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Skewness and Kurtosis on Edge Coloring of Certain Graphs

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Abstract: In this paper we found minimum edge colouring sum based on a minimum proper colouring of a given graph G and we compute the statistical measures Mean, Variance, Median, Standard deviation, Skewness and Kurtosis.
Keywords: Graph Colouring; colouring sum of graphs; colouring mean; colouring variance; colouring median; colouring standard deviation; colouring skewness; colouring kurtosis; χ' -chromatic.

I. INTRODUCTION

Theedge colouring or simply a colouring of a graph is an assignment of colours or labelsto the edges of a graph subject to certain conditions. In a proper colouring of agraph, its edges are coloured in such a way that no two adjacent edges in that graph have the same color.

We extend the concepts of mean,median,variance,standard deviation,skewness and kurtosis are important statistical measures, to the theory of graph colouring and determine the values of these parameters for a number of standard graphs.

A. Preliminaries

1) Let C = {$c_1,c_2,...,c_k$} be a particular type of proper k-colouring of a given graph G and $\theta(c_i)$ denotes the number of times a particular color $c_i$is assigned to the edge of G . Then, the edge colouring sum of a colouring C of a given graph G denoted by $\omega_C(G)$ is defined to be[9,10,11,12,13,14,15,16,17],

$$\omega_C(G) = \sum_{i=1}^{k} i\theta(c_i)$$

2) A graph in which one edge connecting every two consecutive edges and there are no other edges, is called a path [4][6].
3) A simple graph in which every edge must be connected to all other edgesof the graph, is called as a complete graph [4][6].
4) A simple graph with n edges (n ≥ 3) and n edges is called a cycle graph if the degree of each edge in the graph is two and it is denoted by C_n [4][6].
5) The ladder graph Ln is defined as $P_n \circ P_2$.[4][6]

B. Colouring Statistical Parameters of Graphs

We can identify the colouring of the edges of a given graph G with a random experiment. Let C = {$c_1,c_2,c_3,...,c_k$} be a proper k-colouring of G and let X be the random variable (r.v) which denotes the number of edges in G having a particular color. Since the sum of all weights of colors of G is the order of G , the real valued function f(i) is defined by, $f(i) = \begin{cases} \frac{\theta(c_i)}{|E(G)|}; i = 1,2,....k \\ 0 \end{cases}$ is the probability mass function (p.m.f) of the r.v X. If the context is clear, we can also say that f(i) is the p.m.f of the graph G with respect to the given colouring C. Hence, analogous to the definitions of the mean,median,variance,standarddeviation,skewness and kurtosis of random variables, those statistical parameters of a graph G , with respect to a general colouring of G can be defined asfollows.

1) *Definition .1.* Let C = {$c_1, c_2, c_3, \ldots, c_k$} be a certain type of proper k-colouring of a given graph G and $\theta(c_i)$ denotes the number of times a particular color c_i is assigned to edges of G. Then, the colouring mean of a colouring C of a given graph G, denoted by $\mu_C(G)$ is given by, $\mu_C(G) = \frac{\sum_{i=1}^{k} i\theta(c_i)}{\sum_{i=1}^{k} \theta(c_i)}$

2) *Definition .2.* The colouring median of acolouring C of a given graph G, denoted by $M_C(G)$ and is defined to be $M_C(G) = \frac{\sum_{i=1}^{k} \theta(c_i)}{2}$

3) *Definition .3.* The colouring variance of a colouringC of a given graph G, denoted by $\sigma^2{}_C(G)$ is given by,

$$\sigma^2{}_C(G) = \frac{\sum_{i=1}^{k} i^2\theta(c_i)}{\sum_{i=1}^{k} \theta(c_i)} - \left[\frac{\sum_{i=1}^{k} i\theta(c_i)}{\sum_{i=1}^{k} \theta(c_i)}\right]^2$$

4) *Definition .4.* The colouring standard deviation of a colouringC of a given graph G,denoted by by $\sigma_C(G)$ is given by,

$$\sigma_C(G) = \sqrt{\frac{\sum_{i=1}^{k} i^2\theta(c_i)}{\sum_{i=1}^{k} \theta(c_i)} - \left[\frac{\sum_{i=1}^{k} i\theta(c_i)}{\sum_{i=1}^{k} \theta(c_i)}\right]^2}$$

5) *Definition.5.* The colouring skewness of a colouringC of a given graph G, denoted by $\gamma_C(G)$ and is defined to be $\gamma_C(G)$ = $3\left(\frac{Mean \quad - Median}{S\tan dard \quad Deviation}\right)$

6) *Definition 6.* For a positive integer r, the r^th moment of the colouring C is denoted by $\mu_{C^r}(G)$ is given by,

$$\mu_{C^r}(G) = \frac{\sum_{i=1}^{k} i^r\theta(c_i)}{\sum_{i=1}^{k} \theta(c_i)}$$

We have various moments as follows:

a) *1st Moment:* 2nd Moment

$$\mu_{C^1}(G) = \frac{\sum_{i=1}^{k} i\theta(c_i)}{\sum_{i=1}^{k} \theta(c_i)} \quad \mu_{C^2}(G) = \frac{\sum_{i=1}^{k} i^2\theta(c_i)}{\sum_{i=1}^{k} \theta(c_i)} - \left[\frac{\sum_{i=1}^{k} i\theta(c_i)}{\sum_{i=1}^{k} \theta(c_i)}\right]^2$$

b) *3rd Moment*

$$\mu_{C^3}(G) = \frac{\sum_{i=1}^{k} i^3\theta(c_i)}{\sum_{i=1}^{k} \theta(c_i)} - 3\left[\frac{\sum_{i=1}^{k} i^2\theta(c_i)}{\sum_{i=1}^{k} \theta(c_i)}\right]\left[\frac{\sum_{i=1}^{k} i\theta(c_i)}{\sum_{i=1}^{k} \theta(c_i)}\right] + 2\left[\frac{\sum_{i=1}^{k} i^3\theta(c_i)}{\sum_{i=1}^{k} \theta(c_i)}\right]^3$$

c) *4th Moment*

$$\mu_{C^4}(G)=\frac{\sum_{i=1}^{k} i^4\theta(c_i)}{\sum_{i=1}^{k}\theta(c_i)}-4\left[\frac{\sum_{i=1}^{k} i^3\theta(c_i)}{\sum_{i=1}^{k}\theta(c_i)}\right]\left[\frac{\sum_{i=1}^{k} i\theta(c_i)}{\sum_{i=1}^{k}\theta(c_i)}\right]+6\left[\frac{\sum_{i=1}^{k} i^3\theta(c_i)}{\sum_{i=1}^{k}\theta(c_i)}\right]\left[\frac{\sum_{i=1}^{k} i\theta(c_i)}{\sum_{i=1}^{k}\theta(c_i)}\right]^2-3\left[\frac{\sum_{i=1}^{k} i\theta(c_i)}{\sum_{i=1}^{k}\theta(c_i)}\right]^4$$

7) *Definition 7.* The colouring kurtosis of a colouring C of a given graph G, denoted by $\beta_2(G)$ and defined by, $\beta_2(G)=\dfrac{\mu_{C^4}(G)}{(\mu_{C^2}(G))^2}$

χ' - Chromatic Statistical Parameters of Graphs

Colouring mean,median,variance,standard deviation, skewness and kurtosis corresponding to a particular type of minimal proper colouring of the edges of G are defined as follows:

8) *Definition .8.* A colouring mean of a graph G, with respect to a proper edgecolouring C is said to be a χ' - chromatic mean of G, if C is the minimum proper colouring of G and the colouring sum $\omega_C(G)$ is also minimum. The χ' -chromatic mean of a graph G is denoted by $\mu_{\chi'}(G)$.
9) *Definition .9.* Acolouring median of a graph G, with respect to a proper edge colouring C is said to be a χ' - chromatic median of G. The χ' -chromatic median of a graph G is denoted by $M_{\chi'}(G)$.
10) *Definition.10.*The χ' chromatic variance of G, denoted by $\sigma_{\chi'}{}^2(G)$, is a colouring variance of G with respect to a minimal proper edge colouring of G which yields the minimum colouring sum.
11) *Definition .11.* The χ' chromatic standard deviation of G, denoted by $\sigma_{\chi'}(G)$, is a colouring standard deviation of G with respect to a minimal proper edge colouring of G which yields the minimum colouring sum.
12) *Definition.12.* The χ' chromatic skewness of G, denoted by $\gamma_{\chi'}(G)$, is a colouring variance of G with respect to a minimal proper edge colouring of G which yields the minimum colouring sum.
13) *Definition .13.* The χ' chromatic kurtosis of G, denoted by $\beta_{2\chi'}(G)$, is a colouring kurtosis of G with respect to a minimal proper edge colouring of G which yields the minimum colouring sum. If β_2 = 3, then it is known as **MESOKURTIC** Curve, if β_2 < 3, then it is known as PLATYKURTICCurveand if β_2 > 3,then it is known as LEPTOKURTICCurve

Let us now determine the χ' - chromatic mean,median,variance,standard deviation,skewness and kurtosis of certain standard graph classes. The following result discusses on Completegraph K_n.

a) *Proposition1.* The χ' -Chromatic mean of a Complete graph K_n is $\dfrac{n+1}{2}$, χ' -chromatic variance is $\dfrac{n^2-1}{12}$, χ' - chromatic median is $\dfrac{n}{2}$, χ' - chromatic standard deviation , $\sqrt{\dfrac{n^2-1}{12}}$, χ' - chromatic skewness is $3\left(\sqrt{\dfrac{3}{n^2-1}}\right)$ and χ' - chromatic kurtosis $\dfrac{9n^4-10n^2+7}{5n^4-10n^2-5}$.

Proof: Consider a Complete graph K_n has different colours as they are adjacent to each other. (i.e) $\theta(c_i)=1$ for the color c_i ; $1 \le i \le n$

Therefore $\mu_{\chi'}(K_n) = \dfrac{n+1}{2}$ $\sigma^2_{\chi'}(K_n)=\dfrac{n^2-1}{12}$ $M_{\chi'}(K_n) = \dfrac{n}{2}$, $\sigma_{\chi'}(K_n) = \sqrt{\dfrac{n^2-1}{12}}$, $\gamma_{\chi'}(K_n) = 3\left(\sqrt{\dfrac{3}{n^2-1}}\right)$

We can obtain kurtosis by various moments as,

$\mu'_1 = \dfrac{n+1}{2}$, $\mu'_2 = \dfrac{(n+1)(2n+1)}{6}$ $\mu'_3 = \dfrac{n(n+1)^2}{4}$, $\mu'_4 = \dfrac{(n+1)(2n+1)(3n^2+3n+1)}{30}$

$\mu_3 = 0$ $\mu_4 = \dfrac{3n^4-10n^2+7}{240}$ And the χ' - chromatic kurtosis of $\beta_{2\chi'}(K_n) = \dfrac{9n^4-10n^2+7}{5n^4-10n^2-5}$

If $\beta_{2\chi'}(K_n) < 3$, then it is known as PLATYKURTIC Curve.

i) *Theorem 1:* Any proper colouring of a complete graph K_n has the discrete uniform distribution on{1,2,..,k} (D(U(k)) that is discrete uniform distribution.

Proof: Let X be the r.v representing the number of colors in a proper k-colouring of a complete graph K_n . For any proper k-colouring C of the complete graph $K_n, \theta(c_i)=1$ and $k=n$. Hence, the corresponding $p.m.f$ is $f(i) = \begin{cases} \dfrac{1}{n}; n=1,2,\ldots n \\ 0 \ ; elsewhere \end{cases}$ which is that of the discrete uniform distribution on {1,2… k}. Hence, X follows DU (k)

b) *Proposition 2:* The χ' –chromatic mean of a path P_n is

$$\mu_{\chi'}(P_n) = \begin{cases} \dfrac{3}{2}; if \ \ n \ \ is \ \ even \\ \dfrac{3n-4}{2n-2}; if \ \ n \ \ is \ odd \end{cases}$$

the χ' – chromatic variance of a path P_n is

$$\sigma^2_{\chi'}(P_n) = \begin{cases} \dfrac{1}{4}; if \ \ n \ \ is \ even \\ \dfrac{n^2-2n}{4n^2-8n+4}; if \ \ n \ \ is \ odd \end{cases}$$

the χ' – chromatic median of a path P_n is $\dfrac{n-1}{2}$,

the χ' – chromatic standard deviation of path P_n is

$$\sigma_{\chi'}(P_n) = \begin{cases} \dfrac{1}{2}; if \ n \ is \ even \\ \sqrt{\dfrac{n^2-2n}{4n^2-8n+4}}; if \ n \ is \ odd \end{cases}$$

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the χ' –chromatic skewness of P_n is

$$\gamma_{\chi'}(P_n) = \begin{cases} 3(4-n);\ if\ \ n\ is\ even \\ 3\left(\dfrac{-n^2-5n-5}{\sqrt{n^2-2n}}\right);\ if\ \ n\ is\ \ odd \end{cases}$$

the χ – chromatic kurtosis of a path P_n is,

$$\beta_{2\chi}(P_n) = \begin{cases} 1;\ if\ \ n\ is\ even \\ \dfrac{272n^5-1735n^4+4340n^3-5328n^2+3216n-768}{n^4 - 4n^3+4n^2};\ if\ \ n\ is\ odd \end{cases}$$

Proof:. Consider a path P_n on n edges. Then, we have the following cases.

(1) If n is even and is 2-colourable then P_n has exactly $\frac{n-1}{2}$ edgeshavingcolour $c_1$and c_2 each. Then,

the χ' -chromatic mean of P_n is $\mu_{\chi'}(P_n)=\frac{3}{2}$, the χ' chromatic variance of P_n is $\sigma^2{\chi'}(P_n)=\frac{1}{4}$,the χ' chromatic median of P_n is $\frac{n-1}{2}$,the χ' -chromatic standard deviation of P_n is $\sigma_{\chi'}(P_n)=\frac{1}{2}$, the χ' chromatic skewness of P_n is $\gamma_{\chi'}(P_n)=3(4-n)$ we can obtain kurtosisby various moments $\mu'_1=\frac{3}{2}, \mu'_2=\frac{5}{2}, \mu'_3=\frac{9}{2}, \mu'_4=\frac{17}{2}$, $\mu_3=0, \mu_4=\frac{1}{16}$, And the χ- chromatic kurtosis of $\beta_{2\chi'}(P_n)=1$, If $\beta_{2\chi'}(P_n)<3$ then it is known as PLATYKURTIC Curve.

(2) If n is odd, Then, the p:m:f of the corresponding r:v:Xis given by , $f(i) = \begin{cases} \frac{n}{2(n-1)};\ i=1 \\ \frac{n-2}{2(n-1)};\ i=2 \\ 0\quad ;\ elsewhere \\ 0;\ otherwise \end{cases}$ the χ' - chromatic mean of P_n is $\mu_{\chi'}(P_n)=\frac{3n-4}{2n-2}$,the χ' -chromatic variance of P_n is $\sigma^2{\chi'}(P_n)=\frac{n^2-2n}{4n^2-8n+4}$,the χ' -chromatic median of P_n is $\frac{n-1}{2}$, the χ' -chromatic standard deviation of P_n is $\sigma_{\chi'}(P_n)=\sqrt{\frac{n^2-2n}{4n^2-8n+4}}$,the χ' - chromatic skewness of P_n is $\gamma_{\chi'}(P_n)=3\left(\frac{-n^2-5n-5}{\sqrt{n^2-2n}}\right)$, we can obtain kurtosis by various moments,

$$\mu'_1=\frac{3n-4}{2n-2}, \mu'_2=\frac{5n-8}{2n-2}, \mu'_3=\frac{9n-16}{2n-2}, \mu'_4=\frac{17n-32}{2n-2},$$

$$\mu_3=\frac{2n^2-4n}{(2n-2)^3}, \mu_4=\frac{272n^5-1735n^4+4340n^3-5328n^2+3216n-768}{(2n-2)^4},$$ and

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χ' - chromatic kurtosis of $\beta_{2\chi'}(P_n) = \dfrac{272n^5 - 1735n^4 + 4340n^3 - 5328n^2 + 3216n - 768}{n^4 - 4n^3 + 4n^2}$,

If $\beta_{2\chi'}(P_n) < 3$, then it is known as PLATYKURTIC Curve.

c) *Proposition 3:* The χ' –chromatic mean of acycle C_n is

$$\mu_{\chi'}(C_n) = \begin{cases} \dfrac{3}{2}; \text{if } n \text{ is even} \\ \dfrac{3n+3}{2n}; \text{if } n \text{ is odd} \end{cases}$$

And the χ' – chromatic variance of a cycle C_n is

$$\sigma^2{}_{\chi'}(C_n) = \begin{cases} \dfrac{1}{4}; \text{if } n \text{ is even} \\ \dfrac{n^2 + 8n - 9}{4n^2}; \text{if } n \text{ is odd} \end{cases}$$

the χ' – chromatic median of a cycle C_n is $\dfrac{n}{2}$,

the χ' – chromatic standard deviation of a cycle C_n is,

$$\sigma_{\chi'}(C_n) = \begin{cases} \dfrac{1}{4}; \text{if } n \text{ is even} \\ \sqrt{\dfrac{n^2 + 8n - 9}{4n^2}}; \text{if } n \text{ is odd} \end{cases}$$

The χ' – chromatic skewness of a cycle C_n is

$$\gamma_{\chi'}(C_n) = \begin{cases} 3(3-n); \text{if } n \text{ is even} \\ 3\left(\dfrac{-n^2 + 3n + 3}{\sqrt{n^2 + 8n - 9}}\right); \text{if } n \text{ is odd} \end{cases}$$

The χ' – chromatic kurtosis of C_n is,

$$\beta_{2\chi'}(C_n) = \begin{cases} 1; \text{if } n \text{ is even} \\ \dfrac{n^4 + 80n^3 - 270n^2 + 432n - 243}{n^4 + 16n^3 + 46n^2 - 144n + 81}; \text{if } n \text{ is odd} \end{cases}$$

Proof:. Consider a cycle C_n on n edges. Then, we havethe following cases.

(1) If n is even and is 2-colourable then C_n has exactly $\frac{n}{2}$ edges havingcolour C_1 and C_2 each. Then,

i) χ' - chromatic mean of cycle C_n is, $\mu_{\chi'}(C_n) = \dfrac{3}{2}$

ii) χ' - chromaticvariance of cycle C_n is, $\sigma^2{}_{\chi'}(C_n) = \dfrac{1}{4}$

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iii) χ' - chromatic medianofcycle C_n is $\frac{n}{2}$

iv) χ' - chromatic standard deviation of C_n is, $\sigma_{\chi'}(C_n)=\frac{1}{2}$

v) χ' - chromatic skewness of C_n is $\gamma_{\chi'}(C_n)=3(3-n)$

we can obtain kurtosis by various moments,

$$\mu'_1=\frac{3}{2},\mu'_2=\frac{5}{2},\mu'_3=\frac{9}{2},\mu'_4=\frac{17}{2},\ \mu_3=0,\mu_4=\frac{1}{16},$$

And the χ' - chromatic kurtosis of C_n is $\beta_{2\chi'}(C_n)=1$

If $\beta_{2x'}(C_n)<3$ then it is known as PLATYKURTIC Curve.

(2) If n is odd, then is C_n 3-colourable.Let C={ c_1, c_2, c_3 }be the minimal proper colouring of C_n. Then, the p.m.f of the corresponding (r.v.X) is given by $f(i)=\begin{cases}\frac{n-1}{2n};\ i=1,2\\ \frac{1}{n};\ i=3\\ 0;\ elsewere\end{cases}$ then,

1. χ' - chromatic mean of cycle C_n is $\mu_{\chi'}(C_n)=\frac{3n+3}{2n}$

2. χ' - chromatic variance of cycle C_n is, $\sigma^2{}_{\chi'}(C_n)=\frac{n^2+8n-9}{4n^2}$

3. χ' - chromatic median of cycle C_n is $\frac{n}{2}$

4. χ' - chromatic standard deviation of cycle C_n is, $\sigma_{\chi'}(C_n)=\sqrt{\frac{n^2+8n-9}{4n^2}}$

5. χ' - chromatic skewness ofcycle C_n is $\gamma_{\chi'}(C_n)=3(\frac{-n^2+3n+3}{\sqrt{n^2+8n-9}})$

we can obtain kurtosis by various moments,

$$\mu'_1=\frac{3n+3}{2n},\mu'_2=\frac{5n+13}{2n},\mu'_3=\frac{9n+45}{2n},\mu'_4=\frac{17n+145}{2n},$$
$$\mu_3=\frac{9n^2-36n+27}{4n^3},\mu_4=\frac{n^4+80n^3-270n^2+432n-243}{16n^4},$$

And the χ' - chromatic kurtosis of $\beta_{2\chi'}(C_n)=\frac{n^4+80n^3-270n^2+432n-243}{n^4+16n^3+46n^2-144n+81}$,

If $\beta_{2\chi'}(C_n)<3$ then it is known as PLATYKURTIC Curve.

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d) Proposition 4: The χ' - chromatic mean of a ladder graph (L_n) is $\mu_{\chi'}(L_n) = \frac{6n-6}{3n-2}$. Then

i) χ' – chromatic variance of a ladder graph (L_n) is $\sigma^2_{\chi'}(L_n) = \frac{6n^2-8n}{3n-2}$

ii) χ' – chromatic median of a ladder graph (L_n) is $\frac{3n-2}{2}$

iii) χ' – chromatic standard deviation of a ladder graph (L_n) is $\sigma_{\chi'}(L_n) = \sqrt{\frac{6n^2-8n}{3n-2}}$

iv) χ' – chromaticskewness of a ladder graph (L_n) is

$$\gamma_{\chi'}(L_n) = \frac{-9n+12(\sqrt{18n^3-36n^2+16n})}{12n^2-8n}$$

(v) χ' – chromatic kurtosis of a ladder graph (L_n) is

$$\beta_{2\chi'}(L_n) = \frac{54n^4-162n^3+180n^2-136n}{36n^4-96n^3+64n^2}$$

Proof: In a Ladder Graph (L_n), we have $3n-2$ edges and the graph is 3- colourable

Hence the corresponding p.m.f of the corresponding Wn is given by, $f(i) = \begin{cases} \frac{n}{3n-2}; i = 1,2 \\ \frac{n-2}{3n-2}; i = 3 \\ 0; elsewhere \end{cases}$

1. χ' - chromatic mean of (L_n) is $\mu_{\chi'}(L_n) = \frac{6n-6}{3n-2}$
2. χ' - chromaticvariance of (L_n) is $\sigma^2{\chi'}(W_n) = \frac{6n^2-8n}{3n-2}$
3. χ' - chromatic median of (L_n) is $\frac{3n-2}{2}$
4. χ' - chromatic standard deviation of (L_n) is $\sigma_{\chi'}(L_n) = \sqrt{\frac{6n^2\_8n}{3n-2}}$
5. χ' - chromaticskewness of is , $\gamma_{\chi'}(L_n) = \frac{-9n+12(\sqrt{18n^3-36n^2+16n})}{12n^2-8n}$

We can obtain kurtosis by various moments,

$$\mu'_1 = \frac{6n-6}{3n-2}, \mu'_2 = \frac{14n-18}{3n-2}, \mu'_3 = \frac{36n-54}{3n-2}, \mu'_4 = \frac{98n-162}{3n-2},$$

$$\mu_3 = \frac{18n^2 - 36n}{(3n-2)^3}, \mu_4 = \frac{54n^4 - 162n^3 + 180n^2 + 136n}{(3n-2)^4},$$

And the χ' - chromatic kurtosis of $\beta_{2\chi'}(L_n) = \dfrac{54n^4 - 162n^3 + 180n^2 - 136n}{36n^4 - 96n^3 + 64n^2}$

If $\beta_{2\chi'}(L_n) < 3$ then it is known as PLATYKURTIC Curve.

II. CONCLUSION

In this paper,we extend the concept of mean, variance, standard deviation, median, skewnessand kurtosis, some important statistical parameters to various graphs based on edgecoloringsum. Based on the edge coloring sum of graphs, we have investigated these statistical inferences for edge colorable graphs such as Complete graphs, Path, Cycle andladder graphs .This onceptcan be extended to several other operations on graphs such as Cartesian product, total coloring graphs, Johan colouring , lexicographic product,corona product, sum and product of graphs etc.,

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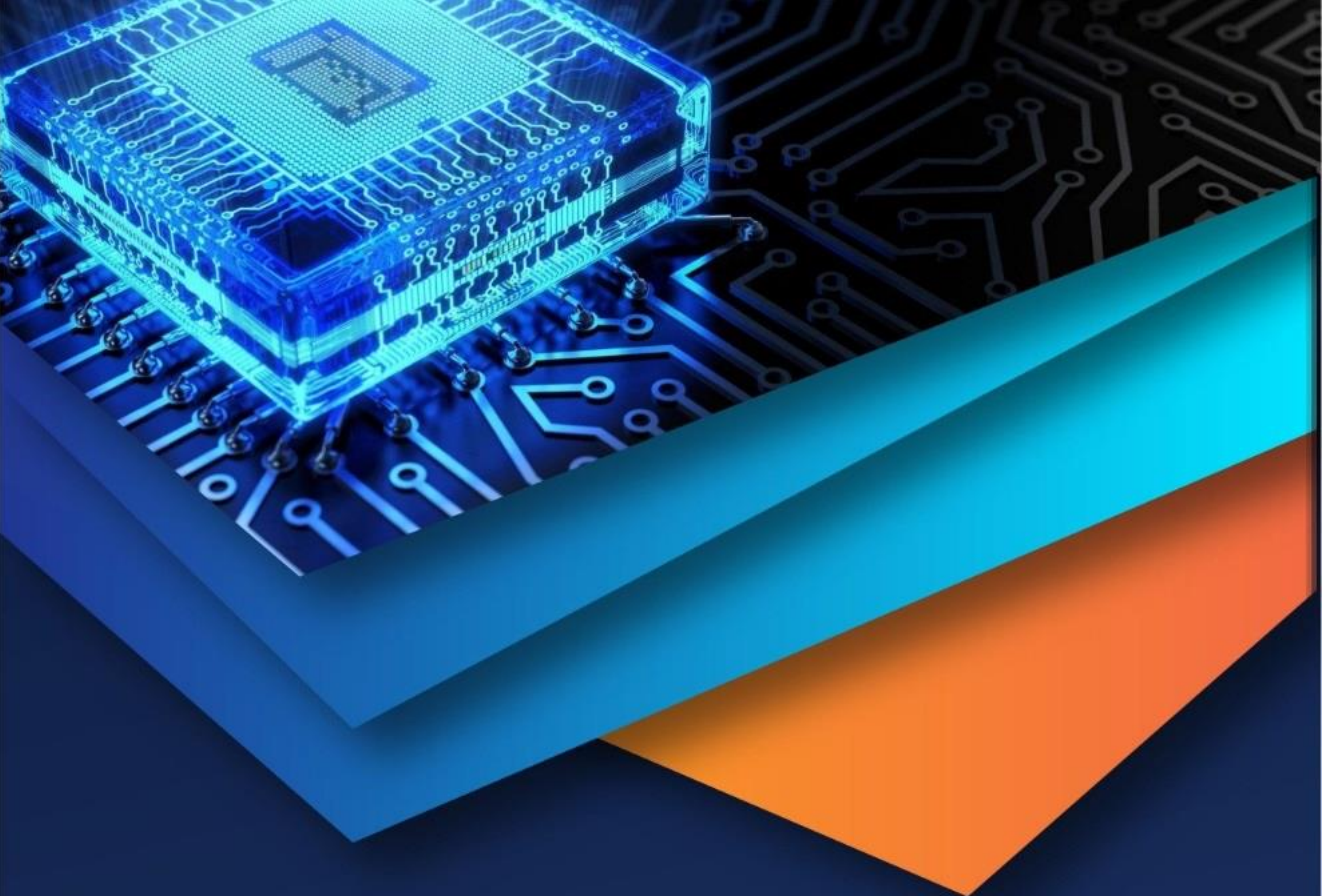

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