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Process Monitoring with Individual Measurements: A Case Study in Corrugated Cardboard Industry

Bireysel Ölçümler ile Proses İzleme: Oluklu Mukavva Endüstrisinde Bir Örnek Çalışma

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Abstract
Monitoring production processes with statistical process control charts can provide useful information about the process. This application aims to reveal whether the production process is in control in terms of the data of the bursting strength through exponentially weighted moving average (EWMA) and individual-moving range (I-MR) control charts. Both EWMA chart and I-MR charts were created using the bursting strength data provided from an enterprise for a certain period of time. Within the scope of the study, a total of 126 data belonging to the bursting strength were used to create the control charts. In the creating of the EWMA chart, the weighting factor (λ) was chosen as 0.2. The results of all univariate process monitoring tools considered within the scope of the study showed that the production process was out of control in terms of the bursting strength. In other words, EWMA and I-MR charts were able to effectively detect the variations for the data set belonging to the quality variable under study. It was seen that the charts can be applied to the production process as effective signal detection and process control or monitoring tools in terms of the quality variable of interest.

Özet
İstatistiksel proses kontrol grafikleri ile üretim proseslerini izleme proses hakkında yararlı bilgiler sağlayabilir. Bu uygulama, üstel ağırlıklı hareketli ortalama (EWMA) ve bireysel-hareketli aralık (I-MR) kontrol grafikleri aracılığıyla patlama direnci verileri açısından üretim prosesinin kontrolde olup olmadığını ortaya koymayı amaçlamaktadır. Hem EWMA grafiği hem de I-MR grafikleri belirli bir zaman periyodu için bir işletmeden sağlanan patlama direnci verileri kullanılarak oluşturulmuştur. Çalışma kapsamında, patlama direncine ait toplam 126 veri kontrol grafiklerini oluşturmak için kullanılmıştır. EWMA grafiğinin oluşturulmasında, ağırlık faktörü (λ) 0.2 olarak seçilmiştir. Çalışma kapsamında dikkate alınan tüm tek değişkenli süreç izleme araçlarının sonuçları, üretim prosesinin patlama direnci açısından kontrol dışı olduğunu göstermiştir. Diğer bir ifadeyle, EWMA ve I-MR grafikleri, çalışma altındaki kalite değişkenine ait veri seti için değişkenlikleri etkili bir şekilde tespit edebilmiştir. Grafiklerin, ilgilenilen kalite değişkeni açısından etkili sinyal tespit ve süreç kontrol veya izleme araçları olarak üretim sürecine uygulanabildiği görülmüştür.

INTRODUCTION

A corrugated cardboard generally consists of a corrugated layer sandwiched between two liner layers (Gok and Akpinar 2020). Its structure comprises odd layers, and their numbers are usually three or five. Inner and outer surfaces consist of a flat paper layer with a corrugated layer in between to achieve the necessary rigidity. It is possible to classify flat layers into different categories in terms of fiber content and strength properties. In the classification, kraftliner represents the group which contains primary cellulose fibers (Pidl et al. 2022). It was reported that the corrugated cardboard is often used in packaging because of its advantages such as its sturdiness and lightweight. However, it is worth mentioning that in such a use, its ability to resist lateral forces during handling, transportation and storage is of critical importance in terms of preserving its structural integrity (Boaca et al. 2024). Undoubtedly, efficacious and continuous control or monitoring of quality variables of product or product components in production may contribute to meeting this expectation or requirement.

A control chart is essentially a graphical representation that shows how the variable values change versus the number of samples (Rifki et al. 2024). In other words, control charts make it possible to plot the statistics belonging to key quality variables that affect the quality of a process or product over time. With a general comment, if any of the statistics of the quality variable

exceeds the limits of chart, it is perceived as a sign of variability that needs to be taken into consideration or that may require action (Zwetsloot et al. 2024).

It was noted that control charts can offer the advantage of providing greater efficiency in production, reducing defects and faulty production, increasing profit and reducing costs (Şengöz 2018). Another benefit of control charts is that they help practitioners distinguish between common and assignable causes of variation (Haq and Khoo 2020). It is possible to mention that process variations are broadly categorized into two branches as common-cause and assignable-cause variations. If a process works only in the impact of common causes, it is said to be in control, while if it operates in the presence of assignable causes, it is described as out of control. In statistical process control literature, similar to the binary classification in the sources of variation, a classification can be made as the memory-less charts and the memory-type charts about control charts. The former is generally renowned for its effective use in determining large changes in the process while the latter is often used for monitoring small and moderate ones (Alevizakos et al. 2024).

The EWMA control chart is a well-known tool for process monitoring and was introduced by Roberts (1959). The ability to quickly detect small and moderate level shifts is known as the main advantage of this chart (Maravelakis and Castagliola 2009). To date, it has been widely used for many purposes in various fields, sometimes alone and sometimes in combination with other techniques. For example, Ramesh and Vasu (2019) tried EWMA control chart in paper industry. Kurt and Karayılmazlar (2021) monitored the tensile strength of particleboard by using EWMA control chart. Abdallah et al. (2021) benefited from EWMA chart to track packaging defects in food industry. Febrina and Fitriana (2022) employed the EWMA chart for quality control of crude palm oil product. Tiryaki (2025) applied the EWMA chart to monitor the changes in the density of MDF.

The I-MR control charts are varieties of Shewhart charts, and it is possible to say that the use of them is appropriate when the subgroup size is equal to 1 (Jin et al. 2022). Literature research has revealed that these charts were employed for different objectives, some examples of which were given below. Mutlu and Altuntaş (2021) aimed to monitor technological changes through the I-MR charts based on patent data. Kurt (2022) employed the I-MR control charts combined with artificial neural network for particleboard screw withdrawal strength values. Essam Eissa (2024) tried the I-MR charts to monitor the quality in medicinal chemical industry. In another study, Erdoğan and Torman (2024) analyzed the causes of deforestation in Türkiye by various techniques, including the I-MR.

The current literature reveals the need for research on monitoring the bursting strength data in the papermaking industry using EWMA and I-MR control charts. On the other hand, considering the above literature knowledge, it is possible to claim that control charts may be useful in monitoring the bursting strength data of the quality variable under study and in understanding whether the process is out of control. Hence, this research aims to build the EWMA and I-MR charts to monitor the variability of the bursting strength data provided from an enterprise.

QUALITY TOOLS

EWMA Control Chart

The EWMA approach is often used for detecting quickly them relative to a Shewhart control chart in case of small degrees of shifts. The traditional EWMA chart is created based on the following statistic (Mitra et al. 2019).

$$\mathrm{Z_i} = \lambda X_\mathrm{i} + (1-\lambda) Z_{\mathrm{i}-1} \quad (1)$$

where , λ is a constant greater than zero and less than or equal to 1, and the starting value (at *i = 1*) is the process target ($Z_0 = \mu_0$). Sometimes, the mean of the preliminary data is taken into account as the starting value ($Z_0 = \bar{x}$). The CL (center line), UCL (upper control limit) and LCL (lower control limit) for the EWMA are as in equations 2-4. It is necessary to specify that *L* represents the width of the control limits in equations (Montgomery 2012).

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

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

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

When large values of *i* are considered, it is possible to state that EWMA limits converge to the constant limits given in equations 5-7 (Abbas et al. 2011).

$$\mathrm{UCL} = \mu_0 + \mathrm{L}\sigma\sqrt{\frac{\lambda}{(2-\lambda)}} \quad (5)$$

$$\mathrm{CL} = \mu_0 \quad (6)$$

$$\mathrm{LCL} = \mu_0 - \mathrm{L}\sigma\sqrt{\frac{\lambda}{(2-\lambda)}} \quad (7)$$

The EWMA considers both the current and historical or past information and is useful for capturing small to moderate shifts (Naveed et al. 2018).

I-MR Control Chart

The traditional Shewhart charts were introduced by Walter Shewhart in 1924 and have subsequently been employed in various manufacturing and service industries. The charts based on sample mean, range, standard deviation, individual data and moving range can be expressed as widely employed control charts. In cases where subgroup size is 1, it is appropriate to monitor the process based on individual observations (Mitra 2016, Mitra et al. 2019). Similar to the situation in the mean-range ($\bar{x}$-R) and mean-standard deviation ($\bar{x}$-*s*) charts, I-MR charts can be used simultaneously to monitor the mean and variance of the process, respectively, requiring the creation of two separate charts (Khoo et al. 2006). The MR of two successive measurements is computed as formulated below (Montgomery 2012).

$$\mathrm{MR}_i = |\mathrm{x}_i - \mathrm{x}_{i-1}| \quad (8)$$

For the I-chart, the UCL, CL and LCL can be calculated using the following formulas (Işığıçok 2012).

$$\mathrm{UCL} = \overline{\mathrm{X}} + 3\frac{\overline{\mathrm{MR}}}{\mathrm{d}_2} \quad (9)$$

$$\mathrm{CL} = \overline{\mathrm{X}} \quad (10)$$

$$\mathrm{LCL} = \overline{\mathrm{X}} - 3\frac{\overline{\mathrm{MR}}}{\mathrm{d}_2} \quad (11)$$

For the MR-chart, the calculation formulas for the UCL, CL and LCL are as below (Mitra 2016).

$$\mathrm{UCL} = \mathrm{D}_4\overline{\mathrm{MR}} \quad (12)$$

$$\mathrm{CL} = \overline{\mathrm{MR}} \quad (13)$$

$$\mathrm{LCL} = \mathrm{D}_3\overline{\mathrm{MR}} \quad (14)$$

It is possible to note that D_3, D_4, d_2 are constants that depend on the sample size (Montgomery 2012).

MATERIAL AND METHOD

Material

In this study, a statistical process control application was carried out using the bursting strength data provided from an enterprise. It was noted that kraftliner is a type of paper with high strength values and is generally obtained from long-fiber coniferous trees such as spruce, fir, and pine. It can be used on the surface of corrugated cardboard (Dalgıç 2020). Within the scope of the study, the production process of kraftliner under investigation was explored in terms of the bursting strength data (kPa).

Method

Research Variable

It was noted that the kraftliner is generally required to have high bursting strength (Tuncer 2010). The burst strength was reported as one of the most representative tests for the mechanical characteristics of paperboard (Bota et al. 2017). It was also mentioned that the bursting strength of the corrugated board is among the most important tests in the packaging industry (Garbowski et al. 2021). In this regard, it can be claimed that the data of

bursting strength can be important in evaluating the product quality or performance. In the current study, the bursting strength characteristic, which may be have an effect on the quality of the product, was taken into account as the quality variable.

Data Acquisition

The bursting strength data were considered in analyzing the process with control charts. A total of 126 samples were used for this quality variable. The data set for the analysis includes the bursting strength data provided from the enterprise for a period between 23 March 2022 and 12 June 2022. During this time period, the tests of the relevant quality variable were performed intermittently. Furthermore, special attention was paid to using the data with the recorded measurement day and time in the analyses since otherwise the chart results may be affected.

Design and Interpretation of Charts

Within the scope of this study, a total of 126 measurements or data of the bursting strength quality variable were employed in creating the EWMA and I-MR charts. Çubukçu (2021) pointed out that the λ, weighting factor, forms the backbone of the EWMA approach. Hamasha et al. (2023) emphasized that the choice of λ in the EWMA chart plays a key role in determining the sensitivity of the chart to detect process shifts. In another study, it was reported that small values of λ are more suitable for determining small shifts while medium and large values are more effective in capturing medium and large-scale shifts, respectively (Alevizakos et al. 2024). Çubukçu (2020) noted that the high values of λ hinders the effectiveness of EWMA in capturing small systematic shifts. In the present study, λ, was taken as 0.2 in the EWMA chart, and the chart was constructed based on this value. Montgomery (2012) reported that this value of λ is one of the most popular choices.

The basic criterion for assessing the control status of a process is whether one or more points lie outside the control limits. In this regard, a point falling outside the control limits is interpreted as evidence that the process is out of control. On the other hand, additional criteria are sometimes used to increase the sensitivity of Shewhart control charts (Montgomery 2012). In the current study, the basic criterion outlined above was adopted in interpreting the charts or process in terms of the quality variable under study, and any point outside the control limits was interpreted as a sign that the process was out of control. In other words, no additional criteria or rules for the charts were taken into account within the scope of the study. Minitab software was used in the construction of all charts.

RESULTS AND DISCUSSION

Assessment of EWMA Results

To monitor the bursting strength variable in the production process of the product under study, a data set with sample size 1 and the data or sample number 126 was provided. The EWMA chart was employed to trace whether the measured values of quality variable is in a status of control or out-of-control. In the current study, λ, an important parameter in the design of the EWMA chart, was chosen as 0.2. The EWMA chart created using this value of λ was presented in Figure 1.

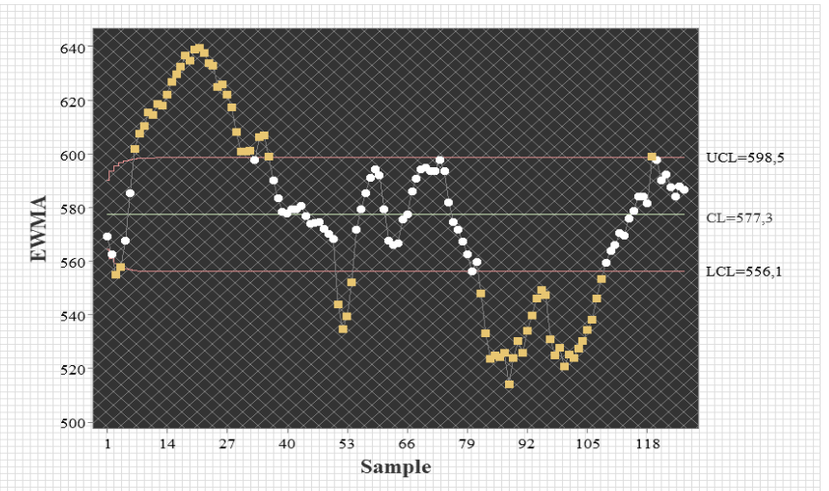


Figure 1. EWMA chart for bursting strength data

When Figure 1, which depicts the results of monitoring the data of the bursting strength variable with the EWMA chart, is examined, it is noticeable that there is a significant amount of data beyond the limits. It was noted that if any value of the EWMA statistic surpasses the limits of the control chart, the process is considered to be out of control (Çubukçu 2020). Therefore, it is possible to define the EWMA control chart as out of control in terms of the considered data set. Table 1 gives more detailed information about the EWMA control chart.

Figure 1 and Table 1 indicates that both the UCL and LCL of the EWMA control chart become almost constant after a certain number of samples were taken into account. It was reported in Montgomery (2012) that after the EWMA chart has been operating for a series of periods of time, its limits approach steady-state values. From Figure 1, it is also possible to conclude that the variability of the bursting strength data is high. Besides, it is noteworthy that in the first half of the chart, most of the out-of-control data points are above the UCL, while in the second half of the chart, the vast majority of the out-of-control data points are below the LCL. Alevizakos et al. (2024) stated that the EWMA is one of the most popular memory-type charts and its statistic is based on both the current and past samples.

Assessment of I-MR Results

In this research, an I-MR control chart was also created to observe the variability of the data of the bursting strength, and it was presented in Figure 2.

It is possible to see in Figure 2 for the I-chart that UCL is 641.0, LCL is 513.6 and CL is 577.3. For the MR-chart, the values of UCL, LCL and CL are 78.3, 0 and 24.0, respectively. It is clear that there are data points outside the limits in both the I and MR charts, indicating that the process is out of control for the quality variable under consideration. On the other hand, it was noted that Shewhart-type charts, which are known as memoryless-type control charts, employes only the most recent observations and forget past information (Chaudhary et al. 2023). More detailed information about the I-MR charts can be found in Table 2 below.

When Figure 2 and Table 2 obtained as a result of monitoring the bursting strength values with I-MR control charts are examined, it is possible to see that 20 of a total of 126 data marked in the I-chart are outside the limits, in other words, either above UCL or below LCL. It is understood that the distribution of out-of-control data is balanced.

Table 1. Information about the EWMA chart

Data no	LCL	UCL	Control status	Data no	LCL	UCL	Control status	Data no	LCL	UCL	Control status
1	564.5	590.0	IC	**43**	556.1	598.5	IC	**85**	556.1	598.5	OCC-
2	561.0	593.6	IC	**44**	556.1	598.5	IC	**86**	556.1	598.5	OCC-
3	559.0	595.5	OCC-	**45**	556.1	598.5	IC	**87**	556.1	598.5	OCC-
4	557.9	596.7	OCC-	**46**	556.1	598.5	IC	**88**	556.1	598.5	OCC-
5	557.2	597.3	IC	**47**	556.1	598.5	IC	**89**	556.1	598.5	OCC-
6	556.8	597.8	IC	**48**	556.1	598.5	IC	**90**	556.1	598.5	OCC-
7	556.5	598.0	OCC+	**49**	556.1	598.5	IC	**91**	556.1	598.5	OCC-
8	556.4	598.2	OCC+	**50**	556.1	598.5	IC	**92**	556.1	598.5	OCC-
9	556.2	598.3	OCC+	**51**	556.1	598.5	OCC-	**93**	556.1	598.5	OCC-
10	556.2	598.4	OCC+	**52**	556.1	598.5	OCC-	**94**	556.1	598.5	OCC-
11	556.1	598.4	OCC+	**53**	556.1	598.5	OCC-	**95**	556.1	598.5	OCC-
12	556.1	598.5	OCC+	**54**	556.1	598.5	OCC-	**96**	556.1	598.5	OCC-
13	556.1	598.5	OCC+	**55**	556.1	598.5	IC	**97**	556.1	598.5	OCC-
14	556.1	598.5	OCC+	**56**	556.1	598.5	IC	**98**	556.1	598.5	OCC-
15	556.1	598.5	OCC+	**57**	556.1	598.5	IC	**99**	556.1	598.5	OCC-
16	556.1	598.5	OCC+	**58**	556.1	598.5	IC	**100**	556.1	598.5	OCC-
17	556.1	598.5	OCC+	**59**	556.1	598.5	IC	**101**	556.1	598.5	OCC-
18	556.1	598.5	OCC+	**60**	556.1	598.5	IC	**102**	556.1	598.5	OCC-
19	556.1	598.5	OCC+	**61**	556.1	598.5	IC	**103**	556.1	598.5	OCC-
20	556.1	598.5	OCC+	**62**	556.1	598.5	IC	**104**	556.1	598.5	OCC-
21	556.1	598.5	OCC+	**63**	556.1	598.5	IC	**105**	556.1	598.5	OCC-
22	556.1	598.5	OCC+	**64**	556.1	598.5	IC	**106**	556.1	598.5	OCC-
23	556.1	598.5	OCC+	**65**	556.1	598.5	IC	**107**	556.1	598.5	OCC-
24	556.1	598.5	OCC+	**66**	556.1	598.5	IC	**108**	556.1	598.5	OCC-
25	556.1	598.5	OCC+	**67**	556.1	598.5	IC	**109**	556.1	598.5	IC
26	556.1	598.5	OCC+	**68**	556.1	598.5	IC	**110**	556.1	598.5	IC
27	556.1	598.5	OCC+	**69**	556.1	598.5	IC	**111**	556.1	598.5	IC
28	556.1	598.5	OCC+	**70**	556.1	598.5	IC	**112**	556.1	598.5	IC
29	556.1	598.5	OCC+	**71**	556.1	598.5	IC	**113**	556.1	598.5	IC
30	556.1	598.5	OCC+	**72**	556.1	598.5	IC	**114**	556.1	598.5	IC
31	556.1	598.5	OCC+	**73**	556.1	598.5	IC	**115**	556.1	598.5	IC
32	556.1	598.5	OCC+	**74**	556.1	598.5	IC	**116**	556.1	598.5	IC
33	556.1	598.5	IC	**75**	556.1	598.5	IC	**117**	556.1	598.5	IC
34	556.1	598.5	OCC+	**76**	556.1	598.5	IC	**118**	556.1	598.5	IC
35	556.1	598.5	OCC+	**77**	556.1	598.5	IC	**119**	556.1	598.5	OCC+
36	556.1	598.5	OCC+	**78**	556.1	598.5	IC	**120**	556.1	598.5	IC
37	556.1	598.5	IC	**79**	556.1	598.5	IC	**121**	556.1	598.5	IC
38	556.1	598.5	IC	**80**	556.1	598.5	IC	**122**	556.1	598.5	IC
39	556.1	598.5	IC	**81**	556.1	598.5	IC	**123**	556.1	598.5	IC
40	556.1	598.5	IC	**82**	556.1	598.5	OCC-	**124**	556.1	598.5	IC
41	556.1	598.5	IC	**83**	556.1	598.5	OCC-	**125**	556.1	598.5	IC
42	556.1	598.5	IC	**84**	556.1	598.5	OCC-	**126**	556.1	598.5	IC

Note: "IC" means in control, "OOC+" means out of control above UCL, and "OOC-" means out of control under LCL.

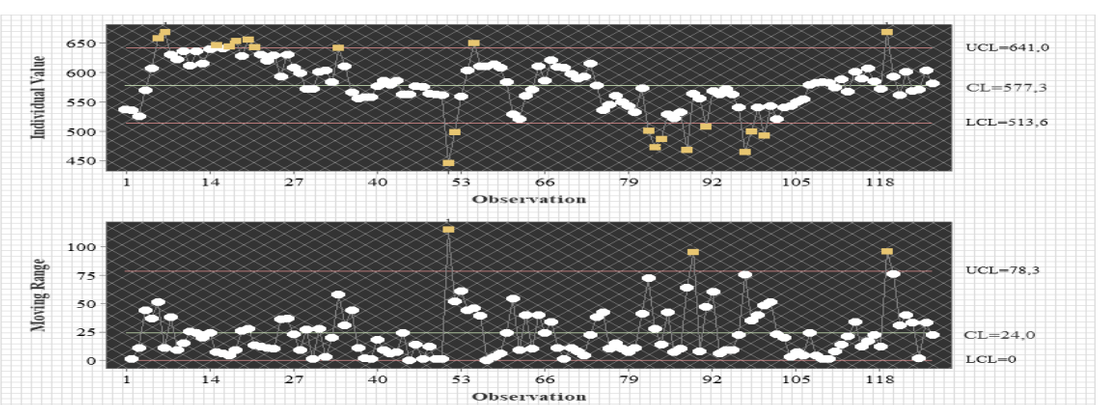


Figure 2. I-MR control charts for bursting strength data

In other words, it is possible to see that 10 of them are above UCL and the remaining 10 are below LCL. An evaluation of the results of the MR-chart revealed that only 3 of the 126 data are above UCL (data no: 51, 89 and 119), in other words, they are out of control. Namely, although only 3 of the data points are out-of-control or exceed the UCL, it does not eliminate the fact that there is an unusual change or variability in the process in terms of the relevant variable. As stated earlier, it was emphasized in the literature that if any data point on the control chart exceeds the chart limits, this is considered as a sign that the process is not in control (Montgomery 2012). On the other hand, another important point to note here is that two (data no: 51 and 119) of the three data points observed as out of control in the MR-chart are also out of control in the I-chart.

Table 2. Information about the I-MR charts

I						MR					
Data no	**Control status**	**Data no**	**Control status**	**Data no**	**Control status**	**Data no**	**Control status**	**Data no**	**Control status**	**Data no**	**Control status**
1	IC	**43**	IC	**85**	IC	**1**	IC	**43**	IC	**85**	IC
2	IC	**44**	IC	**86**	IC	**2**	IC	**44**	IC	**86**	IC
3	IC	**45**	IC	**87**	IC	**3**	IC	**45**	IC	**87**	IC
4	IC	**46**	IC	**88**	OOC-	**4**	IC	**46**	IC	**88**	IC
5	IC	**47**	IC	**89**	IC	**5**	IC	**47**	IC	**89**	OOC+
6	OOC+	**48**	IC	**90**	IC	**6**	IC	**48**	IC	**90**	IC
7	OOC+	**49**	IC	**91**	OOC-	**7**	IC	**49**	IC	**91**	IC
8	IC	**50**	IC	**92**	IC	**8**	IC	**50**	IC	**92**	IC
9	IC	**51**	OOC-	**93**	IC	**9**	IC	**51**	OOC+	**93**	IC
10	IC	**52**	OOC-	**94**	IC	**10**	IC	**52**	IC	**94**	IC
11	IC	**53**	IC	**95**	IC	**11**	IC	**53**	IC	**95**	IC
12	IC	**54**	IC	**96**	IC	**12**	IC	**54**	IC	**96**	IC
13	IC	**55**	OOC+	**97**	OOC-	**13**	IC	**55**	IC	**97**	IC
14	IC	**56**	IC	**98**	OOC-	**14**	IC	**56**	IC	**98**	IC
15	OOC+	**57**	IC	**99**	IC	**15**	IC	**57**	IC	**99**	IC
16	IC	**58**	IC	**100**	OOC-	**16**	IC	**58**	IC	**100**	IC
17	OOC+	**59**	IC	**101**	IC	**17**	IC	**59**	IC	**101**	IC
18	OOC+	**60**	IC	**102**	IC	**18**	IC	**60**	IC	**102**	IC
19	IC	**61**	IC	**103**	IC	**19**	IC	**61**	IC	**103**	IC
20	OOC+	**62**	IC	**104**	IC	**20**	IC	**62**	IC	**104**	IC
21	OOC+	**63**	IC	**105**	IC	**21**	IC	**63**	IC	**105**	IC
22	IC	**64**	IC	**106**	IC	**22**	IC	**64**	IC	**106**	IC
23	IC	**65**	IC	**107**	IC	**23**	IC	**65**	IC	**107**	IC
24	IC	**66**	IC	**108**	IC	**24**	IC	**66**	IC	**108**	IC
25	IC	**67**	IC	**109**	IC	**25**	IC	**67**	IC	**109**	IC
26	IC	**68**	IC	**110**	IC	**26**	IC	**68**	IC	**110**	IC
27	IC	**69**	IC	**111**	IC	**27**	IC	**69**	IC	**111**	IC
28	IC	**70**	IC	**112**	IC	**28**	IC	**70**	IC	**112**	IC
29	IC	**71**	IC	**113**	IC	**29**	IC	**71**	IC	**113**	IC
30	IC	**72**	IC	**114**	IC	**30**	IC	**72**	IC	**114**	IC
31	IC	**73**	IC	**115**	IC	**31**	IC	**73**	IC	**115**	IC
32	IC	**74**	IC	**116**	IC	**32**	IC	**74**	IC	**116**	IC
33	IC	**75**	IC	**117**	IC	**33**	IC	**75**	IC	**117**	IC
34	OOC+	**76**	IC	**118**	IC	**34**	IC	**76**	IC	**118**	IC
35	IC	**77**	IC	**119**	OOC+	**35**	IC	**77**	IC	**119**	OOC+
36	IC	**78**	IC	**120**	IC	**36**	IC	**78**	IC	**120**	IC
37	IC	**79**	IC	**121**	IC	**37**	IC	**79**	IC	**121**	IC
38	IC	**80**	IC	**122**	IC	**38**	IC	**80**	IC	**122**	IC
39	IC	**81**	IC	**123**	IC	**39**	IC	**81**	IC	**123**	IC
40	IC	**82**	OOC-	**124**	IC	**40**	IC	**82**	IC	**124**	IC
41	IC	**83**	OOC-	**125**	IC	**41**	IC	**83**	IC	**125**	IC
42	IC	**84**	OOC-	**126**	IC	**42**	IC	**84**	IC	**126**	IC

Note: "IC" means in control, "OOC+" means out of control above UCL, and "OOC-" means out of control under LCL.

In summary, the results of both EWMA and I-MR charts revealed that there were some out of control points in the charts in terms of the bursting strength variable. It was reported that any value of the control chart statistics that falls outside the control limits is an indication of process variation. In such a case, it is assumed that the variation encountered in the process or product is potentially caused by a removable assignable cause (Zwetsloot et al. 2024). Hence, it is possible to say that the results of the current study raise doubts about the existence of assignable causes.

CONCLUSION

In the current research, the I-MR and EWMA control charts, which are univariate control chart types, was employed to monitor a total of 126 data of the bursting strength provided from an enterprise. Evaluations were made based on the findings obtained. As can be seen from the results of the current study, the EWMA control chart was effective in identifying whether any variation exists in the process for this data set. The use of the EWMA chart demonstrated that the process in terms of the bursting strength quality variable was not in control. When looking at the I-MR control charts, it is possible to understand that the process is out of control in terms of both univariate control charts. Although the process is out of control in the MR chart, it can be said that the process is more stable in terms of bursting strength compared to the I-chart. The results of the control charts revealed that there were most likely some assignable causes affecting the process. Generally speaking, it is possible to claim that continuous control or monitoring of the production process in terms of product quality variable with control charts may help to better understand the actual status of the process and may be a guide in dealing with the factors that cause the process to get out of control. This can help keep a production process in control with as little variability as possible.

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