iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 Issue: XI Month of publication: November 2021

DOI: https://doi.org/10.22214/ijraset.2021.38517

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue XI Nov 2021- Available at www.ijraset.com

Performance Improvement on Some Closed Loop Plastic Recycling Plants

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***Abstract:** This research focuses on pertinent parameters to improve the performance of four plastic recycling plants. The method used in this work is the overall equipment effectiveness (OEE) analysis. After assessing data collected and comparing calculated values with global accepted standards, there was need to optimize the OEE value of 74.40% for plant P48mold which was below the universally accepted value of 85% and for plant P72mold which is exactly 85%. Optimization toolbox is used to select values for cycle time ranging between 0.75min and 0.73min to improve the calculated value of 74.40% for plant P48mold and 85% for plant P72mold. Optimizing the OEE values significantly increases production by making the operation cost-effective. The OEE value was obtained by multiplying the three factors of availability rate, performance rate and quality rate and optimized values of 87% for P48 mould and 115% for P72 mould were obtained respectively. The cycle time was used to optimize the performance of both plants, which improved the OEE values. These values proved that change in cycle time can improve OEE. A Pareto principle 80/20 rule was also used to proactively check the effects of the planned and unplanned downtime.*

***Keywords:** Throughput, Efficiency, Overall Equipment Effectiveness, Cycle time.*
***Cite the Article:** Davids S. O., Sodiki J. I., and Isaac O. E. (2021) Performance Improvement on Some Closed Loop Plastic Recycling Plants. International Journal for Research in Applied Science and Engineering Technology (IJRASET)*

I. INTRODUCTION

In Port Harcourt, Nigeria, there has been a continuous growth in the usage of plastic items over the last decades, resulting in a significant increase in plastic trash in municipal solid waste streams. The use of a more sanitary method of packaging products such as prepared meals, canned beverages, bottled water, soft drinks, and fruit juice became an inventive replacement for a traditional packaging design.

The use of plastics for protection of items had made plastics replace the existing cultural methods. For example, leaf wraps and metal cups were used before the discovery of plastic materials. This widespread replacement of plastics is an indication of the uniqueness of plastics versatility, inertness and flexibility. Thermoplastic resins, on the other hand, account for around two-thirds of total manufacturing, and their use is increasing at a rate of about 5% per year globally (Andrady, 2003).

Plastics are made from petrochemicals generated from fossil fuels and petrochemical feedstock for around 4% of yearly petroleum output (British Plastics Federation, 2008). Because the manufacturing of plastics necessitates the use of energy, it results in the use of a corresponding amount of fossil fuels (Thompson et al., 2009b).

When evaluating the potential benefits of recycling, a life-cycle analysis might be helpful. The recycling plastics reduces the amount of oil consumed and greenhouse gas emissions connected with the virgin polymer's manufacturing (minus emissions from the recycling processes itself) (Plastic Europe, 2008a).

The aim of this study is to improve the performance of four plastic recycling machines of Indorama Eleme Petrochemicals Limited Rivers State, Nigeria. The specific objectives are as follows:

To determine the technical performance (efficiency ratio and throughput) and the practical analysis of operational performance (overall equipment effectiveness) of the different recycling plants.

To ascertain the factors influencing the performance of the four plants using Pareto chart.

To improve the performance by maximizing the overall equipment effectiveness value with an optimization tool in Matlab.

Ljungberg (1998) initiated the overall equipment effectiveness (OEE) method for plant performance losses. He accessed the magnitude of different types of production loss, in order to direct activities and distribute resources in an optimal way, where he considered 20 cases in a company. The OEE was 55% and he concluded that the performance losses are the dominating factors. He recommended that the company utilizes the benefits of OEE to improve productivity.

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II. MATERIALS AND METHODS

This section covers the description of a plastic injection molding plant. The idea of overall equipment efficiency (OEE) is applied to quantify all the time losses affecting the plants. A set of critical factors related to OEE assessment has also been considered and the weak link in the production process has been identified. Overall equipment efficiency is a 0 to 100 percent value variable. A high OEE number implies that a machine is efficiency. OEE does not identify a specific cause why a machine isn't performing as efficiently as it should, but it does provide some information. As a result, utilizing Pareto principles is important to establish where the inefficiency is occurring. A Pareto chart is used to check the ratio of productivity of the plants. Fig. 1 gives a pictorial idea of a recycling plant.

A. Process Description

Data are collected from four plastic recycling plants in Indorama Eleme Petrochemicals Limited. There are several plastic production plants in Indorama but four of these plants were considered in this work. The four plants are named according to the number of molds attached to them (P48, P72, P96 and P128). For instance, P48 has 48 moulds. The parameters to be taken into consideration during collection of data from the daily production checklist are average cycle time, operation break time, preventive time, output mass, input mass, actual output and actual operating time. The efficiency of each plant was assessed in order to evaluate its technical performance. The overall equipment effectiveness (OEE) of the plants was also studied, which relates to the indicator variables of availability rate, performance rate, and quality rate**.** A Pareto principle was used to ascertain the reasons for low efficiency of the plants.

B. Analytical Method

The Indorama plastic production plant runs two shifts for normal operation. However, if a downtime occurs due to equipment alarm fault, slowdown in production, or equipment routine maintenance, the normal working conditions are adjusted. The ideal working hours or plant operating time would be 7 hours for day shift and 7 hours for night shift.

1) *Technical Performance Approach:* The measure of the process flow rate is calculated by the determination of the throughput, which indicates the efficiency of the process and the efficiency ratio (Orhorhoro et al., 2016).

The throughput can be written as:

$$\text{throughput } (R) = \frac{I}{T} \qquad (1)$$

where I =Number of preforms inputted per day, T is the operating time of plant per day.

To estimate the efficiency ratio:

$$\text{Efficiency ratio } = \frac{\sum m\ (out)}{\sum m\ (in)}\ x\ 100\% \qquad (2)$$

where m (out) is the mass of the useful recycled component ignoring all losses and m (in) is the mass input to the hopper.

2) *Overall Equipment Effectiveness (OEE):* The availability rate, performance rate, and quality rate are the OEE indicator factors of assessment. The worldwide benchmark for availability is 90%, on-time performance is 95%, and quality is 100%. The absolute value of OEE is 85% (Vorn Industries, 2019). Comparing this value with data collected from daily operation of 80% OEE, it is necessary to check the performance of the machines in the plastic recycling industry and recommend improvements.

The working time is collected from daily operation data. In 25 days of the month, 400 hours working time was utilized for both day shift and night shift, making it 8 working hours for each shift.

Now, OEE = Availability rate (AR)x Performance rate (PR) x Quality rate (QR)

$$\text{Also, AR} = \frac{\text{Actual operating time (AT)}}{\text{Planned working time (PT)}}\ x\ 100 \qquad (3)$$

Actual operating time (AT) is the time the equipment is really running minus downtime, while planned working time (PT) is the time the equipment is designed to run.

The performance rate is the ratio of the standard time it takes an operational plant to produce a certain number of completed goods divided by the machine's actual working time.

Performance rate (PR)

$$PR = \frac{\text{standard operating time (ST)}}{\text{actual operating time (AT)}}\ \text{x}\ 100\% \qquad (4)$$

The actual output time and cycle time are required to determine the performance rate of each plant.

The standard operating time = Actual output time x cycle time

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The result would be compared with the global standard performance rate of 95% (Vorn Industry, 2019).

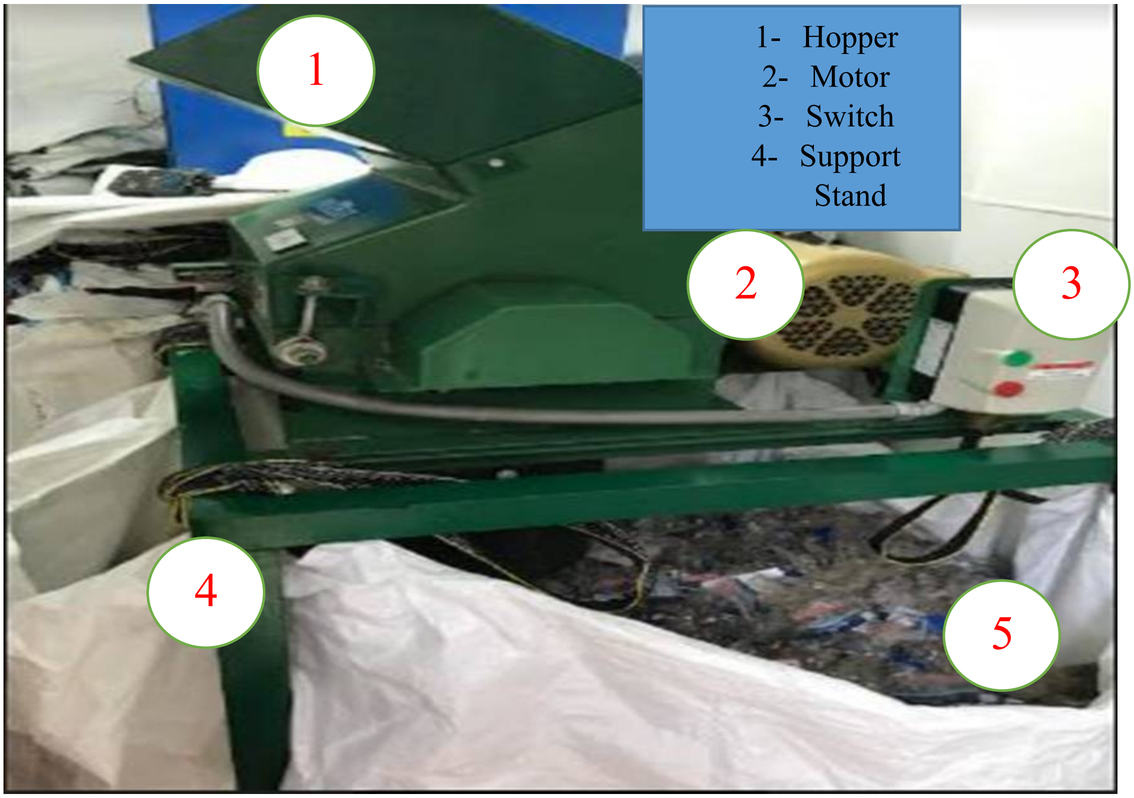

Fig.1: Sample of a recycling machine

The quality rate is measured by the number of recycled plastics rejected due to defect during recycling. It accounts for recycled parts that do not meet quality standard, including products that do not require rework. The equation used to determine the quality rate:

$$\text{Quality rate} = \frac{\text{finsihed good}}{\text{Actual output}} \; x\, 100 \qquad (5)$$

$$= \frac{FG}{AO} \; x\, 100\% \qquad (6)$$

The global standard of quality rate 99%, obtaining a value below the global accepted quality rate is a quality non-conformance.
Finished good = Total production - Total rejection
Actual output is the planned production time = Plant operating time - Planned down time.
Planned downtime for P48 mold = Startup time + Preventive time + Operator break time
OEE is obtained by multiplying the three indicator factors (Vorn Industry, 2019).

3) Maximizing OEE with Optimization Tool Box: Optimization tool box was used to improve the calculated OEE values of P48 and P72.

$$\text{Performance rate} = \frac{Ct\ x\ Ao}{At} \qquad (8)$$

$$\text{OEE} = \frac{CtxAo}{At} xAvxQ \qquad (9)$$

where Ct is the cycle time
Ao is actual output
At is the actual operating time
Av is availability rate
Q is quality rate.

III. RESULTS AND DISCUSSION

A. Results

This section contains results from the daily operational data and process checklist. The OEE of the four plants (P48, P72, P96 and P128 moulds) were determined.

In order to improve on the productive time, a Pareto principle of 80/20 rule was used to determine the factors influencing performance. The input data for the four plants are tabulated in Tables 1 which is an excerpt from the daily operational data.

The throughput (R) for the four plants are determined using equation (1), while the efficiency ratio is obtained using equation (2). The mass output was calculated from the mass for each preform and the mass input is based on demand. The obtained values are expressed in Table 1.

The efficiencies obtained from the four machines

(η_{48} = 90%, η_{72} = 93%, η_{96} = 95%, η_{128}= 92%) shows values above 90% efficiency. The obtained values show that the plants were efficiently utilized. The availability of the four plants exceed criteria standard of 90%, which conform to global accepted standard. The actual output time and cycle time are required to determine the performance rate of each plant. The obtained values are expressed in Table 3 and Figure 3.

Table 1: Data Obtained from Daily Operational Checklist and Calculated Values

Plant	Mass per	Mass input mi	Mass of out	Throughput (R)	Efficiency ratio (η) %
P48	19.5	1000	900	18.5	90
P72	30.00	2160	2000	30.06	93
P96	22.40	2112	2000	12.47	95
P128	17.00	2176	2000	50.46	92

Availability rate takes into account the availability loss, the performance rate takes into account the performance loss and the quality rate takes into account the quality loss. These factors made up overall equipment effectiveness, which evaluates the percentage of scheduled production time.

Table 2: Calculated Values of Availability Rate

Plant	Problem machine (min)	Startup (min	Preventive Maintenance (min)	Operator bre (min)	working time (min)	Planned working time (min)	Actual Operating time (min)
P48	22	90	30	90	2400	2190	2168
P72	60	70	30	90	2400	2210	2150
P96	180	210	40	90	2400	2060	1880
P128	92	10	45	90	2400	2255	2163

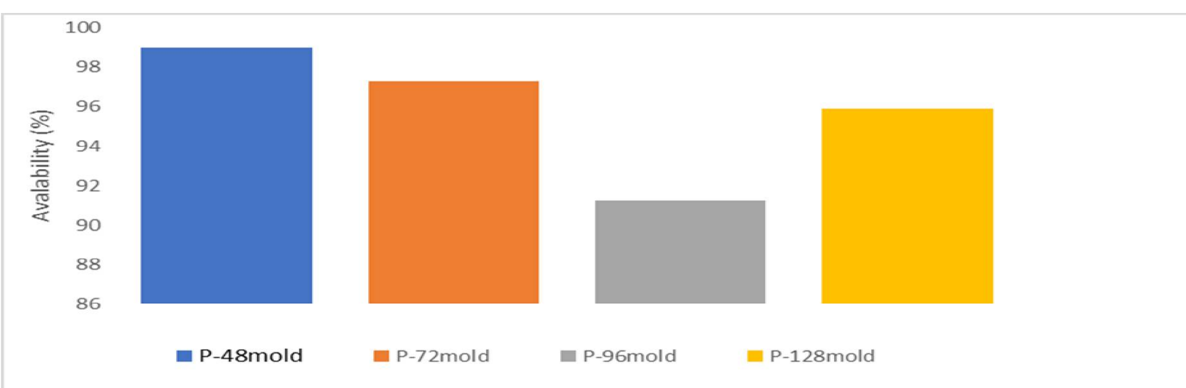

Fig. 2: Plot of Availability Rate vs Plants

Table 3: Calculated Values of Performance Rate

Pla nt	Ac tua l out	Cy cle tim e (m	Actu Oper ing time (min	Sta nd ard op era	Per for ma nc e rat
P48	3000	0.59	2168	1770	81.64%
P72	3500	0.55	2150	1925	89.53%
P96	4500	0.45	1880	2025	108%
P128	4000	0.55	2163	2220	103%

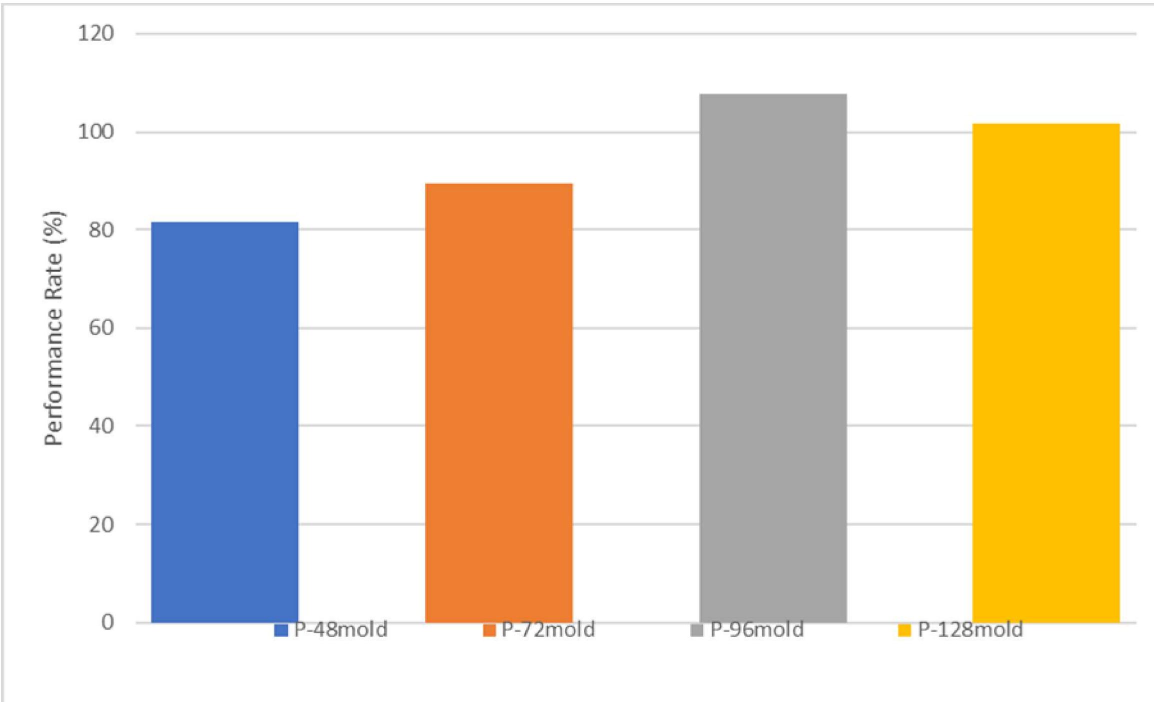

Fig. 3: Plot of Performance rate vs Plants

Table 4: Calculated Values of Quality Rate

Plant number	Finished good (units)	Total produced Parts (unit)	Quality rate
P 48 mold	44000	52000	92%
P 72mold	71500	72000	99%
P 96 mold	93000	99000	97%
P 128 mold	120000	13600	94%

The performance rate of each plants is compared to the global standard performance rate of 95%, P48 and P72 are below 95%, which implies there is lack of reliability on both plants. These calculated values will affect the overall equipment effectiveness of both plants.

Plant P98 has a performance rate of 81.64%, with the difference of 95% - 81.64% = 13.36%.

P72 has a performance rate of 89.53%, with difference of 95% - 89.53% = 5.47%.

This significant difference of 13.36% and 5.47% in both plants will alter the performance of the plants. This difference will be observed during OEE calculations.

The quality rate is calculated by subtracting the total rejected parts from the total production for each day. Quality rate is calculated and the obtained result is expressed in Table 4 and Figure 4.

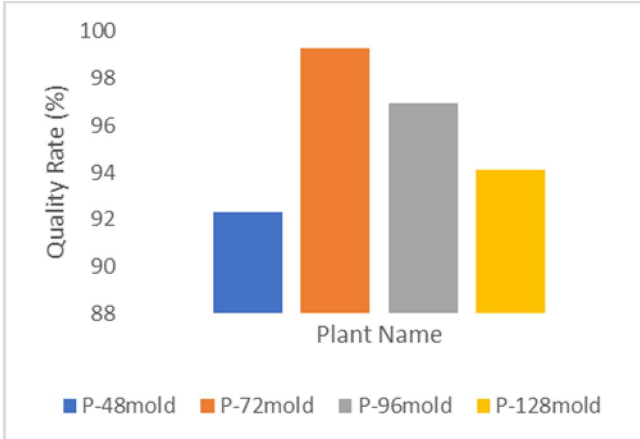

Figure 4: Plot of Quality Rate vs Plants

Quality is conformance to requirement, the required global standard of OEE in quality is 99% but plant P48, P96 and P128 are below 99%. The obtained values are expressed in Table 4 and Figure 4; these calculated values will also affect the overall equipment effectiveness of plants. However, an optimization of the OEE values will improve the performance of the plants.
Overall equipment effectiveness is multiplying available rate, performance rate and quality rate of the four plants. The obtained values are expressed in Table 5 and Figure 5.

Table 5: Calculated values of OEE

Plant	Availability Rate	Performance Rate	Quality Rate	OEE
P 48	98.99%	81.64%	85%	74%
P 72	97.29%	89.53%	99%	85%
P 96	97.70%	108%	94%	95%
P 128	95.92%	103%	89%	92%

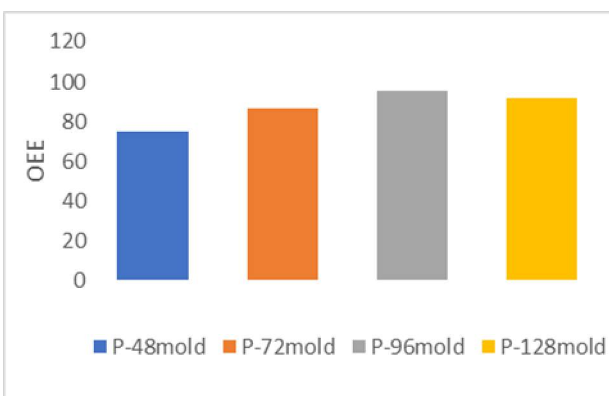

Fig.5: Plot of OEE vs Plants

The availability rate, performance rate, and quality rate are multiplied to get the OEE value**.** Plant P48 is below global standard of OEE 85%, while plant P72 is just at 85%, each with a percentage value of 74% and 85%. A Matlab package called optimization toolbox was used to select a range of constraint values that are used to improve the OEE values. These significant values were used to improve the performance of both plants.

B. Maximizing OEE with Optimization Tool Box

In Tables 5, the OEE values for P48 and P72 are below the global standard requirement. According to Amit and Garg (2012), a performance level above the world-class OEE value of 85% was recommended. This means the optimization of plant P48 and P72 is obtainable, Table 6 show the improved values.

Table 6: Improved values of OEE

Plant	Availability Rate	Performance Rate	Quality rate	OEE
P 48	98.99%	81.64%	85%	87%
P 72	97.29%	89.53%	99%	115%

The change in cycle time has tremendously improved the OEE values for plant P48 and P72 from 74% to 87% and 85% to 115%. Increase in cycle time has improved the overall equipment effectiveness in each plant. A Pareto principle 80/20 rule was also used to proactively check the situation with the planned and unplanned downtimes.

C. Pareto Rule Analysis

When numerous alternative reasons of action compete for attention, the Pareto analysis is a formal helpful method. It is a statistical decision-making approach that is used to pick a task that has a substantial overall effect. The Pareto 80/20 rule aids in identifying the top 20% of reasons that must be addressed in order to solve the majority of issues. Using Pareto principles, assess the limitations impacting the total equipment effectiveness of the four factories. The majority of difficulties (80%) in terms of quality improvement are driven by a few main variables (20%). This study therefore, utilized the Pareto principle to express the different activities leading to the planned and unplanned downtime and the respective time spent on each activity during plastic recycling production.

IV. CONCLUSION

The performance of the four plants were determined using overall equipment effectiveness. From this study therefore, three plants P72, P96 and P128 with overall equipment effectiveness of 85, 95% and 92% met the global standard of 85% OEE respectively. However, plant P72 is just at 85% of OEE, which is considered not good enough. The OEE of P48mold is 74% which is below the specified OEE percentage standard. Both plants P48 and P72 were improved with an optimization toolbox by increasing the cycle time for both plants. The change in cycle time significantly improved the performance of the plants from 74% to 87% for P48 and from 85% to 115% for P72. It is pertinent to note that this improvement has not affected the production time, worker's break time and production cost. The Pareto principle was also used to check the situation with the planned downtime and unplanned downtime.

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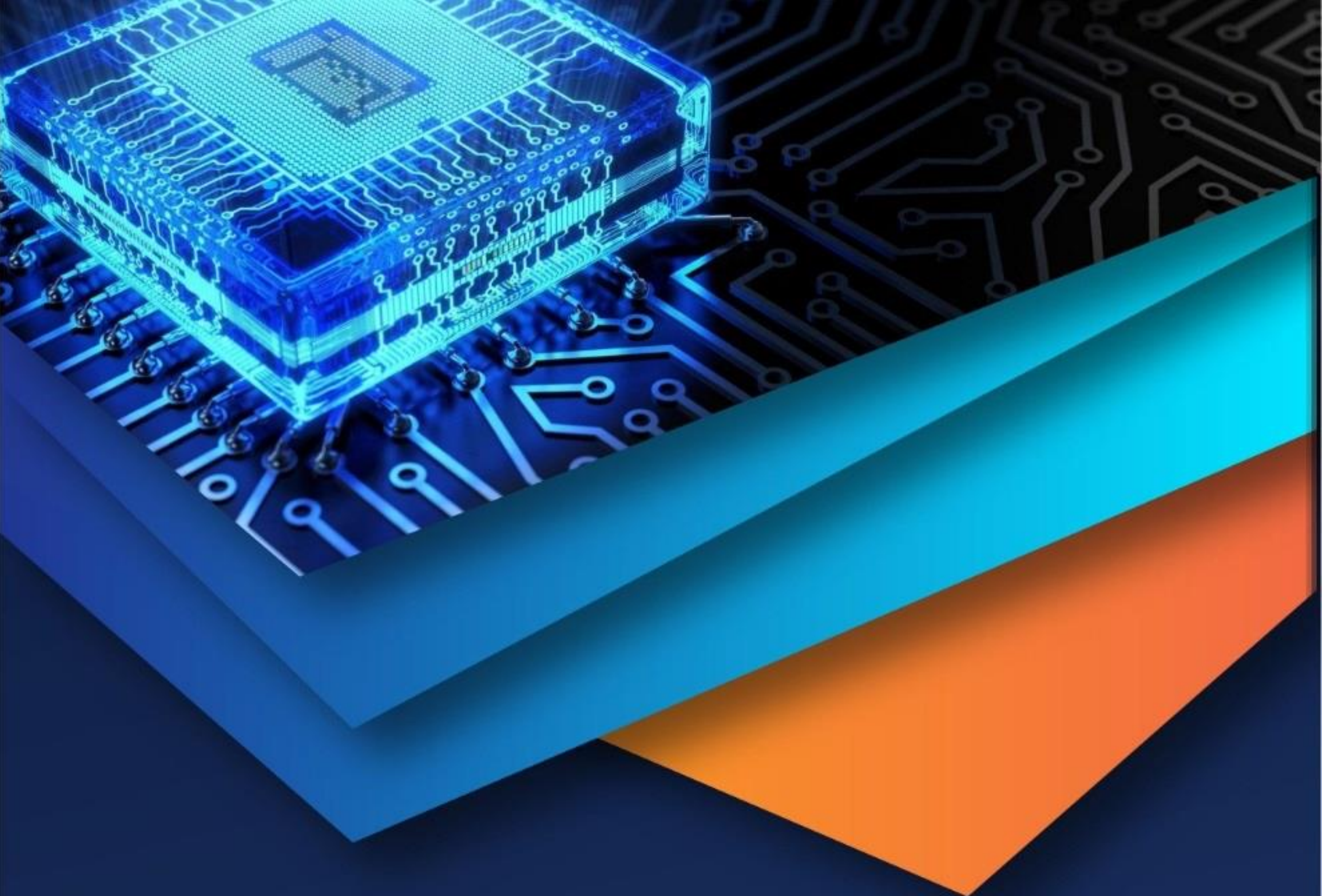

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