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APPENDIX

Appendix A.1 Probability type I error of $\bar{X}$ control chart (Montgomery, 2001)

$$
\begin{aligned}
\alpha &= P(\text{Reject H}_0 \,|\, \text{H}_0 \text{ true}) \\
&= P(\bar{\bar{X}} < LCL \,|\, \mu = \mu_0) + P(\bar{\bar{X}} > UCL \,|\, \mu = \mu_0) \\
&= P(\bar{\bar{X}} < \mu_0 - L\frac{\sigma}{\sqrt{n}} \,\Big|\, \mu = \mu_0) + P(\bar{\bar{X}} > \mu_0 + L\frac{\sigma}{\sqrt{n}} \,|\, \mu = \mu_0) \\
&= P(\bar{\bar{X}} - \mu_0 < -L\frac{\sigma}{\sqrt{n}} \,\Big|\, \mu = \mu_0) + P(\bar{\bar{X}} - \mu_0 > L\frac{\sigma}{\sqrt{n}} \,|\, \mu = \mu_0) \\
&= P(\frac{\bar{\bar{X}} - \mu_0}{\frac{\sigma}{\sqrt{n}}} < -L \,\Bigg|\, \mu = \mu_0) + P(\frac{\bar{\bar{X}} - \mu_0}{\frac{\sigma}{\sqrt{n}}} > L \,|\, \mu = \mu_0) \\
&= P(z < -L_0 \,|\, \mu = \mu_0) + P(z > L_0 \,|\, \mu = \mu_0) \\
&= 2\Phi(-L)
\end{aligned}
$$

Appendix A.2 Probability type II error of $\bar{X}$ control chart (Montgomery, 2001)

$$
\begin{aligned}
\beta &= P(\text{Accept H}_0 \,|\, \text{H}_0 \text{ false}) \\
&= P(LCL < \bar{\bar{X}} < UCL \,|\, \mu = \mu_0) \\
&= P(\bar{\bar{X}} < UCL \,|\, \mu_0) - P(\bar{\bar{X}} < LCL \,|\, \mu_0) \\
&= P(\bar{\bar{X}} < \mu_0 + L\frac{\sigma}{\sqrt{n}}) - P(\bar{\bar{X}} < \mu_0 - L\frac{\sigma}{\sqrt{n}}) \\
&= P(\bar{\bar{X}} - \mu_0 < L\frac{\sigma}{\sqrt{n}}) - P(\bar{\bar{X}} - \mu_0 < -L\frac{\sigma}{\sqrt{n}}) \\
&= P(\frac{\bar{\bar{X}} - \mu_0}{\frac{\sigma}{\sqrt{n}}} < L) - P(\frac{\bar{\bar{X}} - \mu_0}{\frac{\sigma}{\sqrt{n}}} < -L) \\
&= P(Z < L) - P(Z < -L) \\
&= 1 - 2\Phi(-L)
\end{aligned}
$$

Appendix A.3 Probability type I error of EWMA control chart (Montgomery, 2001)

$$\begin{aligned}
\alpha &= P(\text{Reject H}_0 \,|\, \text{H}_0 \text{ true}) \\
&= P(\bar{\bar{X}} < LCL \,|\, \mu = \mu_0) + P(\bar{\bar{X}} > UCL \,|\, \mu = \mu_0) \\
&= P(\bar{\bar{X}} < \mu_0 - L\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}} \,\Big|\, \mu = \mu_0) + P(\bar{\bar{X}} > \mu_0 + L\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}} \,\Big|\, \mu = \mu_0) \\
&= P(\bar{\bar{X}} - \mu_0 < -L\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}} \,\Big|\, \mu = \mu_0) + P(\bar{\bar{X}} - \mu_0 > L\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}} \,\Big|\, \mu = \mu_0) \\
&= P(\frac{\bar{\bar{X}} - \mu_0}{\frac{\sigma}{\sqrt{n}}} < -L\sqrt{\frac{r}{2-r}} \,\Big|\, \mu = \mu_0) + P(\frac{\bar{\bar{X}} - \mu_0}{\frac{\sigma}{\sqrt{n}}} > L\sqrt{\frac{r}{2-r}} \,\Big|\, \mu = \mu_0) \\
&= P(\frac{\bar{\bar{X}} - \mu_0}{\sigma_{\bar{X}}\sqrt{\frac{r}{2-r}}} < -L \,\Big|\, \mu = \mu_0) + P(\frac{\bar{\bar{X}} - \mu_0}{\sigma_{\bar{X}}\sqrt{\frac{r}{2-r}}} > L \,\Big|\, \mu = \mu_0) \\
&= P(z < -L_0 \,|\, \mu = \mu_0) + P(z > L_0 \,|\, \mu = \mu_0) \\
&= 2\Phi(-L)
\end{aligned}$$

Appendix A.4 Probability type II error of EWMA control chart (Montgomery, 2001)

$$\begin{aligned}
\beta &= P(\text{Accept H}_0 \,|\, \text{H}_0 \text{ false}) \\
&= P(LCL < \bar{\bar{X}} < UCL \,|\, \mu = \mu_0 + \varepsilon) \\
&= P(\bar{\bar{X}} < UCL \,|\, \mu_0 + \varepsilon) - P(\bar{\bar{X}} < LCL \,|\, \mu_0 + \varepsilon) \\
&= P(\bar{\bar{X}} < \mu_0 + L\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}} - \varepsilon) - P(\bar{\bar{X}} < \mu_0 - L\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}} - \varepsilon) \\
&= P(\bar{\bar{X}} - \mu_0 < L\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}} - \varepsilon) - P(\bar{\bar{X}} - \mu_0 < -L\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}} - \varepsilon) \\
&= P(\frac{\bar{\bar{X}} - \mu_0}{\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}}} < \frac{L\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}}}{\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}}} - \frac{\varepsilon}{\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}}}) - P(\frac{\bar{\bar{X}} - \mu_0}{\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}}} < -\frac{L\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}}}{\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}}} - \frac{\varepsilon}{\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}}}) \\
&= P(\frac{\bar{\bar{X}} - \mu_0}{\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}}} < L - \frac{\varepsilon}{\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}}}) - P(\frac{\bar{\bar{X}} - \mu_0}{\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}}} < -L - \frac{\varepsilon}{\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}}})
\end{aligned}$$

$$\beta = P(z < L - \frac{\varepsilon}{\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}}}) - P(z < -L - \frac{\varepsilon}{\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}}})$$

$$= 1 - 2\Phi(-L - \frac{\varepsilon}{\frac{\sigma}{\sqrt{n}}\sqrt{\frac{r}{2-r}}})$$

Appendix A.5 Normal distribution (Montgomery, 2001)

If $X_1, X_2, ..., X_n$ denote a random sample from a normal population, $\underset{\sim}{X}' = [X_1, X_2, ..., X_p]$ is a $p \times 1$ random vector with normal distribution with mean μ and variance σ^2, has the probability density function

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-[(x-\mu)/\sigma]^2/2} \qquad -\infty < x < \infty \qquad \text{(A.5.1)}$$

The term $$\left(\frac{x-\mu}{\sigma}\right)^2 = (x-\mu)'(\sigma^2)^{-1}(x-\mu) \qquad \text{(A.5.2)}$$

In the exponent of the univariate normal density function measures the square of the distance from x to μ in standard deviation units. This can be generalized for a $p \times 1$ vector $\underset{\sim}{X}$ of the observations on several variable as

$$(\underset{\sim}{X} - \underset{\sim}{\mu})' \Sigma^{-1} (\underset{\sim}{X} - \underset{\sim}{\mu}) \qquad \text{(A.5.3)}$$

Where $\underset{\sim}{\mu}$ represent $p \times 1$ vector, Σ is the variance-covariance matrix of $\underset{\sim}{X}$.

Assume Σ is positive definite, so the equation (A.5.3) is the square of the generalized distance from $\underset{\sim}{X}$ to $\underset{\sim}{\mu}$

A p-dimensional normal density for the random vector $\underset{\sim}{X}' = [X_1, X_2, ..., X_p]$ has the form

$$f(x) = \frac{1}{(2\pi)^{p/2} |\Sigma|^{1/2} \sqrt{\sigma^2}} e^{-(x-\mu)'\Sigma^{-1}(x-\mu)/2}$$

where $-\infty < x_i < \infty, \ i - 1, 2, ..., p.$

$$E(\underset{\sim}{X}) = \begin{bmatrix} E(X_1) \\ E(X_2) \\ . \\ . \\ . \\ E(X_p) \end{bmatrix} = \begin{bmatrix} \mu_1 \\ \mu_2 \\ . \\ . \\ . \\ \mu_p \end{bmatrix} = \underset{\sim}{\mu} \qquad \text{(A.5.4)}$$

and $\sum = E(\underset{\sim}{X} - \underset{\sim}{\mu})(\underset{\sim}{X} - \underset{\sim}{\mu})'$

$$= E\left(\begin{bmatrix} X_1 - \mu_1 \\ X_2 - \mu_2 \\ \vdots \\ X_p - \mu_p \end{bmatrix} \begin{bmatrix} X_1 - \mu_1 & X_2 - \mu_2 & \cdots & X_p - \mu_p \end{bmatrix}\right)$$

$$= E\begin{bmatrix} (X_1 - \mu_1)^2 & (X_1 - \mu_1)(X_2 - \mu_2) & \cdots & (X_1 - \mu_1)(X_p - \mu_p) \\ (X_2 - \mu_2)(X_1 - \mu_1) & (X_2 - \mu_2)^2 & \cdots & (X_1 - \mu_1)(X_p - \mu_p) \\ \vdots & \vdots & \ddots & \vdots \\ (X_p - \mu_p)(X_1 - \mu_1) & (X_p - \mu_p)(X_2 - \mu_2) & \cdots & (X_p - \mu_p)^2 \end{bmatrix}$$

$$= \begin{bmatrix} E(X_1 - \mu_1)^2 & E(X_1 - \mu_1)(X_2 - \mu_2) & \cdots & E(X_1 - \mu_1)(X_p - \mu_p) \\ E(X_2 - \mu_2)(X_1 - \mu_1) & E(X_2 - \mu_2)^2 & \cdots & E(X_1 - \mu_1)(X_p - \mu_p) \\ \vdots & \vdots & \ddots & \vdots \\ E(X_p - \mu_p)(X_1 - \mu_1) & E(X_p - \mu_p)(X_2 - \mu_2) & \cdots & E(X_p - \mu_p)^2 \end{bmatrix}$$

$$\sum = Cov(\underset{\sim}{X}) = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1p} \\ \sigma_{21} & \sigma_{22} & \cdots & \sigma_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{21} & \sigma_{21} & \cdots & \sigma_{21} \end{bmatrix} \quad \text{(A.5.5)}$$

Appendix A.6 Chi-square distribution χ_p^2 (Montgomery, 2001)

Let X be distributed as $N_p(\mu, \sum)$ with $|\sum| > 0$. Then

1. $(X-\mu)' \sum^{-1} (X-\mu) = Z_1^2 + Z_2^2 + ... + Z_p^2$
2. $(X-\mu)' \sum^{-1} (X-\mu)$ is distributed as χ_p^2, where χ_p^2 denotes the chi-square distribution with p degrees of freedom .
3. The $N_p(\mu, \sum)$ distribution assigns probability $1-\alpha$ to the solid ellipsoid $\left\{X : (X-\mu)' \sum^{-1} (X-\mu) \le \chi_p^2(\alpha)\right\}$, where $\chi_p^2(\alpha)$ denotes the upper $(100\alpha)^{th}$ percentile of the χ_p^2 distribution. Thus

$$P\left[(X-\mu)' \sum^{-1} (X-\mu) \le \chi_p^2(\alpha)\right] = 1-\alpha$$

4. $\frac{1}{n}\sum_{i=1}^{n}\left[(x_i-\mu)'\Sigma^{-1}(x_i-\mu)\right]=\frac{1}{n}\sum_{i=1}^{n}\left[\left(Z_{11}^2+Z_{21}^2+...+Z_{n1}^2\right)+...+\left(Z_{1p}^2+Z_{2p}^2+...+Z_{np}^2\right)\right]$

$$\therefore\frac{1}{n}\sum_{i=1}^{n}\left[(x_i-\mu)'\Sigma^{-1}(x_i-\mu)\right]\sim\chi_{np}^2$$

5. $\frac{1}{n}\sum_{i=1}^{n}\left[(x_i-\bar{x})'\Sigma^{-1}(x_i-\bar{x})\right]\sim\chi_{np-p}^2$

Appendix A.7 The errors of the estimation (e_i) by using the method of least squares (Pongpullponsak, 2011)

The Simple Linear Regression (SLR) model is

$$Y_i=\beta_1+\beta_2X_i+e_i \tag{A.7.1}$$

where the e_i are iid with $E(e_i)=0$ and $VAR(e_i)=\sigma^2$ for $i=1,2,\ldots,n.$
Then Y_i and e_i are random variables while the X_i are treated as known constants.
The parameters β_1,β_2 and $\sigma^2$are unknown constants that need to be estimated.
The normal SLR model adds the assumption that the e_i are idd $N\left(0,\sigma^2\right)$.
For SLR, $E(Y_i)=\beta_1+\beta_2X_i$ and the line $E(Y)=\beta_1+\beta_2X$ is the regression function.
$VAR(Y)_i=\sigma^2$.
For SLR, the least square estimators b_1 and b_2 minimize the least squares criterion

$$Q(\eta_1,\eta_2)=\sum_{i=1}^{n}(Y_i-\eta_1-\eta_2X_i)^2. \tag{A.7.2}$$

For a fixed η_1 and η_2,Q is the sum of the square vertical deviations from the line

$$Y=\eta_1+\eta_2X.$$

The Ordinary Least Squares (OLS) line is:

$$\hat{Y}=b_1+b_2X \tag{A.7.3}$$

where

$$\hat{\beta}_2\equiv b_2=\frac{\sum_{i=1}^{n}(X_i-\bar{X})(Y_i-\bar{Y})}{\sum_{i=1}^{n}(X_i-\bar{X})^2} \tag{A.7.4}$$

and

$$\hat{\beta}_i\equiv b_1=\bar{Y}-b_2\bar{X}. \tag{A.7.5}$$

Find minimum value of $Q(\eta_1,\eta_2)$ by partial derivative in equation(A.7.2),so we get:

$$\frac{\partial Q}{\partial \eta_1} = -2\sum_{i=1}^{n}(Y_i - \eta_1 - \eta_2 X_i)$$

and

$$\frac{\partial^2 Q}{\partial {\eta_1}^2} = 2\eta_1.$$

Similarly,

$$\frac{\partial Q}{\partial \eta_2} = -2\sum_{i=1}^{n}X_i(Y_i - \eta_1 - \eta_2 X_i)$$

and

$$\frac{\partial^2 Q}{\partial {\eta_2}^2} = 2\sum_{i=1}^{n}X_i^2.$$

The OLS estimators b_1 and b_2 satisfy the normal equation:

$$\sum_{i=1}^{n}Y_i = nb_1 + b_2\sum_{i=1}^{n}X_i \tag{A.7.6}$$

and
$$\sum_{i=1}^{n}X_iY_i = b_1\sum_{i=1}^{n}X_i + b_2\sum_{i=1}^{n}X_i^2 \tag{A.7.7}$$

For SLR, $\hat{Y}_i = b_1 + b_2 X_i$ is called the ith fitted value (or predicted value) for observation $\hat{Y}_i$ whiles the ith residual is:

$$r_i = Y_i - \hat{Y}_i. \tag{A.7.8}$$

The error (residual) sum of squares(SSE):

$$SSE = \sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2 = \sum_{i=1}^{n}r_i^2 \tag{A.7.9}$$

For SLR, the Mean Square Error (MSE) is an unbiased estimator of the error variance σ^2:

$$MSE = \frac{SSE}{(n-2)}. \tag{A.7.10}$$

Properties of the OLS line:

1) The residuals sum to zero: $\sum_{i=1}^{n}r_i = 0.$

2) $\sum_{i=1}^{n}Y_i = \sum_{i=1}^{n}\hat{Y}_i.$

3) The independent variable and residuals are uncorrelated: $\sum_{i=1}^{n}X_i r_i = 0.$

4) The fitted values and residuals are uncorrelated: $\sum_{i=1}^{n} \hat{Y}_i r_i = 0$.

5) The least squares line passes through the point $\left(\bar{X}, \bar{Y}\right)$.

Let the $p \times 1$ vector $\beta = \left(\beta_1, \ldots, \beta_p\right)'$ and let $p \times 1$ vector $x_i = \left(1, X_{i1}, \ldots, X_{ip}\right)'$. Notice that $X_{i1} \equiv 1$ for $i = 1, \ldots, n$. then the Multiple Regression (MLR) model is

$$Y_i = \beta_1 + \beta_2 X_{i2} + \ldots + \beta_p X_{ip} + e_i = x_i' \beta + e_i \tag{A.7.11}$$

for $i = 1, \ldots, n$. where the e_i are random variables while the X_{i1} are treated as known constants. the parameters $\beta_1, \ldots, \beta_p$ and σ^2 are unknown constants that need to be estimated.
In matrix notation, these n equations become

$$Y = X\beta + e, \tag{A.7.12}$$

where Y is an $n \times 1$ vector of dependent variables, X is an $n \times p$ matrix of predictors, β is a $p \times 1$ vector of unknown coefficients, and e is an $n \times 1$ vector of unknown errors. Equivalently,

$$\begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix} = \begin{bmatrix} 1 & X_{11} & X_{12} & \cdots & X_{1p} \\ 1 & X_{21} & X_{22} & \cdots & X_{2p} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & X_{n1} & X_{n2} & \cdots & X_{np} \end{bmatrix} \begin{bmatrix} \beta_0 \\ \beta_1 \\ \vdots \\ \beta_p \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \\ \vdots \\ e_n \end{bmatrix}. \tag{A.7.13}$$

For MLR, $$E\left(Y_i\right) = \beta_1 + \beta_2 X_{i2} + \ldots + \beta_p X_{ip} = x_i' \beta \tag{A.7.14}$$

and the regression function with $VAR\left(Y_i\right) = \sigma^2$ is:

$$E\left(Y\right) = \beta_1 + \beta_2 X_2 + \ldots + \beta_p X_p = x' \beta \tag{A.7.15}$$

The least squares estimator $b_1, b_2, \ldots, b_p$ minimize the least squares criterion

$$Q(\eta) = \sum_{i=1}^{n} \left(Y - \eta_1 - \eta_2 X_{i2} - \ldots - \eta_p X_{ip}\right)^2 = \sum_{i=1}^{n} r_i^2. \tag{A.7.16}$$

The least squares estimator is $\hat{\beta} = b$ satisfies the MLR normal equations

$$X'Xb = X'Y \tag{A.7.17}$$

and the least squares estimator is:

$$\hat{\beta} = b = (X'X)^{-1} X'Y. \tag{A.7.18}$$

The vector of predicted is:

$$\hat{Y} = Xb = HY, \tag{A.7.19}$$

where $$H = X(X'X)^{-1} X'$$

The ith entry of $\hat{Y}$ is the ith fitted value

$$\hat{Y}_i = b_1 + b_2 X_{i2} + ... + b_p X_{ip} = x'b_i \tag{A.7.20}$$

for observation $\hat{Y}_i$ while the ith residual is

$$r_i = Y_i - \hat{Y}_i. \tag{A.7.21}$$

The vector of residuals is

$$r = (I - H)Y. \tag{A.7.22}$$

The (residual) error sum of squares (SSE):

$$SSE = \sum_{i=1}^{n} \left(Y_i - \hat{Y}_i\right)^2 = \sum_{i=1}^{n} r_i^2. \tag{A.7.23}$$

For MLR, the MSE is an unbiased estimator of the error variance σ^2 so:

$$MSE = \frac{SSE}{(n-p)}. \tag{A.7.24}$$

Appendix B M-File Function of Expected Hourly Loss

Program M file of Function $E(L)$ of VP MEWMA control chart

n_1 = x(1)
n_2 = x(2)
h_1 = x(3)
h_2 = x(4)
%%
$n_1 < n_2$;
$h_1 > h_2$;
t_0 = 2.5
t_1 = 1
V_0 = 500
V_1 = 50
C_0 = 500
C_1 = 500
λ = 0.01
s = 100;
p = 2;
%%
d_1 = 0;
d_2 = 0.25;
d_3 = 0.5;
d_4 = 1;
d_5 = 1.5;
d_6 = 2;

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% d2
ne1 = n1*(d2^2);
ne2 = n2*(d2^2);
% d3
%ne1 = n1*(d3^2);
%ne2 = n2*(d3^2);
% d4
%ne1 = n1*(d4^2);
%ne2 = n2*(d4^2);
% d5
%ne1 = n1*(d5^2);
%ne2 = n2*(d5^2);
% d6
%ne1 = n1*(d6^2);
%ne2 = n2*(d6^2);
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

w = 2.925;
k = 2.952;

%w = 3.142;
%k = 10.79;

%w = 3.225;
%k = 11.47;

%w = 3.268;
%k = 11.87;

%w = 3.296;
%k = 12.14;

%w = 3.316;
%k = 12.32;

%w = 3.339;
%k =12.56;

%w = 3.349;
%k = 12.69;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Expo
EXPO1 = exp(-(λ*h1));
EXPO2 = exp(-(λ*h2));
NE_EXPO1 = 1-exp(-(λ*h1));
NE_EXPO2 = 1-exp(-(λ*h2));
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
A1 = ncx2cdf(k p,0);
A2 = ncx2cdf(k,p,ne1);
A3 = ncx2cdf(k,p,ne2);

B1 = ncx2cdf(w, p,0);
B2 = ncx2cdf(w, p,ne1);
B3 = ncx2cdf(w p,ne2);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
r = [0 1 0 0 0];
t = [h1 ; h2 ; h2 ; h1 ; h2];
P = [(B1/A1)*EXPO1 ((A1-B1)/A1)*EXPO1 ((1-A1)/A1)*EXPO1 B2*NE_EXPO1
(A2-B2)*NE_EXPO1 ; (B1/A1)*EXPO2 ((A1-B1)/A1)*EXPO2 ((1-A1)/A1)*EXPO2
B3*NE_EXPO2 (A3-B3)*NE_EXPO2; (B1/A1)*EXPO2 ((A1-B1)/A1)*EXPO2 ((1-
A1)/A1)*EXPO2 B3*NE_EXPO2 (A3-B3)*NE_EXPO2 ; 0 0 0 B2 (A2-B2) ; 0 0 0 B2
(A2-B2)];
I = [1 0 0 0 0 ; 0 1 0 0 0 ; 0 0 1 0 0 ; 0 0 0 1 0 ; 0 0 0 0 1];
D = inv(I - P);
m = r*D*t;
```

```
AATS = m-(1/λ);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Find E(FA)
f = [0 ; 0 ; 1 ; 0 ; 0];
E_FA = r*D*f;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

Find E(N)
n = [n1 ; n2 ; n2 ; n1 ; n2];
E_N = r*D*n;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
E_T = m + t0*E_FA + t1;
E_C = v0*(1/λ) + v1*(m-(1/λ)) - c0*E_FA - c1+(s*E_N);
E_L = v0 - (E_C/E_T);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Program M file of Function $E(L)$ of VPSC MEWMA control chart

$n_1 = x(1)$

$n_2 = x(2)$

$h_1 = x(3)$

$h_2 = x(4)$

%%

$n_1 < n_2$;

$h_1 > h_2$;

$t_0 = 2.5$

$t_1 = 1$

$V_0 = 500$

$V_1 = 50$

$C_0 = 500$

$C_1 = 500$

$\lambda = 0.01$

$s = 100$;

p = 2;

%%

$d_1 = 0$;

$d_2 = 0.25$;

$d_3 = 0.5$;

$d_4 = 1$;

$d_5 = 1.5$;

$d_6 = 2$;

%%

```
% d2
ne1 = n1*(d2^2);
ne2 = n2*(d2^2);
% d3
%ne1 = n1*(d3^2);
%ne2 = n2*(d3^2);
% d4
%ne1 = n1*(d4^2);
%ne2 = n2*(d4^2);
% d5
%ne1 = n1*(d5^2);
%ne2 = n2*(d5^2);
% d6
ne1 = n1*(d6^2);
ne2 = n2*(d6^2);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%r=.05,p=3
%w = 9.773
%k = 11.997

%r = .1,p=3
%w = 10.956
%k = 13.165

%r = .15,p=3
%w = 11.566
%k = 13.718

%r = .2,p=3
%w = 11.930
%k = 14.055

%r = .25,p=3
%w = 12.184
%k = 14.271

%r = .05,p=2
%w = 7.689
%k = 9.729

%r = .1,p=2
%w = 8.786
%k = 10.827

%r = .15,p=2
%w = 9.358
%k = 11.366
```

```
r =0.2;p=2;
w = 9.717;
k = 11.688;

%r = .25,p=2
%w = 9.947
%k = 11.906
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Find Expo
EXPO1 = exp(-(λ*h1));
EXPO2 = exp(-(λ*h2));
NE_EXPO1 = 1-exp(-(λ*h1));
NE_EXPO2 = 1-exp(-(λ*h2));
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
A1 = ncx2cdf(k,p,0);
A2 = ncx2cdf(k,p,ne1);
A3 = ncx2cdf(k,p,ne2);
B1 = ncx2cdf(w,p,0);
B2 = ncx2cdf(w,p,ne1);
B3 = ncx2cdf(w,p,ne2);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Find m
r = [0 1 0 0 0];
t = [h1 ; h2 ; h2 ; h1 ; h2];
P = [(B1/A1)*EXPO1 ((A1-B1)/A1)*EXPO1 ((1-A1)/A1)*EXPO1 B2*NE_EXPO1
(A2-B2)*NE_EXPO1 ; (B1/A1)*EXPO2 ((A1-B1)/A1)*EXPO2 ((1-A1)/A1)*EXPO2
B3*NE_EXPO2 (A3-B3)*NE_EXPO2; (B1/A1)*EXPO2 ((A1-B1)/A1)*EXPO2 ((1-
A1)/A1)*EXPO2 B3*NE_EXPO2 (A3-B3)*NE_EXPO2 ; 0 0 0 B2 (A2-B2) ; 0 0 0 B2
(A2-B2)];
I = [1 0 0 0 0 ; 0 1 0 0 0 ; 0 0 1 0 0 ; 0 0 0 1 0 ; 0 0 0 0 1];
D = inv(I - P);

m = r*D*t;

AATS = m-(1/λ);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Find E(FA)
f = [0 ; 0 ; 1 ; 0 ; 0];
E_FA = r*D*f;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Find E(N)
n = [n1 ; n2 ; n2 ; n1 ; n2];
E_N = r*D*n;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Find E(L)
E_T = m + t0*E_FA + t1;
E_C = v0*(1/λ) + v1*(m-(1/λ)) - c0*E_FA - c1+(s*E_N);
E_L = v0 - (E_C/E_T);
```

....

CURRICURUM VITAE

Name	Miss Aoumfar Nakto
Date of Birth	15 May 1962
Education Record	
High School	St. Francis Xavier School, 1980
Bachelor's Degree	Bachelor of Science (Mathematics) Chulalongkorn University, 1984
Master's Degree	Master of Education (Mathematics Education) Chulalongkorn University, 1989
Doctoral Degree	Doctor of Philosophy (Applied Mathematics) King Mongkut's University of Technology Thonburi, 2010
Scholarship	University Development Commission Fund, 1995-1997
Publication	Nakto, A. and Pongpullponsak, A., 2009, "Economic Model for EWMA Variable Parameter Control Chart", **ICMU-MU, 2009**, The Twin Towers Hotel, Rong Muang Patumwan, Bangkok, Thailand, pp. 263-275. Nakto, A. and Pongpullponsak, A., 2010, "Economic Design of MEWMA Control Chart with the Variable Parameter", **International on the occasion of the 4th cycle celebration of KMUTT**, The Imperial Queen's Park Hotel, Bangkok, Thailand, pp. 480-486. Nakto, A. and Pongpullponsak, A., 2011, "Minimizing hourly loss cost of MEWMA Control Chart with Variable Parameter Using Genetic Algorithm", **Far East Journal of Applied Mathematics**, Vol. 53, No. 1, pp. 53-76.

มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี

ข้อตกลงว่าด้วยการโอนลิขสิทธิ์ในวิทยานิพนธ์

วันที่ ..10..... เดือน ..มิ.ย.............. พ.ศ. ..54....

ข้าพเจ้า นางสาว เอื้อมฟ้า นาคโต รหัสประจำตัว 49510104 เป็นนักศึกษาของมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี ระดับปริญญา ( ) โท (/) เอก หลักสูตร ปร.ค. สาขาวิชา คณิตศาสตร์ประยุกต์ คณะวิทยาศาสตร์ อยู่บ้านเลขที่ 36/5 หมู่ 6 ถนน - ตำบล คลองหนึ่ง อำเภอ คลองหลวง จังหวัด ปทุมธานี รหัสไปรษณีย์ 12120 ขอโอนลิขสิทธิ์ในวิทยานิพนธ์ให้ไว้กับมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี โดยมี ผศ.ดร.วรนุช เกิดสินธ์ชัย ตำแหน่ง คณบดีคณะวิทยาศาสตร์ เป็นผู้รับโอนลิขสิทธิ์และมีข้อตกลงดังนี้

1. ข้าพเจ้าได้จัดทำวิทยานิพนธ์เรื่อง ตัวแบบทางเศรษฐศาสตร์สำหรับแผนภูมิควบคุมตัวแปรพารามิเตอร์ของการเคลื่อนที่เฉลี่ยถ่วงน้ำหนักชี้กำลังแบบพหุ ซึ่งอยู่ในความควบคุมของ รศ. อดิศักดิ์ พงษ์พูลผลศักดิ์ ตามมาตรา 14 แห่ง พ.ร.บ.ลิขสิทธิ์ พ.ศ. 2537 และถือว่าเป็นส่วนหนึ่งของการศึกษาตามหลักสูตรของมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี

2. ข้าพเจ้าตกลงโอนลิขสิทธิ์จากผลงานทั้งหมดที่เกิดขึ้นจากการสร้างสรรค์ของข้าพเจ้าในวิทยานิพนธ์ให้กับมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี ตลอดอายุแห่งการคุ้มครองลิขสิทธิ์ตามมาตรา 23 แห่งพระราชบัญญัติลิขสิทธิ์ พ.ศ. 2537 ตั้งแต่วันที่ได้รับอนุมัติโครงร่างวิทยานิพนธ์จากมหาวิทยาลัย

3. ในกรณีที่ข้าพเจ้าประสงค์จะนำวิทยานิพนธ์ไปใช้ในการเผยแพร่ในสื่อใดๆ ก็ตาม ข้าพเจ้าจะต้องระบุว่าวิทยานิพนธ์เป็นผลงานของมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรีทุก ๆ ครั้งที่มีการเผยแพร่

4. ในกรณีที่ข้าพเจ้าประสงค์จะนำวิทยานิพนธ์ไปเผยแพร่ หรืออนุญาตให้ผู้อื่นทำซ้ำ หรือดัดแปลง หรือเผยแพร่ต่อสาธารณชน หรือกระทำการอื่นใด ตามมาตรา 27, มาตรา 28, มาตรา 29 และมาตรา 30 แห่งพระราชบัญญัติลิขสิทธิ์ พ.ศ.2537 โดยมีค่าตอบแทนในเชิงธุรกิจ ข้าพเจ้าจะกระทำได้เมื่อได้รับความยินยอมเป็นลายลักษณ์อักษรจากมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี

ลงชื่อ.....เอื้อมฟ้า นาคโต..... ผู้โอนลิขสิทธิ์

(นางสาว เอื้อมฟ้า นาคโต)

ลงชื่อ.. ผู้รับโอนลิขสิทธิ์

(ผศ.ดร.วรนุช เกิดสินธ์ชัย)

ลงชื่อ .... พยาน

(รศ.อดิศักดิ์ พงษ์พูลผลศักดิ์)

ลงชื่อ .... พยาน

(ดร.ดุษฎี ศุขวัฒน์)