EDE3015-Data Analytics [2024/25 T1]

Data Analytics Project 1

B.Eng. (Hons.) Electronics and Data Engineering

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Abstract

The objective of the project is to give an overview of the injection moulding process. To highlight the importance of process parameters monitoring to ensure product quality. The company's goal is to implement a parameter monitoring system by observing the key parameters responsible for these key parameters.

The project is given with 12 different parameters, 5 of them which are Cylinder Heating Zones.
In the data set, the dependent variable is the product condition. It changes due to different process parameters (independent variables) settings. Key process parameters are measured including:

- Cylinder heating zone 1: temperature at Cylinder heating zone 1
- Cylinder heating zone 2: temperature at Cylinder heating zone 2
- Cylinder heating zone 3: temperature at Cylinder heating zone 3
- Cylinder heating zone 4: temperature at Cylinder heating zone 4
- Cylinder heating zone 5: temperature at Cylinder heating zone 5
- Maximum Injection Pressure: Maximum mould fills pressure
- Mould Temperature Control Unit 1: reheat the mould and then to keep the mould at the temperature set point
- Cycle time: overall moulding cycle time
- Injection time: the time it takes the screw to move from the injection start position to the transfer position
- Dosage time: the time that it takes the screw to move from the injection start position to the transfer position
- Switch-over volume: the V/P switch-overmindicates the point - usually a percentage of the total volume - where the injection moulding machine (IMM) will change the filling process from a velocity driven (fill) to a pressure driven control (pack).
- Material cushion: the material remaining in front of the screw, after the mould filling and pack stages of the injection process is called the cushion. Having a cushion ensures that the screw does not bottom out against the front barrel.

In this project we will use the following concepts for our project workflow- data preprocessing, statistical analysis, and data visualisation, and key findings to aid us with our research.

This project focuses on understanding the dataset's structure, methods for preprocessing the data, performing statistical analysis, and choosing the right visualisation with our given key parameters to better understand the correlation, the relationship of each parameter with each other.

Introduction

Context

Quality experimental data from an injection moulding machine are collected under three different manufacturing conditions: normal, condition 1, and condition 3. The normal condition serves as the baseline, while the other conditions result from adjustments in process parameters. The company aims to implement a parameter monitoring system that can provide early warnings about products produced under varying conditions.

Problem Statement

The task of this project is to identify the key parameters that distinguish between the 3 conditions (normal, condition 1, condition 3), in the dataset given.

Objectives

The objective of this project is to apply the key concepts that we learn in EDE3015 - Data Analytics [2024/25 T1]. Data preprocessing is used to clean our data to further allow us to apply data analysis to determine which parameters significantly impact the classification of different manufacturing conditions and help in early detection of deviation.

Scope

In this project, the project workflow has been broken down into 3 core components - **data processing**, **data visualisation** and **data analysis**. In the 7 weeks that includes 14 labs, and 14 lectures, we have learnt to implement these concepts and utilise python in Project 1:

- Python libraries: Seaborn, Pandas, Matlab (Tut 4)
- Applying statistical analysis with histogram for representation (L4)
- Assessing normality using box-plot (L4)
- Utilising normalisation and Radar-plot for visualisation (L3)

1. Data Description

Dataset Overview - ‘missingdata.csv’

There are a total of 117 rows, 13 key parameters. There are no continuous values found in the dataset hence the result is not a regression issue. The data presented is a classification issue. To show that the possibility of this dataset is a classification issue, this can be identified from the dataset showing the records are catalogued by Condition columns in the moulding process. There are a total of 3 different classes, classified as Conditions: **Normal1, Condition1, Condition3** which is further explained below from our initial observations.

	Condition	Cylinder heating zone 1	Cylinder heating zone 2	Cylinder heating zone 3	Cylinder heating zone 4	Cylinder heating zone 5	Mould temperature control unit 1	Maximum injection pressure	Injection time	Dosage time	Cycle time	Switch-over volume	Material cushion
0	Normal1	288.35	299.23	322.16	295.85	314.59	89.59	1561.72	0.234	3.136	27.870	1.44334	0.918447
1	Normal1	281.62	290.25	296.76	297.53	310.64	89.37	1548.98	0.224	2.998	27.548	1.41334	0.929772
2	Normal1	285.52	304.26	311.49	302.41	320.42	89.96	1419.08	0.234	2.998	30.216	1.44334	0.899388
3	Normal1	NaN	286.23	320.73	319.29	327.56	86.06	1565.21	0.234	NaN	28.256	1.34334	0.996952
4	Normal1	273.88	280.36	299.98	299.78	304.21	89.66	1515.13	0.224	3.118	27.976	1.47334	0.929580
...	...	...	...	...	...	...	...	...	...	...	...	...	...
112	Condition1	NaN	NaN	323.61	315.21	323.65	86.97	1465.74	NaN	2.898	27.432	1.39334	0.950520
113	Condition1	301.68	309.77	316.82	334.03	330.15	92.55	1476.05	0.244	2.916	27.962	1.42334	0.910520
114	Condition1	303.87	310.13	334.06	324.99	327.33	NaN	1478.77	0.244	2.926	28.464	1.40334	0.898255
115	Condition1	297.24	294.73	304.92	323.80	320.90	88.76	1555.17	0.234	2.880	29.044	1.44334	0.868255
116	Condition1	287.87	292.67	322.59	330.20	326.25	94.36	1567.30	0.234	2.920	30.302	1.44334	0.980734

117 rows × 13 columns

Figure 1.1: overview of ‘missingdata.csv’ dataset

Initial Observations

Based on the results, we observed that the ‘**Normal1**’ condition has the highest number of records with 50 entries and can be represented as the most frequently used in the moulding process, followed by ‘**Condition3**’ condition with a total of 40 entries as moderately used and lastly, ‘Condition1’ condition consisting 27 records with the least in the system.

	Condition	Total Records
0	Condition1	27
1	Condition3	40
2	Normal1	50

```
No duplicate rows found.
0      False
1      False
2      False
3      False
4      False
       ...
111    False
112    False
113    False
114    False
115    False
Length: 116, dtype: bool
```

Figure 1.2 & 1.3: No. of data rows for each Condition & calculation of any duplicated rows respectively

```
Missing values distribution by column:
```

Condition	Cylinder heating zone 1	Cylinder heating zone 2	Cylinder heating zone 3	Cylinder heating zone 4	Cylinder heating zone 5	Mould temperature control unit 1	Maximum injection pressure	Injection time	Dosage time	Cycle time	Switch-over volume	Material cushion	Total Missing Values
Condition1	2	2	2	2	2	2	2	2	2	2	2	2	24
Condition3	2	2	2	2	2	2	2	2	2	2	2	2	24
Normal1	2	2	2	2	2	2	2	2	2	2	2	2	24

Figure 1.3: calculation of missing values by column

In our findings, we found that almost all parameters have the same number of missing data values.

In addition, there is almost an equal number of missing values for each condition (23-24 null values each). We split them into each condition and almost all have up to 2 missing values for each parameter.

2. Data Preprocessing

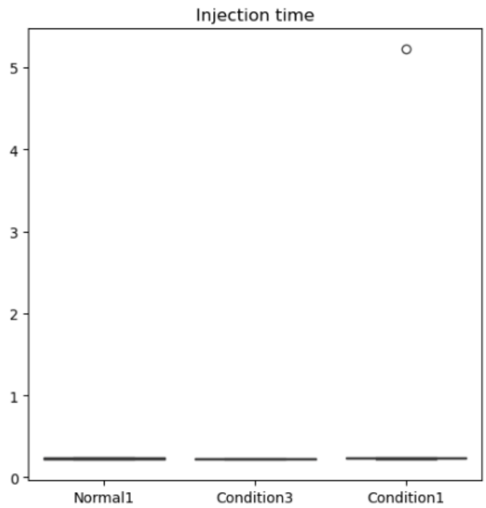
Since there is quite a significant number of missing data values, we opted out for dropping the missing data records. Interpolation method was also not used as the dataset does not seem to be time-continuous based and it is proved to be a classification issue. Hence, we replaced the missing data with mean values based on their condition instead to have the records to be more meaningful. However, this can only be done after removing any outliers or duplicated rows.

```
Outliers detected in Injection time:
     Condition  Injection time
92  Condition1            5.23
```

```
Removing Outliers detected in Injection time:
     Condition  Injection time
92  Condition1            5.23
```

Figure 2.1 & 2.2: Detection and Removing of Outliers

From our testing, we identified an error-type outlier that stood out from the rest of the parameters with box-plot. This can be visualised from the box plot. Since there is only one error-type of outlier detected, we can remove it for better accuracy in our data analysis.




```
No duplicate rows found.
0      False
1      False
2      False
3      False
4      False
       ...
111    False
112    False
113    False
114    False
115    False
Length: 116, dtype: bool
```

Figure 2.3 & 2.4: Extreme outlier spotten in Condition 1 Injection Time & calculation of duplicated rows respectively

We also check if there are any duplicated rows and results are shown that the values are unique in its own record. At this stage, missing data values can be replaced according to their condition column. There are no 'NaN' values that can be found in the dataset. This concludes our data-preprocessing stage and moves on to data analysis and data visualisation.

3. Statistical Analysis

Descriptive Statistics

We calculated the key statistics (mean, median, range, standard deviation) for each parameter under each condition. (normal, condition 1, condition 3)

Under Cylinder heating zones, '**Condition1**' statistics show a higher mean temperature across all heating zones. This can be seen specifically in zone 3, 4 and 5 compared to '**Normal1**' and 'Condition3' statistics.

Under Maximum injection pressure, '**Normal**1' and '**Condition3**' have higher values than '**Condition1**', however the standard deviation readings indicate more than 40 units that there could be moderate variation in the injection pressure.

Comparing the data of cycle time, dosage time and injection time, all conditions have similar readings and low standard deviation. This shows they have minor variation.

Under switch-over volume and material cushion, both respective data show that **'Condition3**' has the highest readings compared to the rest. This shows that they have some changes in the machine's performance in the switch-over process and the quality of the manufacturing.

Normal Condition Statistics:

	Statistics	Cylinder heating zone 1	Cylinder heating zone 2	Cylinder heating zone 3	Cylinder heating zone 4	Cylinder heating zone 5	Mould temperature control unit 1	Maximum injection pressure	Injection time	Dosage time	Cycle time	Switch-over volume	Material cushion
0	Mean	278.5131	296.6952	310.5396	310.1256	316.5706	89.7312	1545.8202	0.2332	2.9418	28.801	1.4052	0.9539
1	Median	277.9366	297.9626	310.8250	311.2400	316.5706	89.6956	1551.7800	0.2340	2.9449	28.811	1.4033	0.9539
2	Standard Deviation	7.9707	9.3102	8.4971	9.8924	8.1596	2.4900	42.4027	0.0080	0.0897	0.898	0.0401	0.0275

Condition 3 Statisics:

	Statistics	Cylinder heating zone 1	Cylinder heating zone 2	Cylinder heating zone 3	Cylinder heating zone 4	Cylinder heating zone 5	Mould temperature control unit 1	Maximum injection pressure	Injection time	Dosage time	Cycle time	Switch-over volume	Material cushion
0	Mean	279.1303	295.9108	309.2111	309.5142	315.3261	89.5789	1539.0629	0.2288	2.8673	28.7359	1.5635	1.0498
1	Median	277.4550	296.7904	309.2111	309.5142	314.8050	89.7150	1536.4214	0.2280	2.8673	28.6500	1.5651	1.0507
2	Standard Deviation	8.7694	9.4153	9.7033	9.2905	8.4328	2.1969	48.1989	0.0076	0.0862	0.8622	0.0388	0.0365

Condition 1 Statistics:

	Statistics	Cylinder heating zone 1	Cylinder heating zone 2	Cylinder heating zone 3	Cylinder heating zone 4	Cylinder heating zone 5	Mould temperature control unit 1	Maximum injection pressure	Injection time	Dosage time	Cycle time	Switch-over volume	Material cushion
0	Mean	288.7450	303.8742	322.0517	318.0192	325.4342	91.0996	1487.9960	0.2361	2.9045	28.8058	1.4204	0.9187
1	Median	288.1900	303.5471	322.8900	318.0192	325.4342	91.0848	1482.2250	0.2340	2.9052	28.8029	1.4219	0.9164
2	Standard Deviation	8.0245	9.4241	8.7363	7.6660	7.7840	2.1450	40.4804	0.0069	0.0892	0.6681	0.0416	0.0277

Figure 3.1: Statistics Table separated by each Condition

Insights

- CYLINDER HEATING ZONES: This parameter helps to highlight the temperature control used in the moulding process to determine the quality and consistency of the products moulded. Any alterations from these zones may affect the consistency in material flow and mould filling.

- MAXIMUM INJECTION PRESSURE: This parameter is important to monitor the moulds are properly filled for its quality and less defects hence it helps to show the variation between the three conditions.
- SWITCH-OVER VOLUME: This is crucial to monitor, especially in Condition 3, because it handles when the machine positions from filling to holding pressure since it impacts for products to be under-filled or over-filled that can have potential to be defects or material waste.
- MATERIAL CUSHION: This plays a significant role for the consistency of products manufactured in its dimensions and shrinkage.

Under different conditions, each of these features varies significantly demonstrating that modifications to these parameters are closely related to the machine's operation.

- **Condition 1** seems to be operated in higher temperatures in Cylinder Heating Zones and lower Maximum Injection Pressure, leading to optimisation for its efficiency and least possible material waste.
- **Condition 3** focuses on operating with higher Switch-over Volumes and Material Cushion which ensure the mould filling to be fully completed.
- **Normal1** condition represents the baseline, with an importance of maintaining high Maximum Injection Pressure for its consistency of product quality.

The conditions can be seen to be represented for different purposes for the moulding process based on the results. There can be a trade-off between the efficiency, quality and material use for each of them in their manufacturing objectives.

4. Data Visualization

Overlapping histograms

The use of overlapping histograms enabled us to observe the variations of each parameter across the three different conditions. This analysis facilitated our assessment of which parameters exhibited greater variability under specific conditions. Specifically, it enabled us to determine the impact on various parameters when the **Cylinder Heating Zones** increased by ~10°C and when the **Switch-over Volume** increased by ~11%.

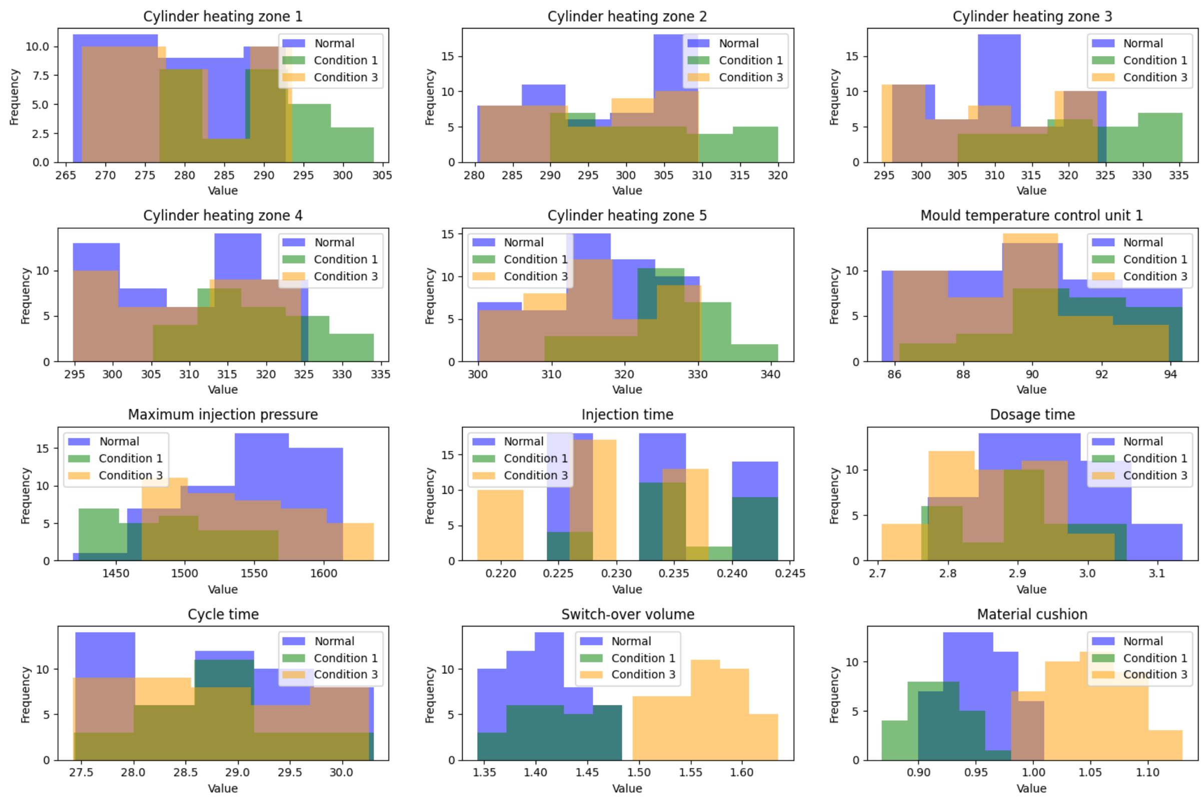


Figure 4.1: Histograms' axes
X-axis: Parameter Value, Y-axis: Frequency (Number of Records)

It should be taken into consideration that the records of the 3 conditions were not equal. Normal condition has 50 records, condition 1 has 26 records, and condition 3 has 40 records. Therefore, to minimise the bias caused by the different number of records, we focused on analysing the patterns within the histograms, in essence, the minimum and maximum values, and the values with the highest and lowest frequencies.

To enhance clarity, we compared each of the two conditions to the normal condition which served as the reference point. This approach allowed us to more effectively visualise the differences in parameter values across the respective conditions.

Condition 1: Cylinder Heating Zones 1-5

A comparison between the normal condition and condition 1 reveals a ~10°C increase in the temperatures within the Cylinder Heating Zones (CHZ) under Condition 1 as seen in Figure 4.1.

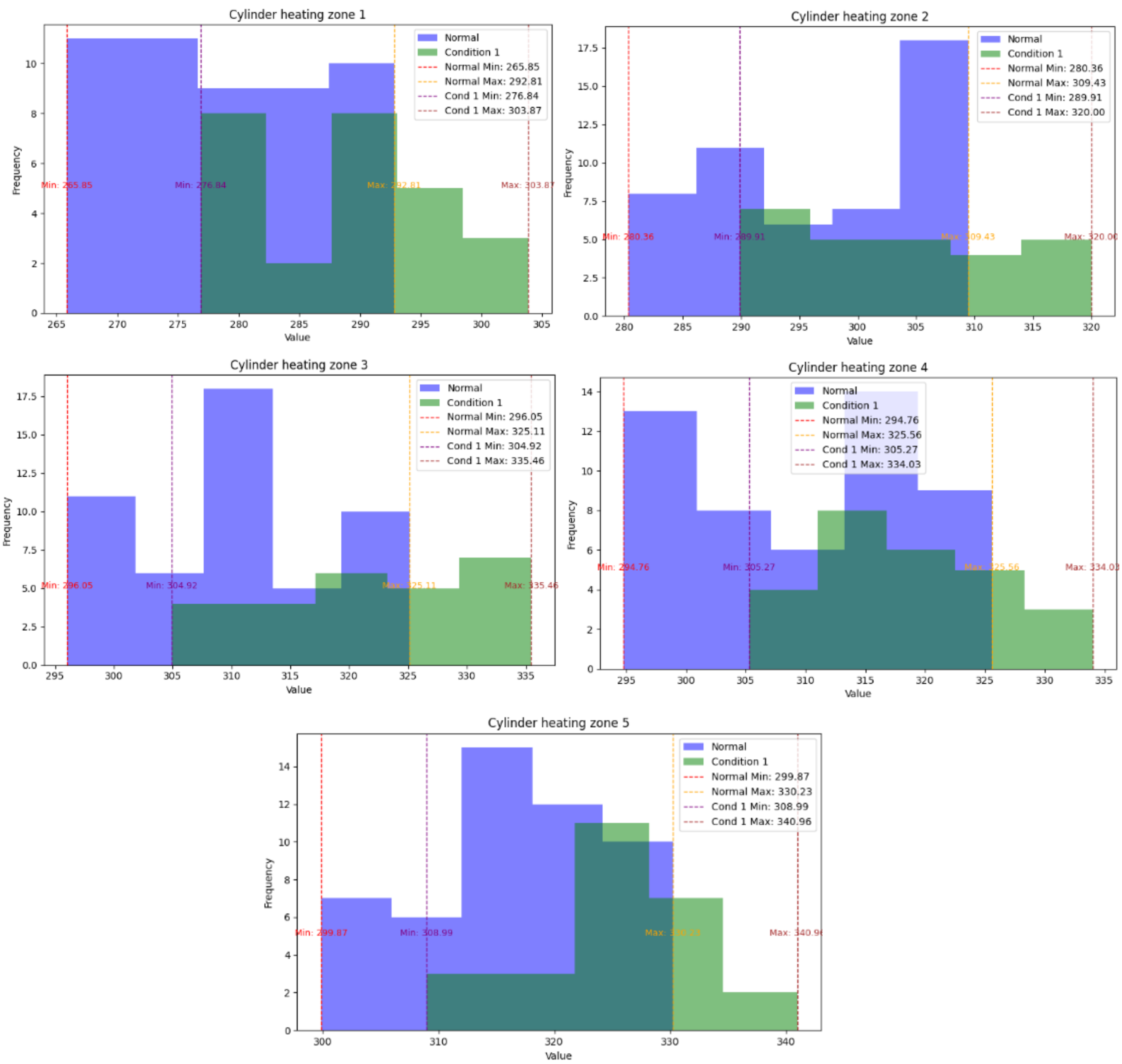


Figure 4.2-6: Histogram comparison of Condition1 and Normal for Cylinder heating zones

After the increase in the CHZ temperatures, we observed that the following parameters were affected:

- **Maximum Injection Pressure,**
- **Material Cushion**
- **and Mould Temperature Control Unit 1.**

Maximum Injection Pressure

Looking at the minimum and maximum values of the maximum injection pressure on Figure 4.2 below, as well as the area where the highest and lowest frequencies of the specific values have occurred for both conditions (circled in red), it can be observed that the maximum injection pressure has decreased significantly for condition 1.

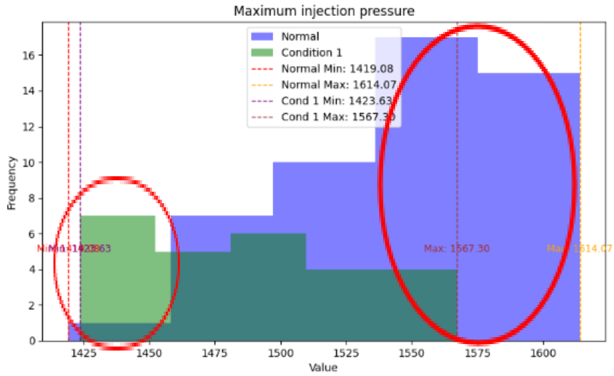


Figure 4.7

Material Cushion

Repeating the same method of observation done previously, it is clearly noticeable that the Material Cushion has decreased for condition 1 as well as seen on Figure 4.8 below.

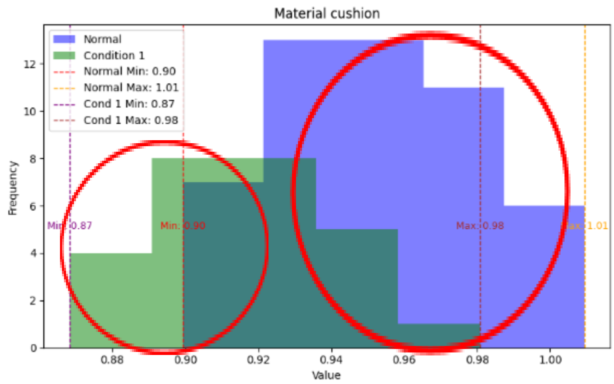


Figure 4.8

Mould Temperature Control Unit 1

Looking at Figure 4.9 below, we observed a sudden spike in frequency under condition 1 (circled in yellow) when the temperature of mould temperature control unit 1 exceeded 90°C. In contrast, when the temperature remained below 90°C (around 86°C to 89.5°C), the frequencies stayed significantly lower (circled in red).

Comparing this with the normal condition, where the frequencies were more consistent across all temperatures (except for a peak around 90°C similar to condition 1), we were able to observe the possibility of temperature rise in mould temperature control unit 1 when condition 1 is applied, whereby there is an **increase in the CHZ temperatures**.

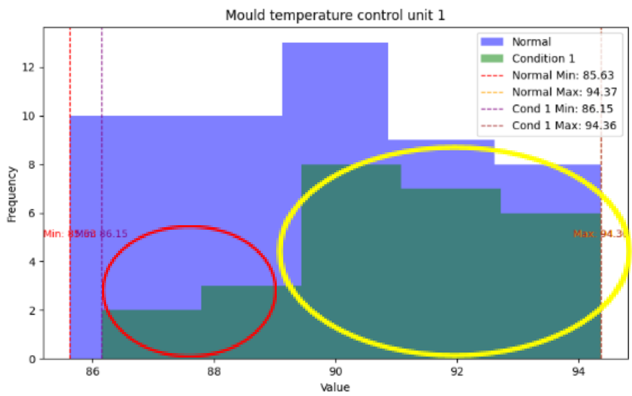


Figure 4.9

Condition 3: Switch-over volume

Figure 4.10 below shows that the minimum and maximum values of the switch-over volume in condition 3 are **~11% higher than** the corresponding values in the normal condition. To be precise, 11.2% higher on the minimum end, and 10.8% higher on the maximum end.

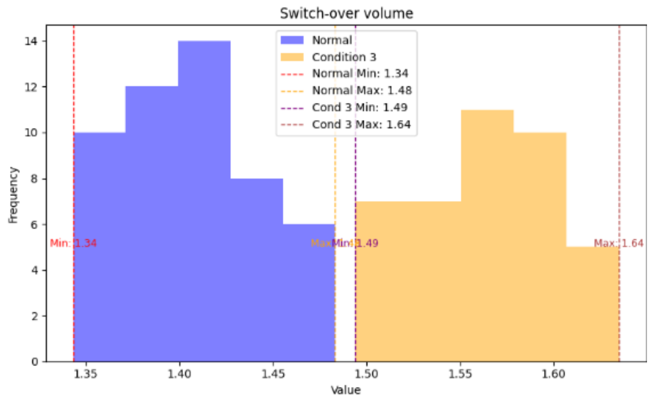


Figure 4.10

After the increase in the switch-over volume in condition 3, we observed that the following parameters were affected:

- Dosage Time,
- Material Cushion,
- and Injection Time.

Dosage Time

Looking at the minimum and maximum values of the dosage time on Figure 4.6 below (circled in blue), as well as the area where the highest and lowest frequencies of the specific values have occurred for both conditions (circled in red), it can be observed that the dosage time has decreased significantly for condition 3.

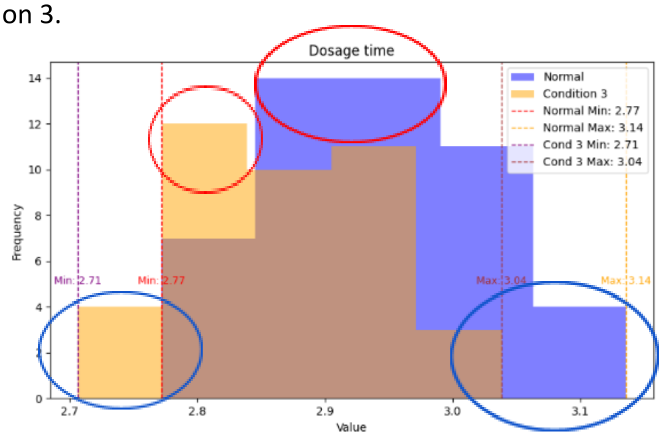


Figure 4.11

Material Cushion

Repeating the same method of observation done previously on the Dosage Time, it is clearly noticeable that the Material Cushion has increased for condition 3 as well as shown in Figure 4.11.

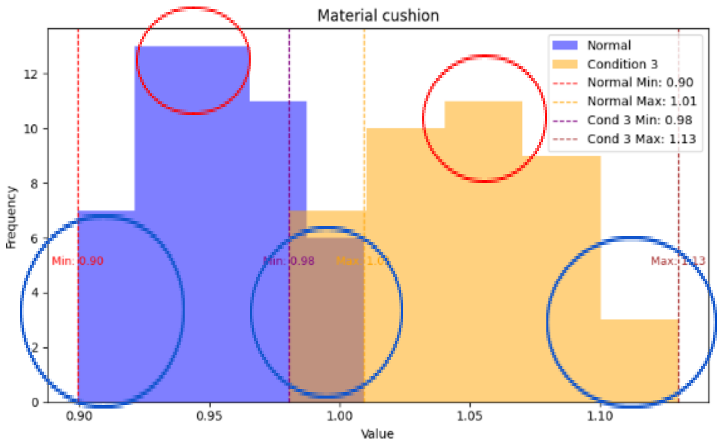


Figure 4.12

Injection Time

Finally, a review of the minimum and maximum values in the histogram below clearly indicates a reduction in Injection Time under condition 3.

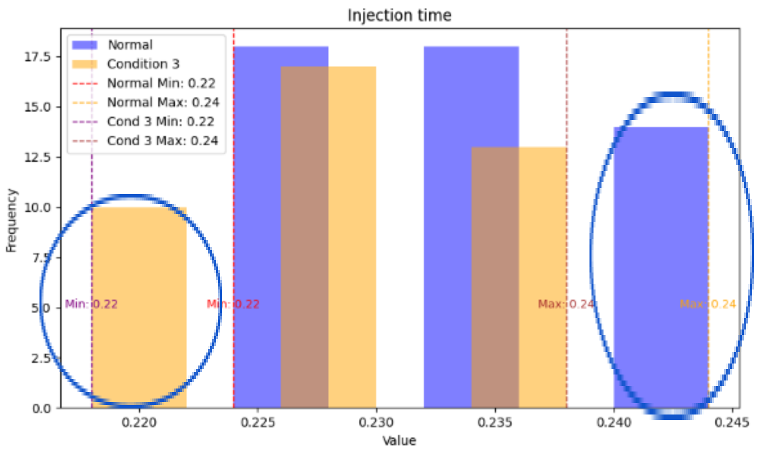


Figure 4.13

Histogram conclusion

Therefore, the analysis of the overlapping histograms revealed that the following parameters —**maximum injection pressure**, **material cushion**, and **mould temperature control unit 1**—are influenced by variations in the temperatures of the cylinder heating zones.

While the variation in switch-over volume affected the dosage time, material cushion and injection time.

Box Plots

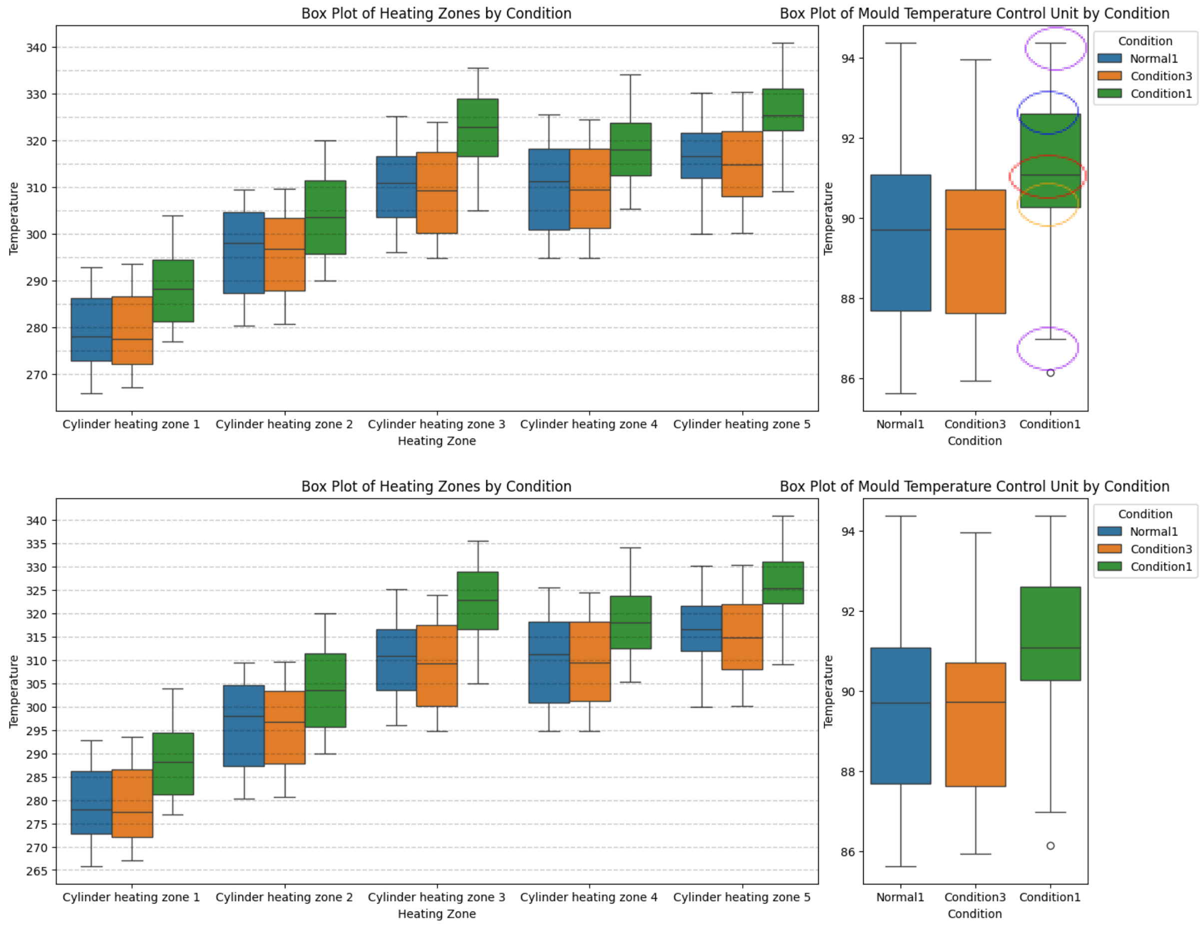


Figure 4.14 & 4.15: y-axis increment by 5 & 10 respectively

To better visualise the difference between the temperature-related parameters across the 3 conditions, boxplots were utilised. They display the following statistical measures:

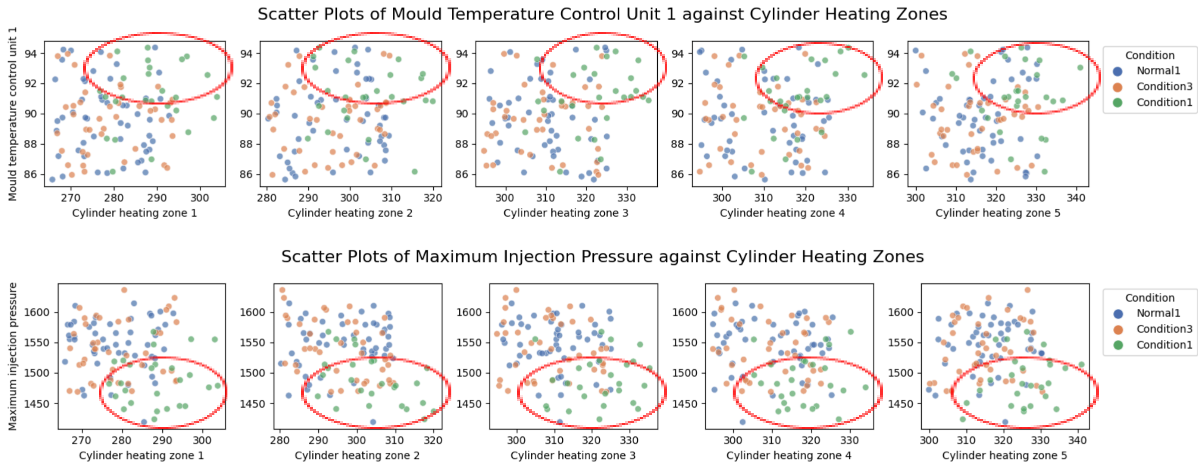
- *Median: Middle value of the parameter by condition, represented by the line in the box.*
- *First Quartile (Q1): The lower edge of the box, representing the value below which 25% of the data falls.*
- *Third Quartile (Q3): The upper edge of the box, representing the value below which 75% of the data falls.*
- *Whiskers: The lines extending from the edges of the box to the largest and smallest value within 1.5 times the IQR range, shows the approximate range of values for that parameter by condition.*

From the boxplots, we observe that the temperatures in **Condition 1** tend to be higher than that of **Condition 3** and the **Normal** Condition. Since only the cylinder heating zones were adjusted to higher levels in Condition 1 , the data suggests that the mould temperature control unit also increased as the temperature of the heating zones rose. This observation is logical as the cylinder heating zones directly affect the temperature of the material being injected into the mould, which in turn could raise the mould's temperature. Thus, we can infer a positive correlation between the cylinder heating zones and the mould temperature control unit.

Pairplot

The purpose of the pairplot is to provide a better visualisation of the relations between different variables in the dataset, giving us an overview of how they interact. It comes in handy to spot correlation, grouping patterns, and odd data points. By examining these relationships, we can figure out which parameters might be connected or separate, which helps to guide further analysis, like selecting features or grouping algorithms.

<u>Condition 1</u>



<u>Figure 4.16</u>

The pair plots in Figure 4.16 shows that all the Heating Zones, when compared with Mould Temperature Control Unit 1 for Condition 1 represented by the green dots, cluster mostly at the top of the pairplot. This indicates an increase in all Heating Zones when compared with Mould Temperature Control Unit 1. For maximum injection pressure, it can be observed that clustering occurs mostly towards the bottom of the pairplot for all the heating zones, which indicates a significant decrease for Condition 1.

Condition3

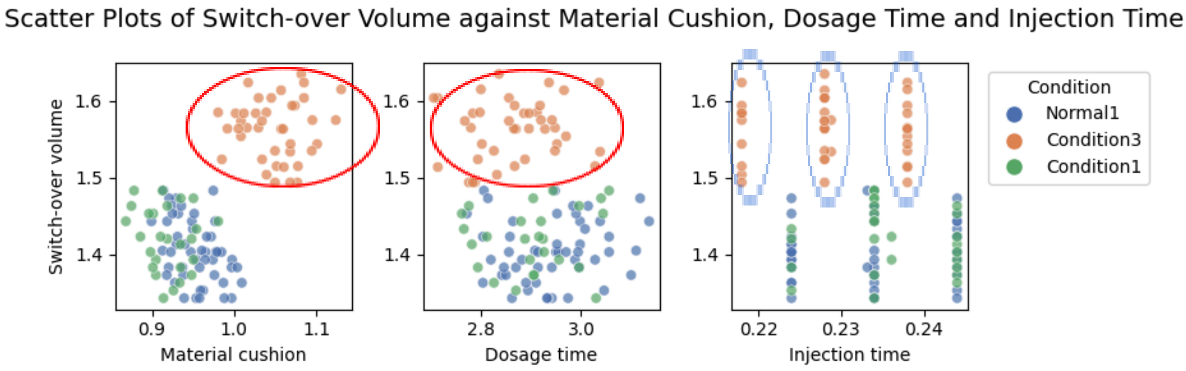


Figure 4.17

The pair plots in Figure 4.17 compares the adjusted parameter: **switch over volume**, with **material cushion, injection time**, and **dosage time**. It shows Condition 3 marked by orange dots standing apart from the other two conditions, without overlap and grouping at the top of the pair plots. As switch-over volume goes up, material cushion values rise too. Yet, dosage time drops , and injection time shifts to the pair plot's left side revealing lower values but no clear correlation for injection time in Condition 3.

Radar Chart

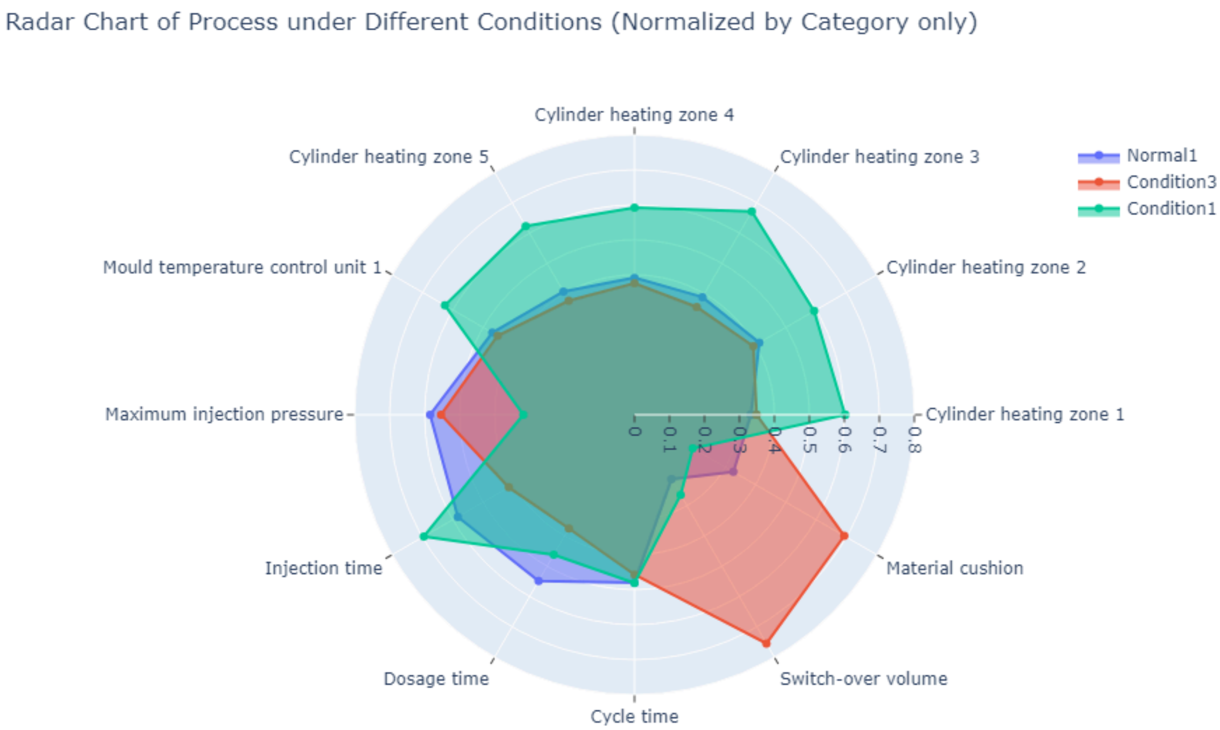
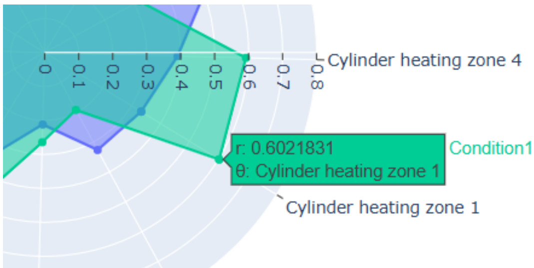


Figure 4.18

For our radar chart, normalisation is needed to give a 1:1 scale across each parameter. The radar chart compares various normalised mean values for different process parameters (e.g., Cylinder heating zones, Injection time, Dosage time, etc.) under three conditions: **Normal1**, **Condition1**, and **Condition3**.

The radar chart allows us to observe how the parameters behave in each condition.

Cylinder heating zones (1-5)



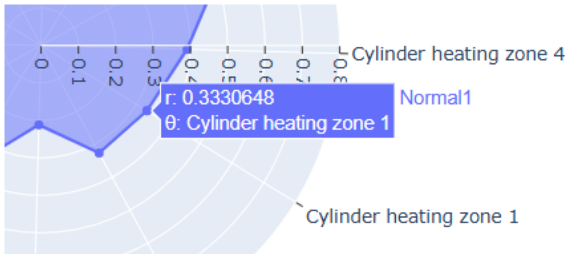


Figure 4.19 & 4.20

Condition 1 shows deviation in Cylinder heating zones (1-5) compared to other conditions, which indicates that this condition operates at higher temperature for the heating zones.

Condition 3 and Normal 1 seem to have no major changes in the heating zones for both conditions, suggesting that they do not require higher heating temperature.

Injection and Dosage Time

Condition 3 shows the lowest dosage and injection time as compared to Normal 1 and Condition 1.

Maximum Injection Pressure

Condition 1 has a relatively lower normalised value for Maximum Injection Pressure, compared to Condition 3 and Normal 1. This could be due to the increase in heating zone temperatures, which cause the material to be less viscous.

Material Cushion and Switch-over Volume

The Material cushion and Switch-over Volume can be seen notably higher in **Condition 3.**

Cycle Time

The cycle time for all 3 conditions are similar and does not appear to have any huge differences.

5. Results

Key Findings

Through our statistical analysis and visual plots, we have identified the key parameters and how they behave under different conditions.

Defining Conditions:

Normal1 serves as the baseline (master setup) for the analysis, due to the behaviour exhibited by Normal1, minimal variance in each parameter is presented. There are no significant spikes observed in any of the graphs, and our analysis done for each condition is based on Normal1 as the baseline.

Settings	Setting Range
Normal 1	Master Setup
Condition 1	Cylinder Heating Zone +10 C, Barrel (325, 320, 320, 305, 290)
Condition 2	Cylinder Heating Zone -10 C, Barrel (305, 300, 300, 285, 270)
Condition3	Switch over position +10% (5mm)
Condition4	Switch over position -10% (4mm)
condition 5	Mold Temperature +10% @ 100 Degree C
condition 6	Mold Temperature -10% @ 80 Degree C
Condition7	Injection Speed +25% @ 100mm per sec
Condition 8	Injection Speed -25% @ 60mm per sec

Figure 5.1

Key Parameter Identification:

We successfully identified these **key parameters**, specifically to each condition:

- Condition 1: Characterised by an increase in **Cylinder Heating Zones (1-5)**
- Condition 3: marked by an increase in **Switch-over Volume.**

These observations are supported by the table above, extracted from the '*DAProject1_1*' document.

Impact of Key Parameters:

We were able to pinpoint the parameters most affected by each condition:

- Condition 1: The increase in Cylinder Heating Zones resulted in higher **Mould Temperature Control Unit** and a decrease in **Maximum Injection Pressure**.
- Condition 3: The increase in **Switch-over Volume** has led to an increase in **Material Cushio**n and decrease in **Dosage Time**.

Further Analysis:

- While the Injection Time parameter showed unusual behaviour, indicated by low correlation in the pair plot, however differences were also observed across the conditions, as seen on the radar plot. This suggests the need for further investigation into Injection Time.

Global Key Parameters:

Material Cushion is identified as a global key parameter influenced by both Condition 1 and Condition 3. These findings demonstrate that this parameter is affected by the changes made in Switch-over Volume and Cylinder Heating Zones.

This analysis highlights the importance of identifying and understanding the behaviour of key parameters under different conditions to optimise the process performances. Further investigation into Injection Time will be necessary to gain deeper Insights.

6. Discussion

Limitations

Limitation of class distribution analysis. A balanced number of data rows for each condition should be presented to prevent biases of data and minimal disturbance for statistical analysis.

Another limitation is the small dataset available for analysis, which amplifies the presence of outliers and introduces greater variability. This, in turn, significantly impacts the reliability of the statistical methods applied to our data.

Future Work

To further analyse Injection Time, we have researched that **T-testing** can be used to compare the mean injection time between two conditions (e.g. Normal1 and Condition1), to determine if the difference is statistically significant. For much further analysis **ANOVA** can be used for analysing across all 3 Conditions.

7. Conclusion

Summary of Findings

The analysis helped identify the key parameters involved in influencing the injection moulding process, allowing for better process monitoring and control. Specifically, Material Cushion is recognized as critical factors under both Condition 1 and Condition 3. Condition 1 exhibited a direct relationship between Cylinder Heating Zones increased in Mould Temperature Control Unit 1 and decrease in Maximum Injection Pressure, while Condition 3 highlighted a significant increase in Switch-over Volume. Further investigation into Injection Time is warranted, as the current analysis revealed unusual patterns as can be seen from the pair plot. The insight gained can guide future adjustments in these process parameters for improved efficiency and quality.

Learning Outcomes

From this project, we gained hands-on experience in cleaning and preprocessing data, identifying key process parameters, and performing data analysis using python using libraries such as matplotlib, seaborn, numpy. We learned how to define our project scope effectively, and identify key parameters through analysis. Additionally, this project provided valuable insights into monitoring and manufacturing processes, particularly injection moulding, which will be useful for future projects, theses or professional roles in process control and optimization.