Proceedings of the 2015 International Conference on Industrial Engineering and Operations Management
Dubai, United Arab Emirates (UAE), March 3 – 5, 2015

Using Statistical Process Control Charts for Monitoring Birth Weight at a National Level

Jawahir Abdalla Alali
Dubai Electicity & Water Authority
Sharjah, UAE

Hamdi Bashir and Fikri Dweiri
Department of Industrial Engineering and Engineering Management, University of Sharjah
Sharjah, UAE

Mariam Salim Khalfan Alalili
315-445 Vigerv west, Montreal, Canada

Amal Yousuf Al-Kubaisi
Qatar General Electricity &Water Cooperation
Doha, Qatar

Abstract— **Birth weight is a key public health indicator that needs to be monitored regularly. However, in the United Arab and worldwide, there is currently no systematic procedure for monitoring shifts or trends in the mean and variability of birth weight at a national level. For this purpose, it is proposed to use statistical process control charts (SPC). This is illustrated through developing SPC charts for monitoring the birth weight of UAE nationals. The developed control charts indicated that the birth weight of UAE nationals is in statistical control. The national mean birth weight, standard deviation of birth weights, percentage of low birth weight, and percentage of high birth weight were estimated to be 3.208 kg, 0.445 kg, 5.59%, and 0.19%, respectively.**

Keywords— Health care; birth weight; control charts

I. Introduction

In most countries, a significant proportion of health care expenditure is spent on people with chronic diseases such as heart disease and stroke, cancer, diabetes, obesity, and respiratory diseases. For instance, according to the study conducted by the Emirates Diabetes Society in collaboration with Johnson & Johnson in 2008, UAE spends every year AED 6 billion on the diabetes patients, and it's expected to rises to AED 31 billion in 2020 [1].

UAE ranked as the second highest rate of diabetes in the world by the spread of between 7.18% - 24% [2], one out of every four citizens has diabetes, at a rate of roughly 20 % for residents, 25% for Emirati nationals [3], and in general 95% of diabetes cases in UAE fall into type 2 [4].

One of the determinants of type 2 diabetes is birth weight, defined as the first weight of a newborn obtained after birth. For live births, birth weight should be measured within the first hour of life before significant postnatal weight loss has occurred. Several studies have reported that genetic and environmental factors affect birth weight [5]. These factors contribute to birth weight variability. According to the World Health Organization (WHO), birth weight is considered normal if it is between 2.5 kg and 4.5 kg. Infants born weighing less than 2.5 kg are considered low birth weight, whereas infants born weighing more than 4.5 kg are considered high birth weight.

Low birth weight is a public health problem in most countries. According to the United Nations Administrative Committee on Coordination, incident rates of low birth weight >15% indicate a major public health problem. It has been estimated that more than 20 million infants worldwide are born with a low birth weight, with almost 70% of such births in Asia [6]. Babies with a low birth weight have an increased risk of short- and long-term complications. For instance, they are four to six times more susceptible to physical and mental handicaps and eight to 10 times more likely to die in the first year of life. Moreover, children who were of low birth weight are 1.6 times more likely to be underweight compared to those children who had a normal birth weight [7]. According to a number of studies, infants with a low birth weight appear to have a high risk of developing Type 2 diabetes later in life [8]. Other studies have shown that infants with a low birth weight <2.5 kg have deficits in average intelligence test scores at school age.

Many studies have demonstrated an increased risk of short- and long-term complications not only in infants with a low birth weight but also in those with a high birth weight. Infants with a high birth weight had a higher risk of stillbirth, birth asphyxia, Erb's palsy, fracture of the clavicles, and admission to special care baby units. High birth weight infants were shown to have a greater risk of delivery by caesarean section. They also had an increased risk of being overweight in adolescence [9]. Being overweight is a primary risk factor for type 2 diabetes

II. Motivation and Research Objectives

It can be inferred from the aforementioned complications that birth weight is a key public health indicator. Low and high birth weights can result in substantial costs to the health sector and impose a significant burden on the economy of any nation. Unfortunately, no estimation of cost could be found regarding the complications of low and high birth weights in the United Arab Emirates (UAE). Moreover, a review of literature revealed that currently in the UAE and worldwide there is no systematic procedure in place for monitoring shifts or trends in the mean and variability of birth weight at a national level. Such a procedure could help to minimize the percentage of infants with low and high weight in a nation and thus the associated complications that have a negative impact on individuals' health and, consequently, the economic and social development of a nation. In response to this need and motivated, in part, by the fact that birth weight is a quality characteristic where variability is associated with chance and assignable causes, this paper reports on work done to construct statistical process control (SPC) charts to monitor shifts or trends in the mean and variability of a nation's birth weight. An additional objective of this work was to provide answers to the following questions:

1. What is the estimated national average birth weight?
2. What is the estimated standard deviation of birth weight?
3. What is estimated the percentage of infants born at low birth weight?
4. What is estimated the percentage of infants born at high birth weight?

III. Related Research

SPC charts were developed by Shewhart in the 1930s for monitoring changes in process variables in manufacturing. However, the number of applications of SPC control charts in domains outside manufacturing has been increasing in the last two decades. These domains include the environment, general service sector, and health care applications.

Since the early 1990s, there has been increasing interest in the applications of SPC charts in different healthcare areas, including public health surveillance at community and hospital levels, benchmarking of hospital performance [10], detecting variations in the outcome of pneumonia patients [11], monitoring the performance of an HIV test [12], monitoring the long-term performance of a clinical chemistry laboratory [13], monitoring peak expiratory flow rate in asthma patients [14], monitoring trends in trauma mortality [15], monitoring the effect of performance improvement in an anesthesia department [16], determining the effects of the introduction of a new monitoring system for fluid absorption [17], monitoring surgical performance [18].

Details on the above applications of SPC charts are not given; they may be referred to in the relevant literature. In the following, a brief review is given on the study by Caron and Neuhauser [19], the most relevant work to the research presented in this paper.

Using specific examples, Caron and Neuhauser [19] explained how to monitor hospital management processes using different types of control charts for key qualitative characteristics and how to link these with the mission, vision, values, and structure of organizations. The clinical key quality characteristics include congestive heart failure, birth weight, and chronic obstructive pulmonary disease. In the birth weight example, the authors constructed a p chart to monitor the rate of low birth weight infants using historical monthly data collected from a hospital for one year. These data then were compared with findings in a previous year. However, there are no details given on the characteristics of the collected data. Most importantly, using the "rate of low birth weights" as an indicator of public health is more useful than using it for monitoring hospital management processes.

IV. Developing SPC Charts for Monitoring Birth Weight

There are several types of control charts, but they are often classified under two major categories: control charts for variables and control charts for attributes [20].

Control charts for variables include:

- $\bar{x}$-R Charts: The $\bar{x}$ and R charts are a type of control charts used to monitor a variable's data when samples are collected at regular intervals from a business or industrial process, these charts used when sample size is < 10.
- $\bar{x}$-s Charts: The $\bar{x}$ and s charts are a type of control charts used to monitor a variables data when samples are collected at regular intervals from a business or industrial process, these charts used when sample size is ≥ 10.

Control charts for attributes include:

- p-Chart: It is a type of control chart used to monitor the proportion of nonconforming units in a sample, where the sample proportion nonconforming is defined as the ratio of the number of nonconforming units to the sample size, n.
- np-Chart: It is a type of control chart used to monitor the number of nonconforming units in a sample. It is an adaptation of the p-chart and used in situations where personnel find it easier to interpret process performance in terms of concrete numbers of units rather than the somewhat more abstract proportion.
- c-Chart: The c-chart is a type of control chart used to monitor "count"-type data, typically total number of nonconformities per unit. It is also occasionally used to monitor the total number of events occurring in a given unit of time. c-charts are used to monitor the number of defects per unit.
- u-Chart: The u-chart is a type of control chart used to monitor "count"-type data where the sample size is greater than one, typically the average number of nonconformities per unit.

The choice of which control chart to use depends on the type of data that will be collected. The design parameters of a control chart include the sample size, the frequency of sampling, and control limits. A typical control chart contains:

- A center line that represents the mean value of the quality characteristic corresponding to the in-control state
- Upper control limit (UCL)
- Lower control limit (UCL)

The development of control charts involves two major phases. In the first phase, past data are analyzed to establish control limits and center lines. Once a set of reliable control limits is established, the control charts can be used for future monitoring. This is called the implementation phase (Phase 2). These phases are illustrated below by developing $\bar{x}$ and s charts for monitoring the birth weight of United Arab Emirates (UAE) nationals. These types of charts were selected since birth weight is a measurement that can assume any value. $\bar{x}$ chart is used for monitoring birth weight mean, whereas s chart is used for monitoring birth weight variability.

Phase 1 involves the following steps:

1. Select a number of random samples, m, with each containing n observations on the quality characteristic. There is agreement in the literature that 20 to 30 subgroups, with at least 20 in each, is optimum. In this study, taking into account the availability of data, 25 subgroups, each with 30 observations, were obtained from the birth records of a public hospital in Dubai between January 1, 2007, and December 31, 2012. The interval of time between the subgroups was three months. The first 20 subgroups were used for Phase 1, and the remaining five subgroups were used for Phase 2. The characteristics of the collected data and assumptions underlying their use are described below:
   - Constructing control charts requires collecting data from a homogeneous source of variation. Although full homogeneity is not achievable, it can be maximized. In this study, homogeneity was maximized by collecting birth weight data from UAE citizens with single birth babies born at 37 to 42 weeks (normal full-term pregnancy).
   - The data were collected by different people and probably using different devices. It was assumed that the collected data were reasonably accurate and consistent.
   - As the hospital where the data were collected provides maternity services for women living not only in Dubai but also in several other cities in the UAE, the data collected from this hospital were assumed to be representative of the entire population.
2. Compute the center lines and the upper and lower trial control limits for the charts using equations (1) and (2) below.

   The control limits for the s chart are as follows:

   $$\text{UCL} = B_4\bar{s},\quad \text{Center line} = \bar{s},\quad \text{LCL} = B_3\bar{s}. \tag{1}$$

   The control limits for the $\bar{x}$ chart are as follows:

   $$\text{UCL} = \bar{\bar{x}} + A_3\bar{s},\quad \text{Center line} = \bar{\bar{x}},\quad \text{LCL} = \bar{\bar{x}} - A_3\bar{s}. \tag{2}$$

   Where:

   $\bar{\bar{x}}$ = the average grand $= \frac{\bar{x}_{1+}\bar{x}_{2+}\ldots\bar{x}_m}{m}$

   $\bar{x}_1, \bar{x}_2, \ldots \bar{x}_m$= the average of each sample

   $\bar{s}$ = the average of m standard deviations

   $A_3, B_3,$ and B_4 = constants tabulated for various sample sizes in [20].

   The calculated control limits for the $\bar{x}$ chart using equation 1 were:

   UCL = 3.451 kg,

   LCL = 2.965 kg.

   The calculated control limits for the s chart using equation 2 were:

   UCL = 0.615 kg,

   LCL = 0.266 kg.
3. Plot the values of each sample on the charts and analyze the resulting display. If all the points of the plot are within control limits, and no systematic behavior is evident using sensitizing rules known as Western Electric rules, it can be concluded that the process was in control in the past and that the trial control limits are suitable for current or future monitoring. It is worth mentioning that according to Western Electric rules, the process is out of control if either :
   - One data point falls outside the 3σ control limits;
   - Two out of three consecutive points fall beyond the 2σ warning limits;
   - Four out of five consecutive points fall at a distance of 1σ or beyond from the centre line;

     or
   - Eight consecutive points fall on the same side of the centre line.
4. If the process appears to be out of control, the control limits must be revised. This is done by examining each of the out-of-control points, looking for an assignable cause. If an assignable cause is found, the corresponding point/points can be discarded, and the process can proceed to step 2. If no assignable cause is found, there are two choices: Eliminate the out-of-control point/points and proceed to step 2, or keep the out-of-control point/points and use the trial control limits for future monitoring. As shown in Fig. 1, as the plotted s and $\bar{x}$ charts exhibit control, it can be concluded that the process is in control and that the trial control limits can be used for future monitoring. The resulting charts are then used in Phase 2 for future monitoring.

To demonstrate the implementation phase, four additional samples were collected and plotted in continuations on the $\bar{x}$ and s charts, as shown in Fig 2. By applying the Western Electric rules, it can be concluded that the process is in control.

The above brief outline of the development of SPC Charts presented only to highlight certain salient features. The detailed mathematical elaboration may be referred to in the relevant literature. Special attention is directed to [20].

V. USEFUL ESTIMATIONS

Once the process is found to be in control, using simple formulas found in any statistical control textbook, several useful estimations can be made. These include the national mean birth weight, standard deviation of birth weight, percentage of infants born at low birth weight, and percentage of infants born at high birth weight. For UAE nationals, the estimated national mean birth weight, standard deviation of birth weight, percentage of infants born at low birth weight, and percentage of infants born at high birth weight were found to be 3.208 kg, 0.445 kg, 5.59%, and 0.19%, respectively.

The data can also be used to determine the average run length, which detects shifts in the birth weight mean. For instance, if the national birth weight mean shifts to a critical value, this shift will be detected, on average, after about six months (two samples). It is worth mentioning that the birth weight mean becomes critical if the corresponding estimate of low birth weight percentage reaches 15%. For UAE nationals, the estimated critical birth weight was 2.963 kg.

VI. CONCLUSIONS

Many chronic diseases are preventable and can be managed by monitoring and controlling their associated determinants through the use of a public health surveillance system.

Although, they have been originally developed for monitoring changes in process in Manufacturing, SPC charts have been proven effective in other domains including health care.

Motivated, in part, by the fact that birth weight is a quality characteristic with variability associated with chance and assignable causes, this paper described the development of $\bar{x}$ and s charts for monitoring shifts or trends in the mean and variability of birth weight at a national level, using the UAE as an example.

Such charts have several uses. For instance:

- Decision makers can easily detect changes in the nation's mean birth weight, investigate the causes, and take appropriate action.
- The charts can be used as an indicator of health care quality at the national level.
- They may help decision makers to determine the effectiveness of implemented plans taken to solve problems concerning birth weight.

However, since it takes a long time until adjusting the process to in-control level, a SPC chart might continue to provide alarms after its first alarm. This is perhaps one of the differences between using the SPC charts for monitoring birth weight versus using them for monitoring a quality characteristic in manufacturing.

It is worth mentioning that the main purpose of this paper was to demonstrate the use of control charts as a useful tool for monitoring birth weight. These charts are easy to construct with several statistical software packages, such as Minitab and SPSS. Thus, they are easy for health practitioners to use.

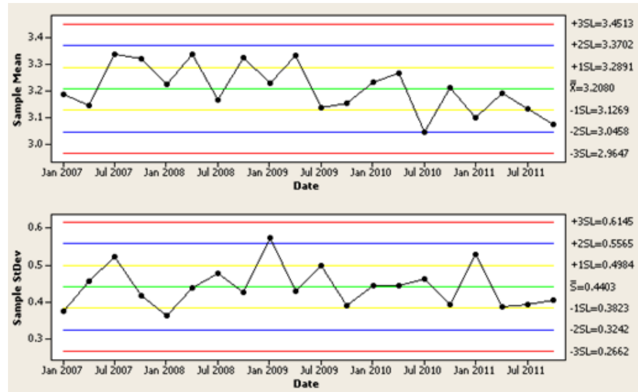

Fig. $\bar{x}$ and s Control Charts of Birth Weight

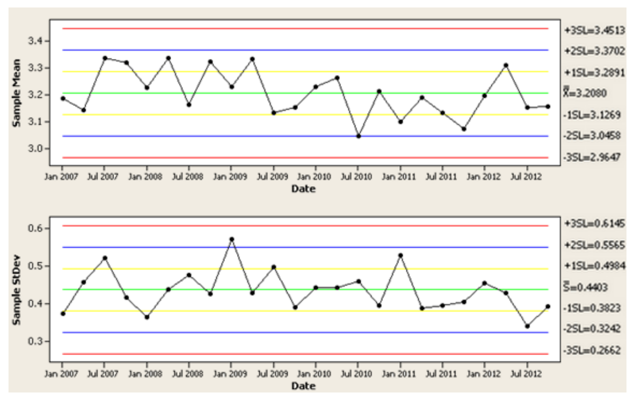

Fig. 2. Continuation of the $\bar{x}$ and s Charts of Birth Weight

REFERENCES

[1] M. Al Khatib. (2011). *AED 6 billion annual cost of treating patients with diabetes in the UAE.* Alkhaleej [online]. Available: http://www.alkhaleej.ae/portal/2e0970d4-9f93-4bf3-a490-8728bc136199.aspx

[2] M. Ibrahim .(2011). *UAE Second in the World in the Prevalence of Diabetes*. Alkhaleej [online]. Available: http://www.alkhaleej.ae/portal/f1645798-51f4-42d3-b38e-1583fd368f7a.aspx.

[3] L. Setrakian. (2007). *UAE and Diabetes: One in Four Has It.* ABC News [online] Available: http://abcnews.go.com/Health/Diabetes/Story?id=4044952&page=1#.T5cwDqsb8-A

[4] L. Clarke (2011). *Diabetes: A Lifestyle to Die for*. [online] Available: http://gulfnews.com/life-style/health/diabetes-a-lifestyle-to-die-for-1.920903

[5] D. Pope et al., "Risk of low birth weight and stillbirth associated with indoor air pollution from solid fuel use in developing countries," *Epidemiol Rev*., vol. 32, no. 1, pp. 70-81, 2010

[6] UNICEF, The State of the World's Children. UNICEF, New York. USA

[7] S. Hasnain and S. Hashmi, "Consanguinity among the risk factors for underweight in children under five: a study from rural Sindh," *J. Ayub Med. Coll.*, vol. 21, no. 3, pp. 111-116, 2009.

[8] M. Gillman et al., "Maternal Gestational Diabetes, Birth Weight, and Adolescent Obesity," *Pediat.,* vol. 111, no. 3, pp.221- 226, 2003.

[9] S. Wassimi et al., "Association of macrosomia with perinatal and postneonatal mortality among First Nations people in Quebec," *Can. Med. Assoc. J.*, vol. 18. no. 3, pp. 322-626, 2011.

[10] W. Woodall, "The Use of Control Charts in Health-Care and Public-Health Surveillance," ***J. Qual. Technol.,*** vol. 38, no. 2, pp. 89-104, 2006.

[11] R. Hand et al., "Use of statistical control charts to assess outcomes of medical care: pneumonia in Medicare patients," ***Am. J. Med. Sci,*** vol. 307, no. 5 pp. 329-34, 1994.

[12] R.C. Gentelman et al., "Statistical quality control of HIV-1 ELISA test performance," ***J. Am. Statist. Assoc.,*** vol.89, no. 428, pp. 1200-1208.

[13] D. Chesherand L. Burnett, "Using Shewhart *p* control charts of external quality-assurance program data to monitor analytical performance of a clinical chemistry laboratory," *Clin. Chem*., vol. 42, no. 9, pp. 1478-1482,1996.

[14] P.B. Boggs et al., "Peak expiratory flow rate control chart in asthma care: chart construction and use in asthma care". ***Ann. of Allergy Asthma, and Immunol.***, vol. 81, no. 6, pp. 552-62, 1998.

[15] D.E. Clark et al. "Monitoring hospital trauma mortality using statistical process control methods," ***J. Am. Coll. Surg***., Vol. 186, No. 6, pp. 630-635, 1998.

[16] T.S. Vitzand and A., Marcio "Setting performance standards for an anesthesia department," ***J .Clin. Anaesthesia***, vol. 10, March, pp. 166-175, 1998

[17] C. Konard et al., "Transurethral resection syndrome: effect of the introduction into clinical practice of a new method for monitoring fluid absorption," ***J. Clini. Anesthesia***, vol. 10, pp. 360-365, 1998.

[18] E.H. Blackstone, "Monitoring surgical performance," ***J. Thorac.*** Cardiovasc. Surg., vol. 128, pp. 807–810, 2004.

[19] A. Caron and D. Neuhauser, "Health care organization improvement reports using control charts for key quality characteristics: ORYX measures as examples," ***Qual. Manage. Health Care***, vol. 9, no. 3, pp. 28-39, 2001

[20] D. Montegomery, *Introduction to Statistical Quality Control*. New York: John Wiley, 2009

BIOGRAPHIES

Jawahir Abdalla Alali received a B.Sc. degree in Industrial Engineering and Management from the University of Sharjah, United Arab Emirates (UAE) in 2012. Currently, she works in Dubai Electricity & Water Authority, Sharjah, UAE. Ms. Alali was one of three team members who won the second prize of the 2013 "Tamiaz & Falak Tayyeb" Award in the Society and Environment Category. Health care operations management and nontraditional applications of statistical process control charts are her main areas of research interest.

Hamdi Bashir received his Ph.D. degree from McGill University, Montreal, Canada. He is currently an associate professor in the Department of Industrial Engineering and Engineering Management, University of Sharjah, UAE. Prior to that, Dr. Bashir held faculty positions at Concordia University, University of Alberta, and Sultan Qaboos University. His current research interests are in the areas of project management, health care operations management, quality management, logistics, and cellular manufacturing systems. Dr. Bashir is a senior member of the Institute of Industrial Engineers (IIE).

Fikri Dweiri holds a PhD in Industrial Engineering from the University of Texas at Arlington. He is an Associate Professor and serves as Vice Dean of the College of Engineering and Acting Chairman of the Industrial Engineering and Engineering Department at the University of Sharjah, UAE. He has also served as Dean of the School of Technological Sciences at the German-Jordanian University. Dr. Dweiri was the Founding Chairman of the Industrial Engineering Department at Jordan University of Science and Technology. His interests include quality management and organization performance excellence, multi-criteria decision making and fuzzy logic.

Mariam Salim Khalfan Alalili obtained her B.Sc. degree in Industrial Engineering and Management from the University of Sharjah, UAE in 2012. Mrs. Alalili was one of three team members who won the second prize of the 2013 "Tamiaz & Falak Tayyeb" Award in the Society and Environment Category. Her research interests include healthcare operation management and nontraditional applications of statistical process control charts.

Amal Yousuf Al-Kubaisi received a B.Sc. degree in Industrial Engineering and Management from the University of Sharjah, UAE in 2012. She is currently an Industrial Engineer in the Qatar General Electricity &Water Cooperation Doha, Qatar. Mrs. Al-Kubaisi was one of three team members who won the second prize of the 2013 "Tamiaz & Falak Tayyeb" Award in the Society and Environment Category. Health care operations management and nontraditional applications of statistical process control charts are her main areas of research interest.