Monitoring Air Quality by Statistical Control Charts

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Abstract

The Exponentially Weighted Moving Average (EWMA) control charts are used to monitor the air quality data of urban and industrial areas of Muscat. Weekly 8-hours maximum concentrations of Carbon Monoxide (CO) over a period of one year were found to have significant first order autocorrelation. Therefore, Box-Jenkins ARIMA models were fitted and residuals were taken to apply EWMA. It was observed that the data in both areas are within the international standard limit.

Keywords: ARIMA, EWMA, Air Quality, Control Charts

Introduction

The Statistical control charts were primarily developed for quality management of manufacturing process. However, these could be used to monitor the environmental data but the methodology of the construction of such charts should be modified because the environmental data usually exhibit the property of autocorrelation while the control charts are commonly made under the assumption of independence of successive observations[1,2]. In the present study we made such analysis by taking air quality data on pollutant concentration of Carbon Monoxide (CO) over a period of one year from Muscat in urban area of Rawi and in industrial area of Al-Rusail The data was taken from the Directorate of Oman Ministry of Environment.

Data

We had concentrations of the pollutant recorded at 8 hourly intervals. The series of 8-hours maximum over a week were constructed and presented in Figure 1. For urban area, the average of weekly maximum was 1.003 ppm and standard deviation was 0.407 ppm and for the industrial area it was1.187 ppm with a standard deviation of 0.508 ppm. For both urban area and industrial area the pollutants were within the international standard of air quality and were found non significant using t-test.

EWMA Control Charts

The Exponentially Weighted Moving Average (EWMA) is a statistic for monitoring the process that averages the data in a way that gives less and less weight to data as they are further removed in time. The statistic that is calculated is as :

$$EWMA_t = \lambda Y_t + (1-\lambda)\, EWMAt_1 \qquad (1)$$

for t = 1, 2, ..., n.

where:

EWMA is the mean of historical data (target)

Y_t is the observation at time t

n is the number of observations to be monitored including $EWMA_0$

$0 < \lambda \leq 1$ is a constant that determines the depth of memory of the EWMA.

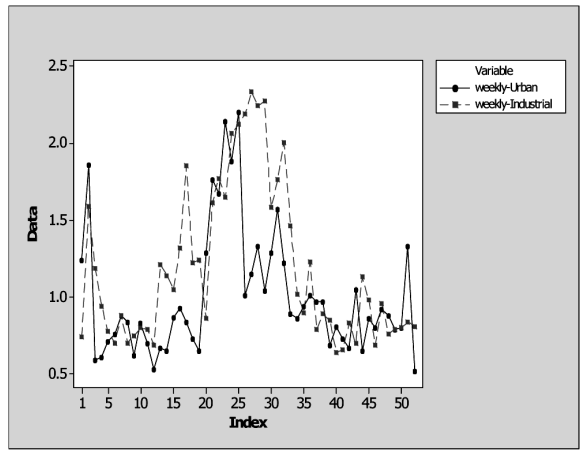

Figure 1 Time Series Plot of weeldy-Urban; weeldy-Industrial

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The control limits for EWMA are:

$$\text{UCL}= \mu_0 + L\sigma\sqrt{\frac{\lambda}{(2-\lambda)}[1-(1-\lambda)^{2i}]} \quad (2)$$

$$\text{CL}=\mu_0 \quad (3)$$

$$\text{LCL}=\mu_0 - L\sigma\sqrt{\frac{\lambda}{(2-\lambda)}[1-(1-\lambda)^{2i}]} \quad (4)$$

where the factor L is either set equal 3 or chosen. The data are assumed to be independent[4]. The EWMA charts for Co for urban and industrial area are in Figure 2 (a) and Figure 2 (b)

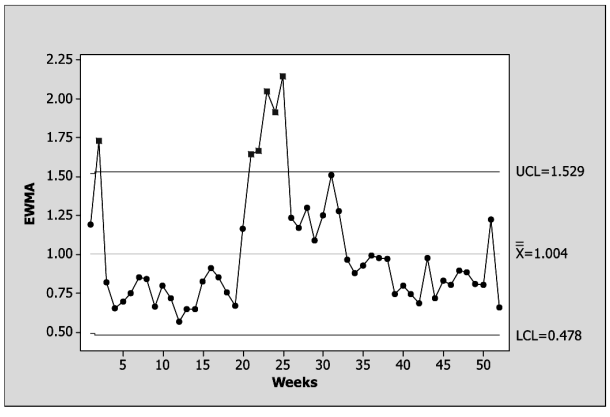

Figure 2 (a) : EWMA Chart of weekly maximum Co for urban area

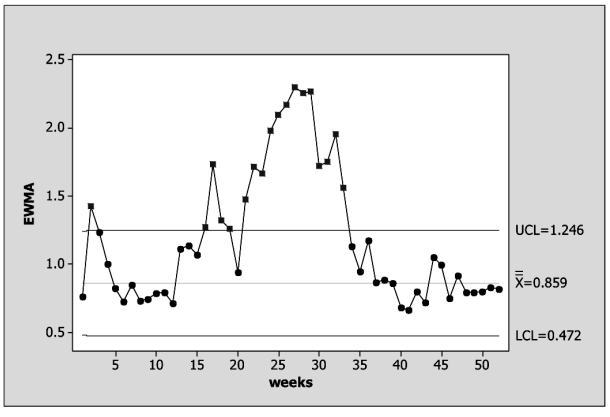

Figure 2 (b) : EWMA Chart of weekly maximum Co for Industrial area

Control Charts for Autocorrelated Data

If the data are not independent, then these are fitted with a suitable model such as Auto-Regressive Integrated Moving Average (ARIMA) models which have the general form as:

$$\text{Øp (B) (1-B)}^{d}\ \text{Zt}=\theta_0+\Theta_q\text{(B)at} \quad (5)$$

where d is positive integer or zero, B is the backshift operator, Øp, Θq, θ_0 are parameters and at white noise [3, 4]. Then the residuals from these models are used to construct control charts.

The ARIMA(0,2,1) models for the CO data were identified and fitted to each of the urban and industrial areas. The residuals frpom these models were normally distributed. The EWMA control chart is applied to these residuals and are presented in the Figures 3 (a) and Figure 3 (b) respectively.

Conclusion

We found that weekly maximum CO of both urban area and industrial area had significant first order aucorrelation.

Therefore, an appropriate modification of existing statistical quality control techniques, in particular, the EWMA chart was very necessay for environmental process management and monitoring. When we used the control chart on the assumption of no autocorrelation then we found that there are huge difference in the amount of CO between urban area and industrial area since most of the observations were seen to be out of control. However when we applied these control charts by assuming that the data of CO were autocorrelated which was done by first fitting appropriate ARIMA models and that model was ARIMA (0, 2, 1). After that we draw the EWMA chart for the residual and we found that the observations are within the control limit. This leads us to say that there is no evidence that the air quality data of industrial area is different from urban area. This means that the air quality in industrial area has not been affected by pollution alarmingly. Based on our analysis, we found that the data in both areas are within the national standard limit.

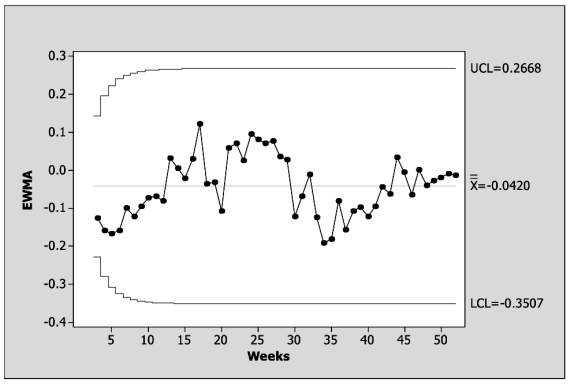

Figure 3 (a) : EWMA Chart of weekly maximum Co for Industrial area

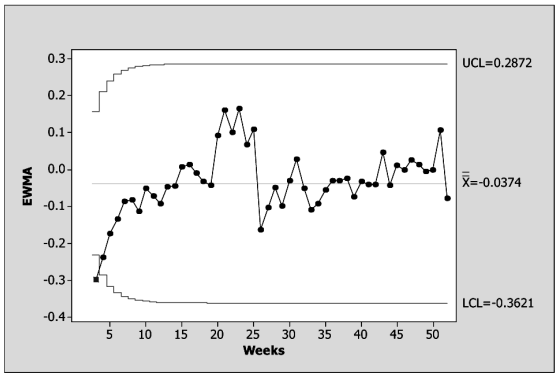

Figure 3 (b) : EWMA Chart of weekly maximum Co for Urban area

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