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Methodology for Constructing Fuzzy Individual and Moving Range Control Chart

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Abstract— The main importance of the control charts is to process the error occurring in the production processes before it occurs. In this paper, single-sample fuzzy moving range control charts will be applied. One of the main problems facing this type of application is the data fuzzing process, that is, the uncertainty of the production process and measurements in the data environment. Choosing the appropriate alpha-fuzzy value (which is used to convert data from crisp values into fuzzy data) depends on experts in the production institute. In this work, the alpha-fuzzy value was chosen based on the arithmetic average of the process, the target average, and the type of production process as well. The wire drawing process was applied in this research as a case study to apply the proposed methodology, a code of the MATLAB-2020 program was applied in the calculation and drawing operations, and the results were compared with the Minitab-2021 program, which draws the traditional control charts. The proposed methodology was applied on a wire drawing process for copper and aluminum wires to control the diameter of the wires. The results showed that the methodology used in the paper was efficient in choosing the right alpha-fuzzy as long as it did not cause high change in the standard deviation of the process. The fuzzy control charts were more flexible and accurate than the traditional control charts, observation 17 of the aluminum wire was out-of-control in the traditional control chart while it was under control in the fuzzy control chart.

Keywords— Fuzzy Control Charts, Individual-Moving Range Control Charts, Quality Control, Target Dimension, Wire Drawing Process

1. Introduction

Quality control procedures are employed in a variety of industries, including those that produce and provide customized (or special) variants that can be accurately detected and regulated. [15] To achieve process stability and improve capability, statistical quality control is a potent set of problem-solving methods that reduce variability [5].

One of the most crucial instruments for regulating statistical quality is the quality control charts. [11] In addition to monitoring the qualitative aspects of production processes, quality control charts are utilized to spot any unusual production process deviations [3].

A sort of variable control chart known as the individual-moving range (I-MR) is actually made up of two charts, the I and MR. Tracking the process level for each reading is possible with a chart. While the MR chart shows the variation in subsequent readings. [4] While the control scheme is a useful tool for analyzing variations in repetitive processes, there are two distinct sorts of differences that can be identified in a general process. The "noise" in production systems is chance or (common) deviations, which cause unmanageable changes. Other types include Variations that can be modified (or made special) and are easily recognized and controlled. [2]

There are four factors that contribute to this variation (processes, materials, operators, and miscellaneous. [8] Recently, fuzzy logic has been used in industrial statistics, particularly when the data is ambiguous. The standard control chart has significant challenges as a result of the data's ambiguity or uncertainty. In its capacity, fuzzy set theory handles ambiguity in data. [1] Operations research, control theory, and management sciences are only a few areas where the fuzzy sets theory has been used. [6] A long rod or wire is drawn through a die to reduce or alter its cross-section during the metal manufacturing process known as wire drawing. [12] This technique establishes mechanical qualities and dimensional tolerances. As the wire is pulled through conical dies, it hardens as a result of the enormous cold work procedure deformation. Although the stresses of up to 63.2% are theoretically achievable, friction and unnecessary work prevent this from happening in practice. [10].

Many researchers used the traditional and fuzzy I-MR control charts to enhance the quality of processes. Some of them are listed below:

(Al-Kafaji, 2019): [3] the research's goal is to suggest a methodology that makes use of prior data to increase accuracy and cut costs. A total of 25 samples, each measuring 5 samples in size, have been used to test the methodology. This study also looked at the process capability outcomes and their indicators that were produced by the suggested technique. It took fewer trials to reach the approved control limits for the ensuing application for the characteristic understudy. As the sample size grows, the standard deviation's value drops.

(Rodríguez-Álvarez et al., 2021):[12] This paper investigated the quality of the papermaking process by keeping an eye on the crucial factor that needs to be under control, the crucial factor in Paper is created by adding moisture to a piece of paper. However, because of the paper's humidity properties, measurement equipment and the structure of the papermaking process may introduce considerable variability in the moisture content results .To overcome these uncertainties, a different strategy that uses fuzzy control charts is suggested in this study. First, the sigma level procedure is used to turn individual data into fuzzy numbers, and then the α-cut fuzzy midrange approach is used to present the fuzzy individual and moving range control charts, with the value of α=0.5. Data from a 240-gram coated paper sample's moisture content is used to show the efficiency of the fuzzy individual control charts. Given that .The suggested method for producing fuzzy numbers is highly useful and can be applied to any sort of process as a result of the fact that it is based on the process sigma level and the variance found in the sample. They are more adaptable than the conventional individual control charts due to the larger amplitude between the upper and lower control limits of the fuzzy individual and moving range control charts. Which is one of the study's most significant findings.

(Kaya & Turgut, 2021): [15] to improve the accuracy and adaptability of the variable control charts in this research, type-2 fuzzy sets have been used in their design. In order to achieve this goal, type-2 fuzzy sets have been used to redesign the $\bar{X}$-R, $\bar{X}$-S, and I MR control charts. Errors in the measurement process when building conventional CCs may be caused by the operator or the measuring equipment. By the way, certain information about CCs may contain "uncertainty" or "vagueness" pertaining to procedure and inspector reviews or assessments. We are aware that traditional CCs are unable to control this process. One of the most crucial methods for resolving these issues is fuzzy set theory (FST), and the CCs created using FST are more practical and effective for process monitoring. The outcomes demonstrate that the charts have been successfully used to track mean and variance variability. They demonstrated the process stability. The I-MR control chart is also used to track the signal strength variations in AMMS devices. Signal strength values may decrease slightly according to regional factors and device characteristics.

In the current research, a methodology for fuzzification of the data and constructing the I-MR control chart was presented.

2. Methodology

Various kinds of fuzzy numbers, including triangular fuzzy numbers (TFN), trapezoidal fuzzy numbers (TrFN), and Gaussian fuzzy numbers (GFN), can be determined based on their respective membership functions. The triangle fuzzy number is utilized in this work since most measurements made throughout the wire drawing process tend to fall in the middle of the specification. [15]

2.1 *Fuzzification of the Data*

The proposed methodology to generate the fuzzy numbers was based on the target dimension and the mean of the sample j of the process and the type of the process is also a dominant factor in the fuzzification of the data. The (1) and (2) equations were used to calculate the mean and mean-target dimensions of the process which is called the deviation from nominal dimension (DNOM).

$$\bar{X}_j = \frac{\sum_{i=1}^{n} x_i}{n} \quad , \; i = 1,2,..,n \tag{1}$$

$$DNOM = \bar{X}_j - X_T \tag{2}$$

W*here* $\bar{X}_j$ is the sample mean, n is the sample size and X_T is the target dimension given by the designer.

The next step was to convert data from crisp values into fuzzy numbers by the equations (3) to (5). [5]

$$X_a = X_b - \alpha * X_b \tag{3}$$

$$X_b = X_i \tag{4}$$

$$X_c = X_b + \alpha * X_b \tag{5}$$

Where Xb is the original observation, Xc, Xa are the left and right sides of the observation and α is the fuzzification value which represent the uncertainty in the process.

The standard deviation of the data before and after fuzzification must be taken into consideration. The standard deviation of the process before and after fuzzification was calculated using equations (6) and (7). [11]

$$S.D=\sqrt{\frac{\sum_{i=1}^{n}(Xi-\bar{\bar{X}})}{n-1}} \quad (6)$$

$$S.D_{fuzzy}=\sqrt{\frac{\sum_{i=1}^{n}[(Xa,Xb,Xc)-(\bar{X}a,\bar{X}b,\bar{X}c)}{n}} \quad (7)$$

Where $\bar{\bar{X}}$ is the overall mean of the process.

2.2 *Construction of Fuzzy Individual-Moving Range (I-MR) Control Chart*

To generate the fuzzy control limits of the individual control chart the overall mean for the fuzzy numbers is shown in equation (8). [7]

$$\left(\overline{\overline{X_a}},\overline{\overline{X_b}},\overline{\overline{X_c}}\right)=\left(\frac{\sum_{j=1}^{m}Xaj}{m},\frac{\sum_{j=1}^{m}Xbj}{m},\frac{\sum_{j=1}^{m}Xcj}{m}\right) \quad (8)$$

Where m is the number of samples.

The fuzzy moving range can be calculated as in equation (9) to (11) [15]

$$X_i=(X_{ai},X_{bi},X_{ci}) \quad (9)$$

$$MR_i=\left|(X_{ai},X_{bi},X_{ci})-(X_{ai-1},X_{bi-1},X_{ci-1})\right| \quad (10)$$

$$\overline{MR}=\left|\frac{\sum_{j=1}^{m}MR_{aj}}{m},\frac{\sum_{j=1}^{m}MR_{bj}}{m},\frac{\sum_{j=1}^{m}MR_{cj}}{m}\right| \quad (11)$$

The fuzzy control limits for individual control charts are listed in equations (12) to (14).

$$\widetilde{UCL}=(\bar{\bar{X}}_a,\bar{\bar{X}}_b,\bar{\bar{X}}_c)+3\frac{(\overline{MR}a,\overline{MR}b,\overline{MR}c)}{d2} \quad (12)$$

$$\widetilde{CL}=(\bar{\bar{X}}_a,\bar{\bar{X}}_b,\bar{\bar{X}}_c) \quad (13)$$

$$\widetilde{LCL}=(\bar{\bar{X}}_a,\bar{\bar{X}}_b,\bar{\bar{X}}_c)-3\frac{(\overline{MR}a,\overline{MR}b,\overline{MR}c)}{d2} \quad (14)$$

Where d_2 is the control chart constant [3], $\widetilde{UCL}$ is the fuzzy upper control limit, $\widetilde{CL}$ is the centerline, and $\widetilde{LCL}$ is the lower control limit.

While the fuzzy control limits of the moving range control chart were calculated using equations (15) to (17). [7]

$$\widetilde{UCL}=d_4(\overline{MR}_a,\overline{MR}_b,\overline{MR}_c) \quad (15)$$

$$\widetilde{CL}=(\overline{MR}_a,\overline{MR}_b,\overline{MR}_c) \quad (16)$$

$$\widetilde{LCL}=d_3(\overline{MR}_a,\overline{MR}_b,\overline{MR}_c) \quad (17)$$

Where d_4 and d_3 are control charts constants [3].

The α-cut level midrange transformation was used for the transformation from the fuzzy control limits to the crisp control limits in order to draw control charts.

The control limits of the α-cut midrange individual control limits can be rewritten as in equations (18) to (20). [15]

$$\widetilde{UCL}_{mr-x}^{\alpha}=\widetilde{CL}_{mr-x}^{\alpha}+3\left(\frac{\overline{MR}_a^{\alpha}+\overline{MR}_c^{\alpha}}{d_2}\right) \quad (18)$$

$$\widetilde{CL}_{mr-x}^{\alpha}=f_{mr-x}^{\alpha}=\frac{\bar{\bar{X}}_a^{\alpha}+\bar{\bar{X}}_c^{\alpha}}{2} \quad (19)$$

$$\widetilde{LCL}_{mr-x}^{\alpha}=\widetilde{CL}_{mr-x}^{\alpha}-3\left(\frac{\overline{MR}_a^{\alpha}+\overline{MR}_c^{\alpha}}{d_2}\right) \quad (20)$$

Where the α-cut moving range and the α-cut mean of the fuzzy data are listed in equations (21) to (24). [7]

$$\overline{MR}_a^{\alpha}=\overline{MR_a}+\alpha(\overline{MR_b}-\overline{MR_a}) \quad (21)$$

$$\overline{MR}_c^{\alpha}=\overline{MR}_c+\alpha(\overline{MR}_c-\overline{MR}_b) \quad (22)$$

$$\bar{\bar{X}}_a^{\alpha}=\bar{\bar{X}}_a+\alpha(\bar{\bar{X}}_b-\bar{\bar{X}}_a) \quad (23)$$

$$\bar{\bar{X}}_c^{\alpha}=\bar{\bar{X}}_c+\alpha(\bar{\bar{X}}_c-\bar{\bar{X}}_b) \quad (24)$$

Where α is the α-cut level, which represent the tightness of inspection of the process.

3. Case Study

To apply the proposed methodology and get the results, data of a wire drawing process were collected from Al-rowad factory for production of cables and electrical wires. The factory produces aluminum and copper cables with different diameters.

The production of the cables goes through several operations, the first operation and the most important one is the wire drawing process.

The sampling strategy of the factory is 10% for the drawn wires. After the drawing process the diameter of the sample is measured using calibrated micrometer. Then a laboratory tests for elongation and tensile strength are done on each sample.

The selected data of this work are a drawn Aluminum wire of a target diameter (2.44mm) with (±0.03mm) tolerance and copper wire of target dimension (2.35mm) with (±0.03mm) tolerance.

The data of the actual diameter measured in the 30 samples collected are listed in table (1).

Table 1: The Actual Diameter of the Aluminum Wire

Sample No.	Actual Diameter (mm) Aluminum (Al)	Target Diameter (mm) Aluminum (Al)	Target Diameter (mm) Copper (Cu)	Actual Diameter (mm) copper (Cu)
1	2.374	2.44	2.35	2.374
2	2.377	2.44	2.35	2.377
3	2.377	2.44	2.35	2.377
4	2.376	2.44	2.35	2.376
5	2.375	2.44	2.35	2.375
6	2.376	2.44	2.35	2.376
7	2.376	2.44	2.35	2.376

8	2.378	2.44	2.35	2.378
9	2.374	2.44	2.35	2.374
10	2.373	2.44	2.35	2.373
11	2.376	2.44	2.35	2.376
12	2.376	2.44	2.35	2.376
13	2.376	2.44	2.35	2.376
14	2.380	2.44	2.35	2.380
15	2.379	2.44	2.35	2.379
16	2.378	2.44	2.35	2.378
17	2.375	2.44	2.35	2.375
18	2.374	2.44	2.35	2.374
19	2.378	2.44	2.35	2.378
20	2.375	2.44	2.35	2.375
21	2.374	2.44	2.35	2.374
22	2.377	2.44	2.35	2.377
23	2.372	2.44	2.35	2.372
24	2.373	2.44	2.35	2.373
25	2.375	2.44	2.35	2.375
26	2.374	2.44	2.35	2.374
27	2.377	2.44	2.35	2.377
28	2.380	2.44	2.35	2.380
29	2.377	2.44	2.35	2.377
30	2.376	2.44	2.35	2.376

4. Data Reduction

The first step was to choose the α-fuzzy to fuzzify the data. The proposed methodology depends on the deviation from nominal dimension (DNOM) as well as the nature of the production process to choose the α-fuzzy. For that reason, the DNOM were calculated using equations (1) and (2). The results are in table (2).

Table 2: The Deviation from Nominal Dimension for Al and Cu Wires

Sample No.	DNOM for Al wire	DNOM for Cu wire
1	0.010	0.024
2	0.010	0.026
3	0.008	0.0267
4	0.014	0.025
5	0.007	0.024
6	0.007	0.025
7	0.009	0.025
8	0.001	0.028
9	0.008	0.024
10	0.006	0.023
11	0.010	0.025
12	0.010	0.025
13	0.005	0.025
14	0.010	0.029
15	0.010	0.028
16	0.012	0.028
17	0.019	0.024
18	0.010	0.024
19	0.005	0.028
20	0.007	0.024
21	0.008	0.024
22	0.005	0.026
23	0.006	0.021
24	0.012	0.023
25	0.007	0.024
26	0.010	0.024
27	0.005	0.026
28	0.006	0.029
29	0.003	0.026
30	0.008	0.025

The value of α-fuzzy represent the least value of the DNOM values because the process is a wire drawing process and positive value of the DNOM means that the samples diameters are all higher than the target diameter, which can be reworked to obtain the target diameter, the smaller value of the DNOM gives an indication of getting below the target diameter which is unwanted situation. The value of α-fuzzy used was equal to 0.001 for the Al wire and 0.021 for the Cu wire.

A Matlab2020 code was developed to calculate the DNOM, falsify the data, the fuzzy I-MR control limits and drawing the fuzzy I-MR control charts. The fuzzy numbers (a, c) which represents the left and right hand sides of the observation were generated using equations (3-5) by the Matlab2020 code provided.

The standard deviation of the data before fuzzification for the aluminum wire was 0.003453 and after fuzzification became 0.003962 so the standard deviation did not increase to a high value that would cause a high diverge of the fuzzified data from the original data for this reason the fuzzified data were used to obtain the fuzzy control limits. For the copper wire the standard deviation of the process before the fuzzification was 0.001999 while it became 0.042963 and it is a very high increment, which may cause a high diverge of the fuzzified data from the original data. The value of α-fuzzy is not appropriate to use here so a condition in the maMatlab2020 code was used to lower the α-fuzzy to a value that would give a fuzzy standard deviation that approximate the original data's standard deviation. The value of α-fuzzy = 0.001 gave a standard deviation of 0.002777, which approximate the original standard deviation. The fuzzified data of the copper wire with α=0.001 are listed in Table (3).

Table 3: Fuzzified Data of Cu Wire

Sample No.	A	c
1	2.371626	2.376374
2	2.374623	2.379377
3	2.374623	2.379377
4	2.373624	2.378376
5	2.372625	2.377375
6	2.373624	2.378376
7	2.373624	2.378376
8	2.375622	2.380378
9	2.371626	2.376374
10	2.370627	2.375373
11	2.373624	2.378376
12	2.373624	2.378376
13	2.373624	2.378376
14	2.37762	2.38238
15	2.376621	2.381379
16	2.375622	2.380378
17	2.372625	2.377375
18	2.371626	2.376374
19	2.375622	2.380378
20	2.372625	2.377375
21	2.371626	2.376374
22	2.374623	2.379377
23	2.369628	2.374372
24	2.370627	2.375373
25	2.372625	2.377375
26	2.371626	2.376374
27	2.374623	2.379377
28	2.37762	2.38238
29	2.374623	2.379377
30	2.373624	2.378376

The fuzzified data in Table (3) were used to calculate the fuzzy I-MR control chart by Matlab2020 uses equations (12-17). The α-cut level midrange transformation approach was used to get the fuzzy control limits. The value of α-cut was 0.65 which is the most used value in the manufacturing processes.

5. Results and Discussion

For the purpose of comparison between the traditional and fuzzy I-MR control chart, the traditional control chart was obtained using the Minitab21 software. Figure (1) shows the traditional I-MR control charts drawn using Minitab21 software for the Al wire.

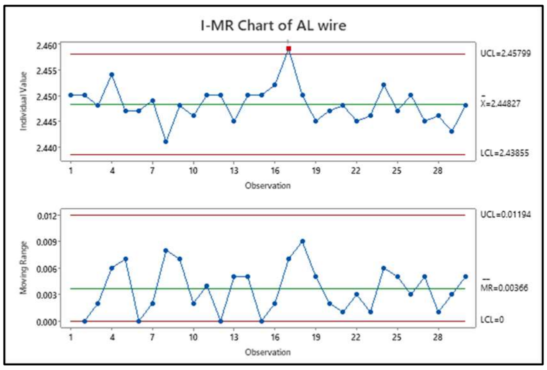

Figure 1: Traditional I-MR Control Chart of the Al Wire

Figure (1) shows that one observation was out of the upper control limit (observation 17). This means that this control limits are not the approved control limits and observation 17 must be eliminated to re-calculate the approved control limits. Figure (2) shows the approved control limits of the traditional I-MR chart.

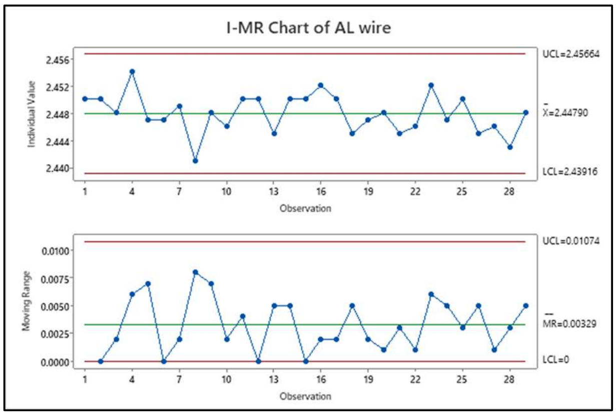

Figure 2: Approved Traditional I-MR Control Chart of the Al Wire

Figure (3) shows the Fuzzy I-MR control chart drawn by Matlab2020.

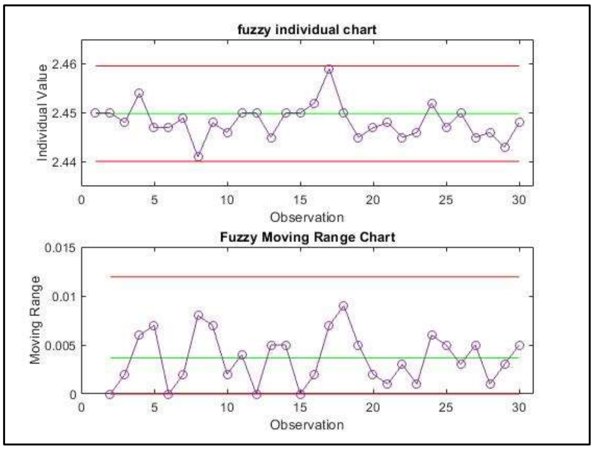

Figure 3: Fuzzy I-MR Control Chart of Al Wire

Figure (3) shows that all observations were under control, no sample was out-of-control for the fuzzy I-MR control. This result reflects the accurecy of the fuzzy control charts over the traditional control charts. [12] The process of fuzzing the data, as well as drawing the fuzzy control limits, took into account the slight changes that occur in the measure of dispersion between the data itself due to factors that are installed in the traditional control charts, but have an imperceptible effect, which is indicated by the fuzzy control charts. [15]

The upper control limit of the traditional individual control chart is with difference of (0.014) from the upper specification limit. The fuzzy upper conrol limit of the individual control chart is with difference o (0.01) from the upper specification limit which is smaller than the traditional difference, this redult gives a good flexibility in the production limits. [17]

The Figure (4) shows the traditional I-MR control chart of the Cu wire.

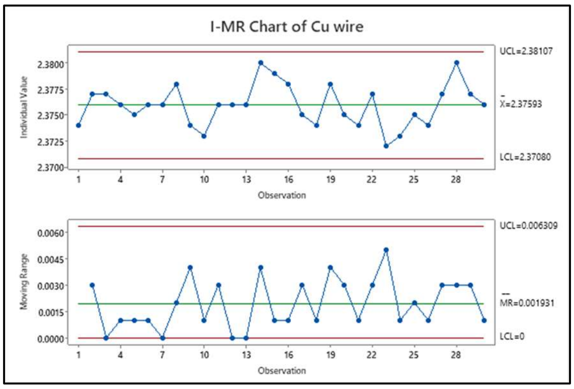

Figure 4: Traditional I-MR Control Chart of Cu Wire

Figure (4) shows that the process is under control. The control limits are the approved control limits for the Cu wire. The fuzzy I-MR control chart was also drawn and shown in Figure (5).

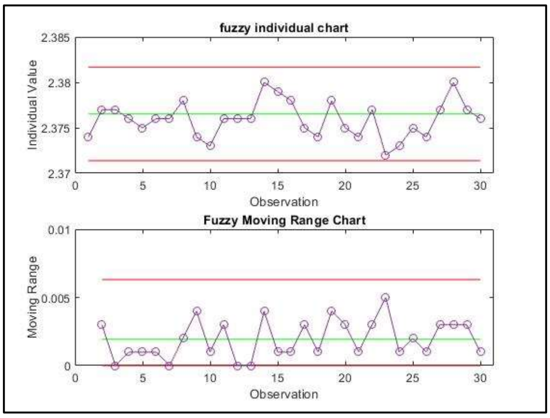

Figure 5: Fuzzy I-MR Control Chart of the Cu Wire

The fuzzy control chart shows that the process was in control. The fuzzy control charts are more flexible and accurate when dealing with vague data. [17]
The fuzzy and traditional control limits in the Cu wire were so close because the value of the α-fuzzy was small (0.001), also from Table (6) the control limits of the process tends toward the upper specification limit (2.35+0.003) which is preferred in the wire drawing process to re-work instead of scrap the out-of-control samples.

6. Conclusion

The aim of this study was to show the effect of mean and target dimension on the α-fuzzy value and compare between traditional and fuzzy I-MR control chart for the wire drawing process. The conclusions can be extracted as:

- It is possible to choose the right α-fuzzy value by using the DNOM methodology. The alpha-fuzzy was equals to 0.001 in the Al wire and 0.022 in the Cu wire.
- The type of the manufacturing process plays an important role in the fuzzification of the data and choosing the α-fuzzy. In the wire drawing process the smallest DNOM were used.

- The standard deviation of the process increases with the fuzzification of the data. Because the fuzzy control charts take into consideration the small variations that occurs as a result of the random variations that the manufacturing process work with.
- One observation was out of control in the traditional control chart observation (17) and it was eliminated to reach the approved control limits.
- The traditional control charts give false alarm of out-of-control observations.
- The fuzzy control charts are more accurate and flexible than the traditional control charts.

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منهجية لبناء لوحات الضبط للعينة المفردة والمدى المتحرك الضبابية

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الخلاصة – تتمثل الأهمية الرئيسية لمخططات التحكم في معالجة الخطأ الذي يحدث في عمليات الإنتاج قبل حدوثه. في هذا البحث، سيتم تطبيق مخططات التحكم في المدى المتحرك الضبابي ذات العينة الواحدة. إحدى المشاكل الرئيسية التي تواجه هذا النوع من التطبيقات هي عملية تضبيب البيانات، أي عدم الدقة في عملية الإنتاج والقياسات في بيئة البيانات. يعتمد اختيار قيمة ألفا الضبابية المناسبة (والتي تستخدم لتحويل البيانات من القيم الهشة إلى بيانات ضبابية) على الخبراء في مؤسسات الإنتاج. في هذا العمل تم اختيار قيمة ألفا الضبابية على أساس المتوسط الحسابي للعملية، والمتوسط المستهدف، ونوع عملية الإنتاج أيضا. تم تطبيق عملية سحب الأسلاك في هذا البحث كدراسة حالة لتطبيق المنهجية المقترحة، وتم تطبيق كود برنامج MATLAB-2020 في عمليات الحساب والرسم، وتمت مقارنة النتائج مع برنامج Minitab-2021 الذي يرسم مخططات التحكم التقليدية وأظهرت النتائج أن المنهجية المستخدمة في البحث كانت فعالة في اختيار ألفا الضبابية الصحيحة طالما أنها لم تسبب تغيرا كبيرا في الانحراف المعياري للعملية. وكانت مخططات التحكم المضببة أكثر مرونة ودقة من مخططات التحكم التقليدية، حيث كانت العينة 17 لسلك الألمنيوم خارج حدود السيطرة في مخطط التحكم التقليدي بينما كانت تحت السيطرة في مخطط التحكم المضبب.

الكلمات الرئيسية – لوحات التحكم الضبابية، السيطرة النوعية، البعد المستهدف، عملية سحب الاسلاك.