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Assessing the Relationship between Down Time and Product Quality in the Plastic Manufacturing Sector

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Abstract

Maximizing production while avoiding downtime has become crucial for industries in the complex industrial landscape of today. In order to satisfy client demands, it is essential to provide high-quality products, which may be done by following efficient maintenance procedures. Examining the link between maintenance practices and product quality in the plastic processing industries is the primary goal of this study. The researchers watched the production unit and reviewed documentary material to learn more about the production procedures, equipment performance, and equipment condition. After that, statistical analysis, including chi-square tests and correlation tests, was used to find the nature of the connection between maintenance and product quality in the plastics business. By contrasting the estimated chi-square value with the crucial table value, the chi-square test's findings revealed that there is indeed a substantial correlation between the maintenance and quality of a product. The correlation analysis also showed a significant association between maintenance procedures and product quality. This study emphasizes the significance of a proper maintenance culture in the plastic processing sector for raising productivity and achieving consumer expectations for high-caliber goods. The results highlight the value of spending money on carefully thought-out maintenance tasks to improve product quality.

Keywords: product quality, plastic industry, chi-square, correlation coefficient, downtime, maintenance

1. Introduction

Nowadays plastic have become a major commodity used in both commercial and industrial settings. And due to its high demand, it is essential for plastic manufacturing industries to implement an effective procedure towards improving product quality (Dijkstra, Van Beukering, & Brouwer, 2020). Maintenance helps to consistently produce products free of flaws by guaranteeing the smooth operation of machinery and equipment. The relationship between maintenance and quality control has received a lot of attention as manufacturers try to reorganize their operations, reduce downtime, and maintain effective quality standards. Ensuring the creation of adequate quality plastic products though expensive is crucial in dynamic and competitive environment to satisfy clients and keep a competitive edge on the market (Eygen, Laner, & Fellner, 2018).

This study aims to assess the link between down time and quality of plastic processing in the plastic manufacturing industry. Data will be gathered for the study through the analysis of documentaries and production unit observations. We intend to establish the level of relationships between the number of targets, number of produce, and down times. The Kolmogorov-Smirnov (K-S) Test of Normality will be used to check whether the data follows a normal distribution due to its advantage of no sample size restrictions as it works well for small samples. The Chi-square tests and correlation tests, will be used the significant, strength and direction of relationship between the variables. The findings are intended to offer industry professionals information that will help them effectively satisfy consumer expectations by optimizing maintenance plans and enhancing product quality.

1.1 Literature Review

Poor maintenance practices and a lack of qualified labour are the main causes of low product quality (Eja & Ramegowda, 2020) (Iheanachor, Umokoro, & David-West, 2021). In plastics processing, maintenance and quality control are extremely difficult because out-of-spec components cost the manufacturer money not only for the materials and machine time required to rerun the batch, but also for disposal and recycling fees (Benyathiar, Kumar, Carpenter, Brace, & Mishra, 2022) (Ghoshal, 2019). Identification of important dimensions that could threaten to drift out of tolerance is essential since injection-moulding batches of plastic components can reach millions (Zhao, et al., 2020).

In the current global economy, a company's ability to survive depends on both its capacity to maintain an efficient manufacturing process as well as its ability to improve the quality of its product (Zhou, Li, Zhou, Wang, & Meng, 2018). Companies must advance more quickly than their rivals if they want to be a stakeholder in their segment (Farida & Setiawan, 2022). However, the rapidity of the injection moulding procedure and its maintenance, with conversion processes that are prone to natural variations, present a significant obstacle for effective quality control (Aminadabi, et al., 2022) (Chang, Su, Lu, & Zhang, 2022).

Maintenance was described as the sum of all operations carried out with the intent of keeping production units in place or keeping them in the condition deemed necessary for the performance of their production function (Muchiri, Ikua, Muchiri, Irungu, & Kibicho, 2017). In the past, problems with production were handled through the maintenance process. Its objective was to keep the process going, and the time needed to prepare maintenance activities was minimal. Many plastic companies are now realizing the importance of using a properly maintained systems and facilities for manufacturing (Shahriar, Parvez, & Lutfi, 2020). Industrial facilities, machinery, and equipment are evolving technologically while also growing more complicated and challenging to manage. Due to the maintenance function's significance in preserving and improving availability, efficiency, timely deliveries, and productivity, its importance has grown more than previously (Alsyouf, 2007).

Historically, maintenance has been significant to industries because to its varied operations, resource assessment, and administration (Simões, Gomes, & Yasin, 2011) (Lundgren & and Skoogh, 2021). However, as a result of advancing operational technology and the shifting maintenance function, the necessity to handle the many aspects of maintenance more efficiently has become even more crucial recently (Aracıoğlu, Zalluhoğlu, & Candemir, 2013). Nowadays' open-system manufacturing businesses see maintenance from a wider angle. As a result, the maintenance focus in these companies has evolved from a strictly operational perspective to an organizational strategy perspective (Cooke, 2003) (Al-Najjar, 2007) (Wu, Niknam, & Kobza, 2015)

The secret to success of any company in the market is providing consumer with appropriate quality items in the shortest amount of time at the lowest cost (Rivera-Gómez, Gharbi, Kenné, Ortiz-Zarco, & Corona-Armenta, 2021). Any manufacturing industry must continue to prioritize a quality-driven maintenance system to adapt to and maintain its position in this environment (Gouiaa-Mtibaa, Dellagi, Achour, & Erray, 2018). Without suitable maintenance strategies, the industry cannot manage quality issues effectively (Lopes, 2018). Therefore, current quality management practices aiming for long-term success go beyond simply avoiding the delivery of defective goods to customers to achieving optimum efficiency throughout all business operations. Total quality management can be implemented with such efficient processes to deliver high-quality products (Lu, Lee, & Wang, 2023).

Total quality is a concept and a set of guiding principles for managing an organization that is founded on the core notion that there must be a constant, corporate-wide improvement (Dejanović, Nikolic, & Spajić, 2015). Only a fundamental shift in the organization's culture, as well as changes to its procedures, strategic priorities, and beliefs, among other things, may result in the successful adoption of TQM (Machado, Correa, Queiroz, & Costa, 2023).

Total Quality Process Control (TQPC) is a thorough strategy used by the plastics sector to guarantee the best performance and quality evaluation of the entire production process (Gordon, 2010) (Debnath, et al., 2023). The goal of this approach is to continuously produce quality products, while satisfying the unique requirements of the clients (Hashmi, Hewage, & Visvanathan, 2023).

A wide range of industrial and business networking support systems are engaged in the plastic moulding process, and the creation of superior-quality products depends on these coordinated variables (Feng, Ye, Yang, & Liu, 2021). Product suppliers must coordinate design and manufacturing specifications with materials, numerous machine operations, and auxiliary equipment while guaranteeing a qualified staff in order to deliver high-quality products to their customers (Ahmed, 2023) (Chowdhury, et al., 2023) (Ando, Yokoi, Masuda, & Asari, 2023).

2. Methods

To gather in-depth data on various aspects of maintenance and its effect on the quality of goods in the plastic manufacturing industry, the research methodology combined data collection techniques such as documentary reviews, and in-plant observation.

With the help of the questionnaire, researchers were able to learn more about the maintenance habits and opinions of key stakeholders, including production workers, management, and maintenance employees. The reliability of the available machines, the effectiveness of the manufacturing processes, and the condition of the equipment were evaluated using documentation reviews and observations.

Subsequently, statistical analysis, including chi-square tests and correlation tests, was conducted on the collected data. The chi-square test allowed for the examination of any significant relationship between maintenance efforts and product quality, while the correlation test measured the strength and direction of this relationship. The correlation coefficient was calculated using Microsoft Excel software, providing a quantitative assessment of the association between maintenance practices and product quality. A flow diagram depicting the research methodology is as in Fig 1.

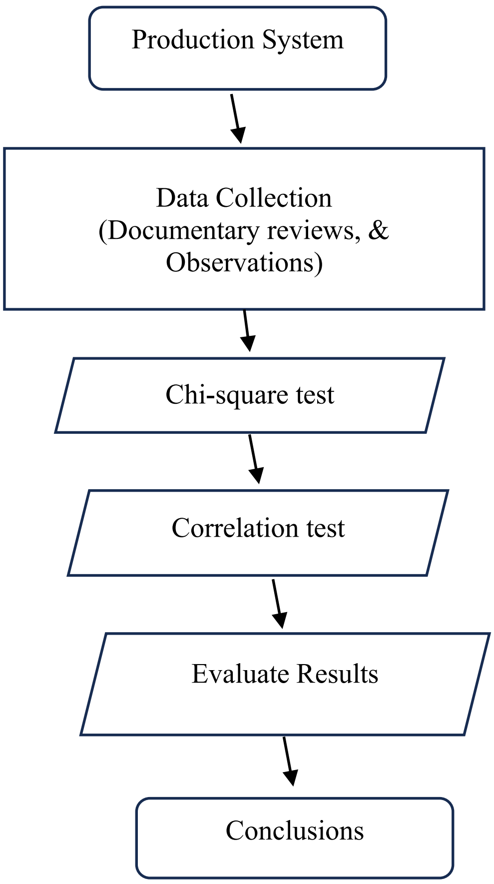

Fig. 1: Research methodology flow diagram

Moving to Fig 4(b), the correlation coefficient between plant downtime (x) and the targeted product quantity (y) is highlighted. Throughout all sessions, the calculated correlation coefficient (r) maintains negative values. This suggests that the escalation in plant downtime is associated with the inability to meet the intended product quantity. In essence, an upsurge in plant downtime directly contributes to the failure to achieve the targeted production levels.

2.1 Chi-square Test

The test statistic for the test of independence is called chi-square statistics, and it is denoted by χ^2. Chi-square formular is stated in (1).

$$\chi^2 = \sum_{i}^{k} \frac{(O_{ij}-e_{ij})^2}{e_{ij}} \quad (1)$$

Where O_{ij} represents the observed frequency (value) in the cell that is located at row i and column j, e_{ij} denotes the expected frequency (value) in the same cell.

The chi-square test of independence's degree of freedom is denoted by the symbol v. Using the formula in (2), the degree of freedom is determined depending on the quantity of rows (r) and columns (c) in the contingency table.

$$v = (r-1)(c-1) \quad (2)$$

2.2 Correlation Coefficient

The coefficient of correlation is a statistical measure that expresses the quality of the linear connection that exists between two variables, x, and y. It is given in (3) and is indicated by the letter "r".

$$r = \frac{n\sum xy-(\sum x)(\sum y)}{\sqrt{n\sum x^2-(\sum x)^2}.\sqrt{n\sum y^2-(\sum y)^2}} \quad (3)$$

The characteristic of the coefficient of correlation (r) includes the following:

(a) Whether we label one set of data as “x” or “y” has no effect on the coefficient of correlation. Without regard to the labels of the variables, it shows the strength and direction of the linear connection.

(b) r satisfies the inequality -1 < r < 1.

(c) When r is close to 1, both variables are highly positively correlated. A weak negative correlation is shown by a r value that is close to -1, meaning that one variable is increasing while the other is linearly decreasing. A very weak correlation or the absence of a linear connection is indicated by a r value close to zero.

(d) The degree to which r is near -1 or +1 reflects how accurate the least squares line is as a predictor. The least squares line is an excellent predictor when a strong connection exists (r is close to -1 or +1). The least squares line, however, could not be a useful predictor when r is near 0, which denotes a minimal correlation (Xia & Li, 2022) (Tian, et al., 2023).

2.3 Data Collection and Analysis

The injection moulding unit, extrusion unit, clamping unit, gate unit, and hybrid unit were among the components of the business that the researchers thoroughly examined. However, information for the analysis was especially gathered from the industrial facility that creates school desk and chair, plates, bowl, appliance housing, stools, bottles and jar, garbage bags, and shopping bag. From the very beginning until the finished product, the entire production process was closely watched.

Table 1: Production and down time records

Type of Moulding Machine	Age of Machine (Years)	No. of Cavity	Cycle time	No. of targets	Products	No. of Products produced per hour	No of Waste	Downtime (Minutes)	Reasons for Downtime
First Session									
Injection	4	50	2	770	School desk	730	40	120	Flash
Hydraulic	6	20	2	850	Plates, bowls	800	50	60	Jetting
Hydraulic	6	25	4	210	Appliance housing	150	60	180	Breaktime
Hybrid	8	10	4	220	Stools	200	20	150	Breaktime
Electric	2	70	2	480	Bottles and jar	450	30	240	Warping
Injection	3.5	30	2	150	CD Cases	120	30	210	Colour
Electric	2	50	3	760	School chair	750	10	90	Strike
Hybrid	9	25	6	170	Garbage bags	100	70	390	Machine
Hybrid	10	20	2	140	Shopping bag	110	40	300	Faulty
Second Session									
Injection	4	50	2	180	School desk	150	30	240	Flash
Hydraulic	6	20	2	250	Plates, bowls	200	50	210	Jetting
Hydraulic	6	25	4	440	Appliance housing	400	40	150	Breaktime
Hybrid	8	10	4	300	Stools	250	50	180	Breaktime
Electric	2	70	2	960	Bottles and jar	950	10	60	Warping
Injection	3.5	30	2	1000	CD Cases	900	100	120	Colour
Electric	2	50	3	770	School chair	750	20	90	Strike
Hybrid	9	25	6	190	Garbage bags	150	40	390	Machine
Hybrid	10	20	2	150	Shopping bag	120	50	300	Faulty
Third Session									
Injection	4	50	2	300	School desk	150	150	180	Flash
Hydraulic	6	20	2	230	Plates, bowls	200	30	150	Jetting
Hydraulic	6	25	4	640	Appliance housing	620	20	60	Breaktime
Hybrid	8	10	4	150	Stools	90	60	240	Breaktime
Electric	2	70	2	100	Bottles and jar	200	80	390	Warping
Injection	3.5	30	2	600	CD Cases	500	100	90	Colour
Electric	2	50	3	150	School chair	100	50	300	Strike
Hybrid	9	25	6	200	Garbage bags	120	100	210	Machine
Hybrid	10	20	2	650	Shopping bag	600	50	120	Faulty

Table 1 shows the production and down time records for machines, the equipment's are operated in three shifts of 8 hours per day respectively. The data was collected in three (3) production sessions.

Normality test was conducted on the number of targets, Number of products produced per hour, and the downtime using Kolmogorov-Smirnov (K-S) Test of Normality. The test result indicates the data set does not differ significantly from that which is normally distributed. And this informed our decisions of using Chi square which is a distribution free (non-parametric) test. The descriptive statistics for the normality tests are shown in Table 2. Fig 2(a) - (c) shows the quantile-quantile (q-q) plot, while Fig 3(a) - (c) shows the distribution histogram plot.

Table 3 shows the observed and expected frequency of machine breakdown in each session of the production process, based on the proportion of the total frequency. Alpha of 0.05 level of significance was adopted.

Table 2: The descriptive statistics for the Kolmogorov-Smirnov test of normality

Descriptive statistics	No. of targets	No. of products per hour	Downtime (Minutes)
Mean	407.78	365.16	272.22
Median	250	200	200
Standard deviation	289.49	288.39	235.80
Skewness	0.7666	0.7826	1.9694
Kurtosis	- 0.9078	- 0.9549	3.3302
K-S test statistics	0.2404	0.2758	0.2419
p-value	0.0739	0.0763	0.07083

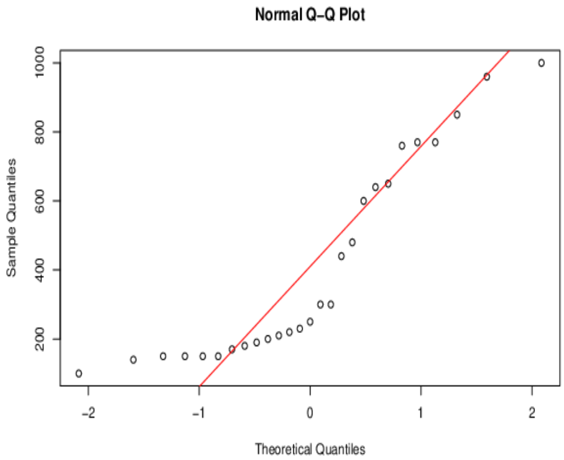

Fig. 2(a):Q-Q plot for number of production target

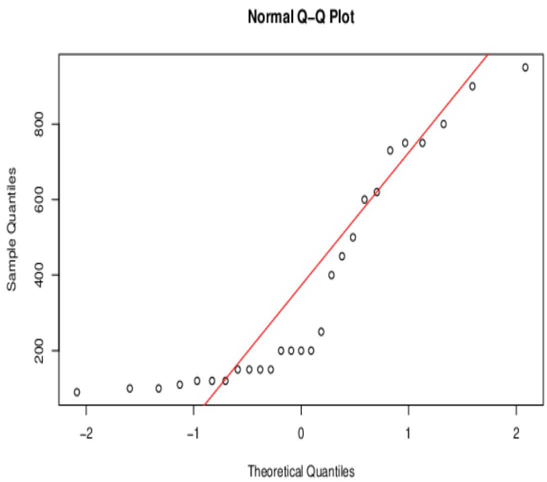

Fig. 2(b): Q-Q plot for number of products produced per hour

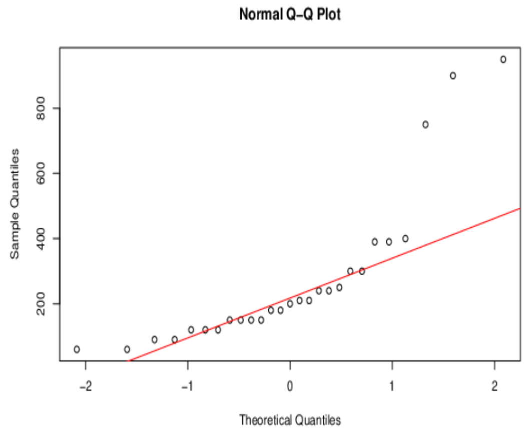

Fig. 2(c): Q-Q plot for downtimes

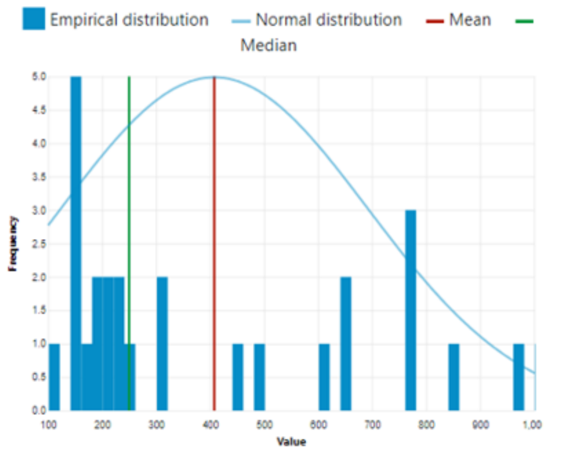

Fig. 3(a): Histogram plot for number of production target

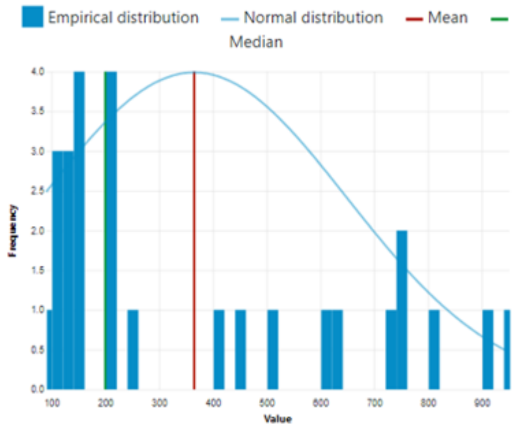

Fig. 3(b): Histogram plot for number of products produced per hour

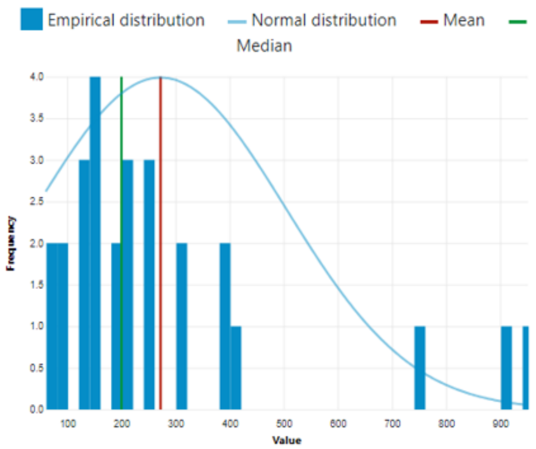

Fig. 3(c): Histogram plot for downtimes

The test hypothesis for the Chi-square (χ^2) test is as stated below, let the null hypothesis be H_0, while the alternative hypothesis be H_a;

Table 3: The observed and expected frequency of machine breakdown during sessions of production under study

	No of waste/ defects	No of targets	No of produce	Total
First Session				
Caused by machine breakdown	350 (497)	3750 (3753)	3410 (3255)	**7510**
Not caused by machine breakdown	650 (503)	3800 (3797)	3150 (3295)	**7600**
Total	**1000**	**7550**	**6560**	**15100**
Second Session				
Caused by machine breakdown	390 (540)	4240 (4216)	3870 (3742)	**8500**
Not caused by machine breakdown	603 (452)	3500 (3523)	3000 (3127)	**7103**
Total	**993**	**7740**	**6870**	**15603**
Third Session				
Caused by machine breakdown	640 (453)	3020 (3064)	2560 (2702)	**6220**
Not caused by machine breakdown	250 (436)	3000 (2955)	2750 (2607)	**6000**
Total	**890**	**6020**	**5310**	**12220**

H_0: There is no significant difference in product quality when the plant downtime is caused by machine failure.

$H_{a:}$ There is significant difference in product quality when the plant downtime is caused by achine failure.

The expected frequencies were determine using the observed frequencies and the total number of waste/defects, number of targets, number of produce, down time caused by machine breakdown, and down time not caused by machine breakdown.

Consequently, Table 4 shows the calculation of the Chi-square using (1), at alpha of 0.05 level of significance.

The degree of freedom using (2)

$$= (2-1)(3-1) = 2$$

The tabulated $\chi^2_{0.05,2} = 5.991$.

The correlation coefficient between the plant's downtime, the number of products produced, and the number of targeted products was calculated using (3). The result is as in Fig 4(a) and 4(b) respectively.

In Fig 4(a), the consistently negative correlation coefficient between plant downtime (x) and the quantity of produced products (y) across all sections is clear. This signifies that to enhance machinery productivity, reducing downtime is imperative. A rise in downtime instances leads to a reduction in the production of products, and conversely, a decrease in downtime is associated with an increase in product output

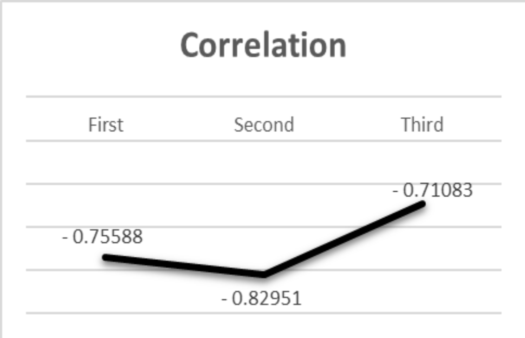

Fig. 4(a): The correlation coefficients between downtime (x) and number of products produced (y)

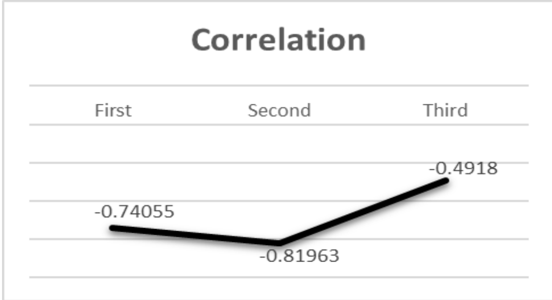

Fig. 4(b): The correlation coefficients between downtime (x) and number of targeted products (y)

Table 4: The calculation of the Chi-square (χ^2)

O_{ij}	e_{ij}	$O_{ij} - e_{ij}$	$(O_{ij} - e_{ij})^2$	$\frac{(O_{ij} - e_{ij})^2}{e_{ij}}$
First Session				
350	497	-147	21609	43.48
650	503	147	21609	42.96
3750	3753	-3	9	0
3800	3797	3	9	0
3410	3255	155	24025	7.38
3150	3295	-145	21025	6.38
Chi-square χ^2				**100.21**
Second Session				
390	540.95	-150.95	22785.903	42.12
603	452.05	150.95	22785.903	50.41
4240	4216.50	23.5	552.25	0.13
3500	3523.50	-23.5	552.25	0.16
3870	3742.55	127.45	16243.503	4.34
3000	3127.45	-127.45	16243.503	5.19
Chi-square χ^2				**102.35**
Third Session				
640	453.01	186.99	34965.26	77.18
250	436.99	-186.99	34965.26	80.01
3020	3064.19	-44.19	1952.7561	0.64
3000	2955.81	44.19	1952.7561	0.66
2560	2702.80	-142.8	20391.84	7.54
2750	2607.20	142.8	20391.84	7.82
Chi-square χ^2				**173.86**

Moving to Fig 4(b), the correlation coefficient between plant downtime (x) and the targeted product quantity (y) is highlighted. Throughout all sessions, the calculated correlation coefficient (r) maintains negative values. This suggests that the escalation in plant downtime is associated with the inability to meet the intended product quantity. In essence, an upsurge in plant downtime directly contributes to the failure to achieve the targeted production levels.

3 Result and Discussion

The obtained calculated values (100.21, 102.35, and 173.86) exceeds the tabulated value at a 0.05 significance level (5.991). Therefore, it is determined that the null hypothesis is not accepted, and concluded that product quality is influenced by machine breakdown.

In Fig 4(a), the consistently negative correlation coefficient between plant downtime (x) and the quantity of produced products (y) across all sections is clear. This signifies that to enhance machinery productivity, reducing downtime is imperative. A rise in downtime instances leads to a reduction in the production of products, and conversely, a decrease in downtime is associated with an increase in product output.

Moving to Fig 4(b), the correlation coefficient between plant downtime (x) and the targeted product quantity (y) is highlighted. Throughout all sessions, the calculated correlation coefficient (r) maintains negative values. This suggests that the escalation in plant downtime is associated with the inability to meet the intended product quantity. In essence, an upsurge in plant downtime directly contributes to the failure to achieve the targeted production levels.

4 Conclusions

The study's conclusion is based on the researchers' analysis of production and maintenance logs from a range of equipment in the plastic industry. These documents included production numbers as well as instances of non-production. A 0.05 significance level (5.991) is exceeded by the calculated chi-square values of 100.21, 102.35, and 173.86 for each session. Consequently, it was found that the inability to produce hinge on machine breakdown imparts negatively on product quality. The study also revealed a negative relationship between downtime and the volume of goods produced. This implies that machine productivity can be greatly increased by reducing downtime. Furthermore, a negative correlation was found between the number of targeted items and plant downtime. This suggests that an increase in plant downtime may be the cause of a failure to reach production targets. Essentially, the study's conclusions highlight a significant relationship between maintenance practices and the end quality of manufactured goods.

We suggest that plastics industries increase their maintenance budget in all aspects of plastic production, including machine operation, mold making, and forging. It is expected that this action will have a significant positive impact on the quality of plastic products.

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