. Quality control personnel can thus easily study data traces to find evidence of non-independence and to determine whether a simple EWMA control procedure might be of value.

The EWMA provides the bridge, the interface, between statistical quality control and engineering process control.

References


Statistics Division Job Openings

The Statistics Division is seeking members to work in various capacities. The job descriptions are printed below. If you have an interest in any of these openings, complete the Member Interest Record Form and return it to Rick Lewis. Rick’s address is included on the page with the form itself.

**AQC Division Session Manager**

Purpose: To coordinate the Statistics Division session at the AQC.

Responsibilities: 1) Develop the Statistics Division session topic, obtain the speakers, approve the papers/expand abstracts for publication in the proceedings, and assure that presentation visuals meet the AQC standards. 2) Moderate the session or obtain a moderator for the session. 3) Submit articles to the Division Newsletter for inclusion in the Winter and Spring issues describing the session.

**AQC Technical Paper Reviewer**

Purpose: To review papers for the AQC.

Responsibilities: Review, score and provide comments for 10-20 assigned draft papers.

**AQC Topic Session Manager**

Purpose: To manage the development and presentation of a topic session for the AQC.

Responsibilities: 1) Develop a session using selected papers provided by the review process. 2) Coordinate the presentations by working with speakers through ASQC-provided conference calls. 3) Approve final papers for publication and assure that the presentation visuals meet the AQC standards. 4) Moderate the topic session at the AQC.

**Standards Committee Member**

Purpose: Represent the Statistics Division in development of key quality/statistical standards.

Responsibilities: 1) Review of national and international standards dealing with quality and statistics, and/or 2) Work on writing committees to initiate work on new statistical quality standards.
Statistics Division Job Openings

The Statistics Division has several job openings for which we are seeking members willing to do some work for the Division. The openings are as follows:

1. Program Committee Members for the 1997 AQC in Orlando. The jobs include:
   - AQC Division Session Manager
   - AQC Technical Paper Reviewer
   - AQC Topic Session Manager

2. Standards Committee Member

3. Publications Committee Chair

4. New Products Coordinator

The Job Descriptions are printed in this Newsletter. If you have an interest in any of these openings, please fill out the form below and return it to Rick Lewis,
Monsanto Co., Mail Zone O4B, 800 N. Lindbergh Blvd., St. Louis, MO 63167

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