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Fuzzy Logic Technique Based on Classification Function Application in Quality Control

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Abstract

This work introduces a method for fuzzy control charts. Fuzzy theory and the foundations of Shew Hart control charts form the foundation of the process. The information was gathered from one of the key production facilities to raise the quality standard for one of Iraq's industrial products. Fuzzy control charts were used to quickly and accurately identify the production specifications and efficiency. This work uses the triangle membership function to generate fuzzy numbers, which are then transformed into quality control charts for the real data obtained using the proposed ranking function. Next, contrast the quality control of crisp and fuzzy attributes. The graphs demonstrate how professional techniques can increase output and lower defect rates. To meet the control limits for quality control and defective percentages for all samples using (w = 0.2, 0.5, 0.6) and (λ = 0.5, 0.7, 0.9), then compare the adoption of the traditional technique with fuzzy logic while adopting variable cases through the arrangement function. It can be noticed that the chart of fuzzy control is more economically quicker and more accurate at monitoring production quality, enabling the diagnosis of defective units throughout the production process.

Keywords: Attribute Control Charts; Fuzzy Sets Theory; Quality control; Ranking function.; Statistical process control

1. Introduction

Statistical techniques to control production have received attention in recent research. They are used as control charts to monitor production quality changes by examining samples and developing plans that enable supervision, diagnosis, and control of defects. To choose any product, several samples are examined according to specifications, through which the quality of production can be identified and what is defective or not [1]. Enhancing quality is a crucial business strategy in today's globally competitive marketplace. This requires continually improving the instruments used to track the quality process. A key tool for conducting quality improvement initiatives in many manufacturing environments is statistical process control (SPC) [2]. The SPC process comprises observation, assessment, diagnosis, choice, and execution. In SPC tools, control charts are frequently used. Despite Shewhart's initial 1924 proposal, control charts are widely used, particularly in industrial applications' manufacturing processes [3], [4].

The corporation sets out to produce goods free of flaws and by requirements and then uses control charts to respect statistical methods to oversee high-quality production [5], [6]. Control charts are one of the most often used statistical techniques for tracking the variations that can occur through the phases of the product process. Observations from samples taken are used to establish whether the process is statistically accurate. Control charts are one of the most often used statistical techniques for tracking variations through the phases of the product process, and observations obtained from samples taken are used to establish if the process is statistically accurate [7]-[9].
A control chart is the most crucial tool typically used to decide if the process is within a statistical control state. In addition, the chart of control is a graphical representation of a quality feature that can be estimated or measured from the sample versus the sample size or time, as reported in Montgomery [2]. Variable control charts are used to track the products' enduring properties, while control charts are used to track quality characteristics that can be stated on a numerical scale.

In traditional P-control charts, products are divided into conformed and non-conforming categories. Since many spired scenarios contain numerous intermediate levels and call for strong mathematical methods to improve control chart performance, binary classification may not always be applicable. As a result, fuzzy control charts have lately been expanded to assess data that is unclear, partial, or defined verbally [3].

From the membership (characteristic) function, it can be defined as a set that gives each item a grade of membership between zero and one [10].

Many scholars attempt to integrate control charts and SPC with fuzzy set theory. Estimating a reliable case can result from previous experiences in obtaining appropriate control functions by selecting appropriate and useful data to build the practical case. Many academics have tried to combine fuzzy set theory, control charts, and SPC. Ambiguous data can be transformed into clear data. To build a useful process in different ways and by setting levels and limits for controlling that data [11]-[17]. It is preferable to estimate the process condition directly without needing any transformation. A Previous work [13] developed a novel method, defined as the methodology of direct fuzzy to track the fuzzy nonconformity number in the production processes. To establish the process condition, they determine the proportion of the mean area of the fuzzy sample that is still beyond the fuzzy control bounds rather than employing transformation techniques. Engin used a fuzzy method to control the attributes of the process, including multiple stages, and a genetic algorithm was used to solve the problem [18]. Spiridonica recommends a fuzzy approach incorporating Shewhart charts, A. et al. to ensure improved competitiveness for an industrial process [19]. Khan et al. [20] suggested EWMA with limits of fuzzy control, and they used fuzzy combinations. Sabegh et al. [14] developed an explanation of the fuzzy environment by adopting the review process to include an analysis of the various classifications within a control scheme in that environment. Application techniques for artificial intelligence, including neural networks and fuzzy logic, were also discussed. Work in these techniques was carried out according to the mechanism of converting linguistic variables into values within a control scheme. These values represented a set used for processing and ensuring quality and accuracy in performance. The fuzzy control was considered faster and more accurate through the control scheme results, which can show the defective sample during its production and identify the error to treat it as quickly as possible and avoid it in subsequent samples. An appropriate design must be provided for the fuzzy statistical control schemes within working limits that suit the samples to be produced. Rules were set within patterns that show the possibilities of changes by adopting the solution and developing these schemes by adopting the fuzzy logic to monitor and improve production quality. Several simulations have been conducted to raise production quality by adopting monitoring schemes and controlling them by adopting clear and fuzzy accurate data samples. The control depends on an order function suggested between zero and one, such as ($w = 0.2$, $\lambda = 0.9$) [21].

This work presents a method of using the triangle membership function to apply explicit and fuzzy control charts to actual data. When (w=0.5, =0.5), (w=0.6, =0.7), and (w=0.2, =0.9), the attribute quality control is then determined by using the suggested ranking function. The paper structure was built as follows: The mathematical creation and representation of control charts will be shown in Section 2. The manufacturing and implementation models will be presented mathematically in Section 3. Results will be analyzed in Section 4. Conclusions will be presented in Section 5.

2. Mathematical Representation and Construction of Control Charts:

A P-control chart is used in statistical quality control to track the percentage of returned product units. It displays the total number of nonconforming products throughout the procedure.

In industry, some samples are usually valid and defect-free because they meet standards and are designed as such (1-P). In addition, some of the samples are invalid, defective, and do not conform to the specifications, referred to as (P). When a random production sample is taken, symbolized by the symbol (n), it results from a process during a specific and regular period. It is possible to represent the mathematical relations between the rate of production rates and the defective and all the relations that help to build and draw clear and fuzzy control schemes. P-control charts' upper and lower bounds are traditionally calculated using the following equations [22]-[24] and based on raw data.

$$P = \frac{D}{p} \tag{1}$$

P: proportion of defective, D: total of defective in a subgroup, p: number of items inspected.

$$\text{Central Line } (CL) = \bar{P} = \frac{\sum P}{n} = \frac{\textit{Total number of defective in a period}}{\textit{The total number of samples}} \tag{2}$$

$$\text{Upper control limit } (UCL) = CL + 3\sqrt{\frac{p^{-}(1-p^{-})}{n^{-}}} \tag{3}$$

$$\text{Average sample size } (n^{)} = \frac{\textit{Total number of items insepected}}{\textit{The total number of samples}}, \tag{4}$$

The percentage of faulty items is shown in Eqs. 1 and 2. In Eq. 3, the midpoint. The top limit and lower limit are equal to Eq. 4. According to the above equations, controlling production depends on certain limits subject to monitoring during the production process. Limits tested to determine the valid production rates, i.e., non-defective and defective. These limits are called the control limits, and they have two levels: one is the upper level, and the other is the lower level. In Eq. 5 and Eq. 6, the fuzzy set and ranking function. Fuzzy logic depends on defining a group of clear samples and then expressing it with a fuzzy group. The group's address has a link in the form of ordered pairs. There is also a group called Membership. Both groups can be expressed as the clear, X, and the obscure or fuzzy, A. Thus, the function can be written for the membership of the fuzzy group by fuzzy logic, as in the following equation [25]-[32]:

$$\mu_A(x) = \begin{cases} \frac{\lambda(x-a)}{(b-a)} & Where, \quad a \le x \le b \\ \lambda & at, \quad x = b \\ and, \ \frac{\lambda(c-x)}{(c-b)} & Where, \ b \le x \le c \end{cases} \quad (5)$$

The fuzzy sums can be represented by fuzzy logic trigonometry, which adopts their values and expresses them with $(\tilde{A})$= (a, b, c), which can be included in the following equation:

$$R(\tilde{A}) = \frac{\lambda(a+2b+c)+w(2b-c-a)}{\lambda w+\lambda^2} \quad (6)$$

3. Samples of Production and mathematical implementation models

In this section, two stets are shown in the sections below:

3.1 Samples of production

There are four cases, the first being the traditional case, after taking samples of the production of an electric heater for two months, which is an industrial product (the Ishtar kerosene heater) from one of the major production companies (Light Industries Company), as shown in Table 1. Then, mathematical calculations were carried out to find values for the upper and lower bounds and the middle bound. The percentage of defects for all samples is shown in Table 2 and Fig. 1. For the other cases, fuzzy logic is used.

In the second case, the fuzzy order function is used when w = 0.5 and λ = 0.5. Mathematical calculations were performed to find the values of the upper and lower bounds and the middle bound, as well as the percentage of defects for all samples, as in Tables 3 and 4 and Fig.2.

In the third case, the fuzzy ranking function is used when w = 0.6 and λ = 0.7. Mathematical calculations were performed to find the values of the upper and lower limits and the middle limit, in addition to the percentage of defects for all samples, as in Tables 5 and 6 and Fig. 3.

In the fourth case, the fuzzy ranking function is used when w = 0.2 and λ = 0.9. Mathematical calculations were performed to find the values of the upper and lower limits and the middle limit, in addition to the percentage of defects for all samples, as shown in Tables 7 and 8 and Fig. 4.

Table 1 The production and defective for all samples in two months

N	Def	Pro	N	Def	Pro	N	Def	Pro
1	9	212	11	12	211	21	14	214
2	12	224	12	11	180	22	10	224
3	6	224	13	6	160	23	9	201
4	8	151	14	12	220	24	13	184
5	11	201	15	6	220	25	7	198
6	15	160	16	14	210	26	7	212
7	7	153	17	20	190	27	10	210
8	12	184	18	11	214	28	7	158
9	8	205	19	13	208	29	12	201
10	16	188	20	10	163	30	9	180

Now, by using Eq. 1, it can be shown that the proportion of defective samples for all samples shown in Table 2:

For example, sample one is:

$$P = \frac{D}{p} = \frac{9}{212} = 0.04245283$$

Table 2 The value of the proportion of defective (P) for all samples

No.	P	No.	P	No.	P
1	0.042452	11	0.056872	21	0.065420
2	0.0535714	12	0.061111	22	0.044642
3	0.0267857	13	0.0375	23	0.044776
4	0.0529801	14	0.054545	24	0.070652
5	0.0547263	15	0.027272	25	0.035353
6	0.09375	16	0.066666	26	0.033018
7	0.0457516	17	0.105263	27	0.047619
8	0.0652173	18	0.051401	28	0.044303
9	0.039024	19	0.0625	29	0.059701
10	0.0851063	20	0.0613496	30	0.05

The second step is to use Equations (2-4) to calculate the middle limit, the upper limit, and the lower limit: Eq. 2 calculates the middle limit, Eq. 3 calculates the upper limit, and Eq. 4 calculates the lower limit.

$$CL = \bar{p} = \frac{\sum P}{n} = \frac{1.639337}{30} = 0.0541$$

Average sample size (n^{-}) =

$$\frac{Total\ number\ of\ items\ insepected}{The\ total\ number\ of\ samples} = \frac{5860}{30} = 195$$

$$UCL = CL + 3\sqrt{\frac{p^{-}(1-p^{-})}{n^{-}}} = 0.1027$$

$$(LCL) = CL - 3\sqrt{\frac{p^{-}(1-p^{-})}{n^{-}}} = 0.0055$$

Results for Samples of Production: After this step, the attribute control charts for the quality control charts can be obtained using the software Minitab (16), as shown in Fig. 1.

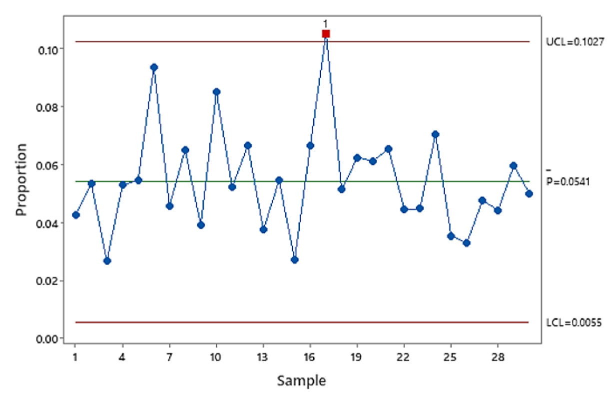

Figure 1. A p- p-chart to illustrate the trail central line and control limits using the data from Table 2

3.2. Mathematical implementation models

By providing the values of the w, where their values are between zero and one w, [0, 1], the fuzzy numbers can be derived by using equal (5) and taking into account that (a, b, c) = (all samples x, all samples + x), respectively, as shown in

Table 3. Three examples were selected for the current work, and they included the following:
Now, compute a new ranking function using the values of λ = 0.5 and w = 0.5.
The ranking function is then discovered using Eq. (6).

Table 3. Defective samples by using the Fuzzy ranking function when w=0.50, λ=0.50

No.	Def.	No.	Def.	No.	Def.
1	18	11	24	21	56
2	24	12	22	22	40
3	12	13	12	23	36
4	16	14	24	24	52
5	22	15	12	25	28
6	30	16	28	26	28
7	14	17	40	27	40
8	24	18	22	28	28
9	16	19	26	29	48
10	32	20	20	30	36

Applying attribute control charts to all samples when λ = 0.5 and w = 0.5 is the next step. Find (p) in the equation first (4), as shown in Table 4.

$P1 = \frac{18}{212} = 0.0.0849056604$, and so that

$$CL = \bar{P} = \frac{\sum_{i=1}^{30} P_i}{30} = 0.109289163$$

Table 4. P-fuzzy value when w= 0.5 and λ= 0.5

No.	P	No.	P	No.	P
1	0.084906	11	0.113744	21	0.130841
2	0.107143	12	0.122222	22	0.089286
3	0.053571	13	0.075	23	0.089552
4	0.10596	14	0.109091	24	0.141304
5	0.109453	15	0.054545	25	0.070707
6	0.1875	16	0.133333	26	0.066038
7	0.091503	17	0.210526	27	0.095238
8	0.130435	18	0.102804	28	0.088608
9	0.078049	19	0.125	29	0.119403
10	0.170213	20	0.122699	30	0.1

Second, determine the equation's middle limit for the attribute control (1).
The upper limit is also obtained using the mathematical representation of the attribute control element in Eq. 2.
The lowest limit of attribute control can be calculated now according to the following Eq. 3:

$$UCL = CL - 3 \times \sqrt{\frac{p^{-}(1-p^{-})}{n^{-}}} = 0.423$$

Lastly, the attribute control charts are used to draw the quality control charts, as shown in Fig. 2.

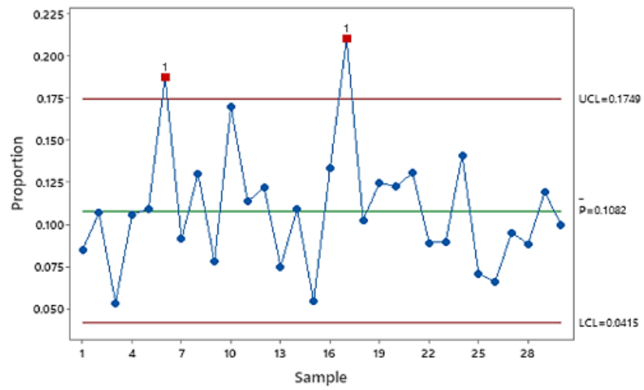

Figure 2. Fuzzy P Control Chart at w =0.5 and λ=0.5,

The values of w are now used to generate a new ranking function: w = 0.6, λ = 0.7. The ranking function (6) is derived using one of the above equations, as shown in Table 5.

Table 5. The imperfect ranking of faulty samples

No.	Def.	No.	Def.	No.	Def.
1	25.2	11	33.6	21	39.2
2	33.6	12	30.8	22	28
3	16.8	13	16.8	23	25.2
4	22.4	14	33.6	24	36.4
5	30.8	15	16.8	25	19.6
6	42	16	39.2	26	19.6
7	19.6	7	56	27	28
8	33.6	18	30.8	28	19.6
9	22.4	19	36.4	29	33.6
10	44.8	20	28	30	25.2

When λ = 0.7 and w = 0.6, apply attribute control charts to all samples by first locating (p) in Eq. 4, as illustrated in Table 6.
$P1 = 25.2 / 212 = 0.118868$

Table 6. P-fuzzy value when w= 0.6 and λ= 0.7

No.	P	No.	P	No.	P
1	0.1188	11	0.1592	21	0.1831
2	0.15	12	0.1711	22	0.125
3	0.075	13	0.105	23	0.1253
4	0.1483	14	0.1527	24	0.1978
5	0.1532	15	0.07636	25	0.0989
6	0.2625	16	0.18666	26	0.0924
7	0.1281	17	0.29473	27	0.1333
8	0.1826	18	0.14392	28	0.1240
9	0.1092	19	0.175	29	0.1671
10	0.2382	20	0.17177	30	0.14

Calculate the equation's middle limit for the attribute control (1).

$$CL = \bar{P} = \frac{\sum_{i=1}^{30} P_i}{30} = 0.153004828$$

Then, use the equation to get the upper limit of the attribute control (2).

$$UCL = CL + 3 \times \sqrt{\frac{p^{-}(1-p^{-})}{n^{-}}} = 0.23027$$

The lower limit of attribute control is calculated using equation (3).

$$UCL = CL - 3 \times \sqrt{\frac{p^{-}(1-p^{-})}{n^{-}}} = 0.075732$$

Lastly, the quality control charts will be created using the attribute control charts, as illustrated in Fig. 3.

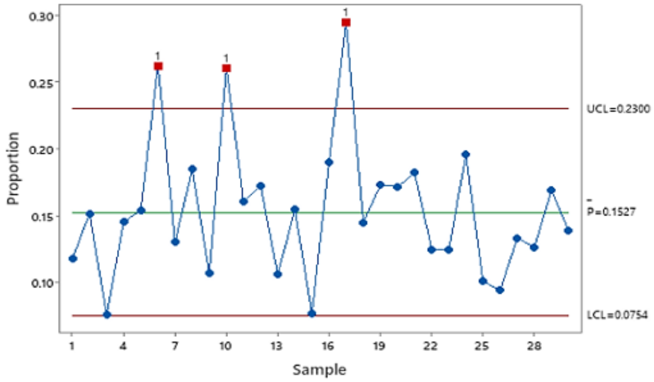

Figure 3. Fuzzy P Control Chart when λ=0.7, w=0.6

Now, a new ranking function may be computed using the values of w, which are λ = 0.9 and w = 0.2. The equation is then used to derive the ranking function (6), as illustrated in Table 7.

Table 7. Defective samples by using the Fuzzy ranking function when w = 0.2 and λ = 0.9

No.	Def.	No.	Def.	No.	Def.
1	32.4	11	43.2	21	50.4
2	43.2	12	39.6	22	36
3	21.6	13	21.6	23	32.4
4	28.8	14	43.2	24	46.8
5	39.6	15	21.6	25	25.2
6	54	16	50.4	26	25.2
7	25.2	17	72	27	36
8	43.8	18	39.6	28	25.2
9	28.8	19	46.8	29	43.2
10	57.6	20	36	30	32.4

When λ = 0.9 and w = 0.2, apply attribute control charts to all samples by first locating (p) in Eq. 4, as illustrated in Table 8.

$P = \frac{32.4}{212} = 0.1528301887$ and so that

Table 8. Value of P for Fuzzy ranking function if w=0.2, λ =0.9

No.	P	No.	P	No.	P
1	0.15283	11	0.20473	21	0.23551
2	0.19285	12	0.22	22	0.16071
3	0.09642	13	0.135	23	0.16119
4	0.19072	14	0.19636	24	0.2543
5	0.19701	15	0.09818	25	0.1272
6	0.3375	16	0.24	26	0.1188
7	0.16470	17	0.37894	27	0.1714
8	0.23478	18	0.18504	28	0.1594
9	0.14048	19	0.225	29	0.2149
10	0.306383	20	0.22085	30	0.18

Second, determine the middle limit of the attribute control (1).

$$CL = \bar{P} = \frac{\sum_{i=1}^{30} P_i}{30} = 0.196720493$$

Then, use the equation to get the upper limit of the attribute control (2).

$$UCL = CL + 3 \times \sqrt{\frac{p^{-}(1-p^{-})}{n^{-}}} = 0.282048$$

Calculate the equation's lower limit of attribute control now (3).

$$UCL = CL - 3 \times \sqrt{\frac{p^{-}(1-p^{-})}{n^{-}}} = 0.111393$$

Lastly, the quality control charts will be created using the attribute control charts, as illustrated in Fig. 4.

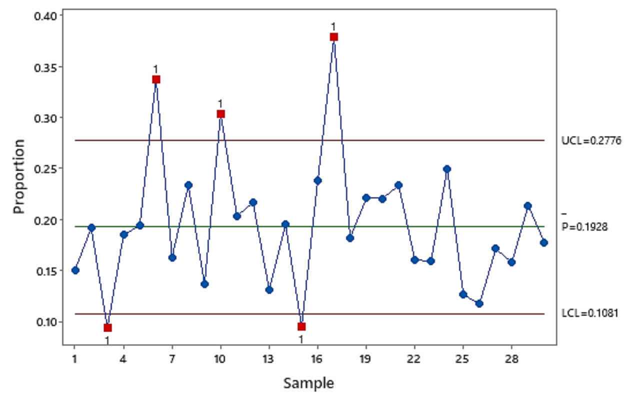

Figure 4. Fuzzy P Control Chart when λ=0.9, w= 0.2

4. Results

After completing the required calculations and drawing the traditional and fuzzy P-chart and fuzzy chart for 30 samples of an industrial product (Ishtar Kerosene Heater) at Light Industries Company, using the MINITAB 21 software, it turns out as follows:

1. Fig. 1 displays the values of the control limits for the P-faulty CHART's proportions. The three control limits—upper control limit, center limit, and lower control limit—as well as the two samples (6 and 17) produce the upper limit of the line.
2. Fig. 2 shows the fuzzy chart's control limit values at λ = 0.5 and w = 0.5. The two samples (6 and 17) produce the upper control limit of the line, which is equal to 0.1749, 0.0822 for the center limit, and 0.0415 for the lower control limit.
3. Fig. 3 shows the fuzzy chart's control limit values at λ = 0.7 and w = 0.6. Three samples (6, 11, and 17) produced the upper limit of the line, while two samples (3, 15) applied the lower control limit. The upper control limit was 0.2300, the center limit was 0.1527, and the lower control limit was 0.0754.
4. The fuzzy chart's control limit values at λ = 0.9 and w = 0.2 are shown in Fig.4. Three samples (6, 11, and 17) produce the upper limit of the line, while two samples (3, 15) produce the lower control limit. The higher control limit equals 0.2776, the center limit is 0.1928, and the lower control limit is 0.1081.

Through the above four points, only two samples are outside the upper limit of control in the p-chart, while (2-5) samples in the fuzzy chart are outside the upper and lower limits of control shown in Fig. 2 to Fig.4, which means they were more sensitive to the changes taking place in product quality. The results showed that fuzzy multinomial control charts with varying sample sizes were more adept at spotting changes in quality. Because it considers all product levels and whether they are acceptable or not. Therefore, this type of control chart must be considered to monitor the quality while accurately classifying the goods according to specialists. Because of the size of the variable samples of the heater product examined in the research, it is better to use the appropriate type of chart to control the quality of the product. Which is not dependent (acceptable or unacceptable) when examining the product, as in the P chart, so applied fuzzy multinomial control chart with a variable sample size, which is more sensitive in giving warning of the change in the level specification quality of the product and better than the conventional chart.

5. Conclusions

Through the use of computer programs to simulate the proposed manufacturing environment to achieve high quality and reliability. Two methods were adopted to conduct the proposed tests, specifying the type and quantity of the sample to be tested according to the process of creating blueprints, first by the traditional method and second by the improvement method proposed, which is fuzzy logic. The suitability of the proposed control method was verified according to the sample, which included the quality control scheme environment to estimate the percentage of defective items in the total group. The results show that it is more sensitive to the limits of uncertainty within the scheme and represents the existing features. It can also be concluded that it is highly efficient. These diagrams can be used in the control process of industrial applications. In researching future industrial applications, reducing elements of uncertainty or mismatches is useful. It requires those working in the industry and production within manufacturing quality to create an appropriate environment that includes developing production control schemes of the proposed type, i.e., fuzzy logic. Crisp and fuzzy control charts for all production samples were analyzed and compared with reference results to determine whether production was under control. It was found that the fuzzy control chart is economically faster and highly accurate in controlling production quality, leading to the better detection of defective items throughout the production process, which in turn aids in the rapid detection of errors. The results analysis showed that control charts based on fuzzy sets produce more accurate and practical results.

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Author Contributions:
All authors conducted the work equally.

Conflicts of Interest:

The authors declare no conflict of interest

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