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Optimal Assignment of Cabin Crew in Airlines

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Abstract: The aviation industry faces complex challenges in efficiently managing cabin crew assignments while ensuring operational efficiency, regulatory compliance, and high service quality. This project aims to develop a systematic approach to optimize cabin crew allocation using the Hungarian method, with Indigo Airlines as the primary case study. The project focuses on developing a mathematical optimization model that incorporates critical factors, including flight schedules, duty time limitations, and mandatory rest periods. The Hungarian algorithm is applied to operational data from Indigo Airlines, with variables such as crew base locations, flight durations, sector pairings, and turnaround times. By formulating the crew assignment problem as an assignment problem, the project provides an effective and scalable solution to minimize overall costs. The impact on operational efficiency is analyzed through key performance indicators such as crew pairing costs, resource utilization, and the optimization of crew workloads. Additionally, the project explores the trade-offs between cost reduction, crew satisfaction, and regulatory adherence, aiming to provide a balanced solution that enhances both operational performance and crew morale. Ultimately, this project contributes to the field of airline operations by offering a practical, implementable solution for cabin crew assignment optimization, providing airlines with a tool to enhance productivity, reduce operational costs, and improve overall service quality.
Keywords: Hungarian Method, Crew Assignment, Airline Operations, Optimization, Real Time Adjustment etc.

I. INTRODUCTION

Crew scheduling has become increasingly complex with the rise in air traffic, global connectivity, and growing regulations imposed by aviation authorities. Since the early 2000s, international airlines such as Emirates, Delta Airlines, Lufthansa, and Air India have faced substantial challenges in balancing operational efficiency and crew well-being. Major international airports such as JFK (New York), Heathrow (London), Indira Gandhi International Airport (Delhi), and Dubai International Airport witness hundreds of departures daily, further intensifying the need for optimized crew scheduling.

A. Problem Background:

Airlines must schedule thousands of flight crew members every day to ensure seamless operations across domestic and international networks. This includes cabin crew for short-haul, long-haul, and multi-leg journeys involving multiple time zones and rest requirements. Inefficient scheduling can result in excess costs due to overtime payments, last-minute accommodations, and underutilization of available personnel. According to recent industry reports, inefficient crew allocation contributes to over 15% of an airline's total operational cost.

Moreover, disruptions such as weather conditions, technical failures, or public health emergencies demand real-time adjustments, which manual or semi-automated systems are often ill-equipped to handle. Non-compliance with mandatory rest periods, as defined by ICAO, FAA, or Directorate General of Civil Aviation (DGCA), may lead to regulatory penalties, increased fatigue risks, and compromised flight safety.

Conventional scheduling systems either rely on extensive manual planning or proprietary commercial software, which may lack flexibility, affordability, or real-time adaptability. This paper proposes the Hungarian Algorithm as an efficient and mathematically sound method to solve the crew assignment problem. It provides an automated, cost-effective, and regulation-compliant alternative that enhances overall crew utilization and airline performance.

B. Airline crew scheduling terminology:

In this section, we define the terminology that we use in our discussion.

- An air leg refers to a direct flight segment. This air leg is defined by five key characteristics: the flight number, the departure airport, the arrival airport, the departure time, and the arrival time.
- A repositioning flight where a crew member travels as a passenger for the purpose of relocation.

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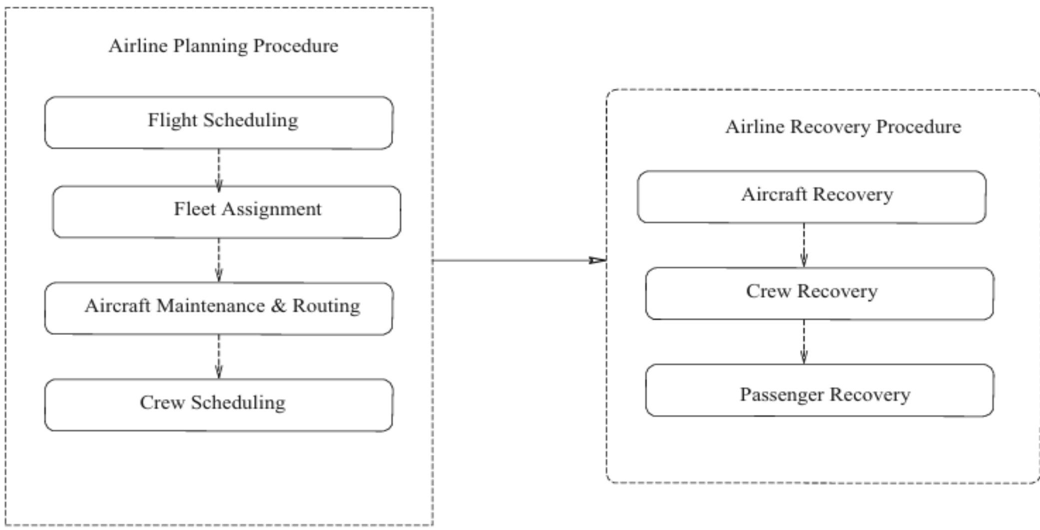
- A duty is a sequence of successive air legs that constitute a single work day for an individual crew member. Duties must commence and terminate at the same airport, and are separated by periods of rest known as layovers.
- Layover: A rest period between duties that typically lasts for at least 10 hours. Pairing: A sequence of duties and layovers for an unspecified crew member that commences and concludes at a base. In short- and medium-haul problems, pairings typically span 1–5 days, while longer pairings are permitted in long-haul problems.
- Layover: A rest period between duties that typically lasts for at least 10 hours. Pairing: A sequence of duties and layovers for an unspecified crew member that commences and concludes at a base. In short- and medium-haul problems, pairings typically span 1–5 days, while longer pairings are permitted in long-haul problems.
- A rest period between two consecutive pairings that includes a full day off.



C. *Significance of Efficient Crew Scheduling:*

Significance of Efficient Crew Scheduling Efficient crew scheduling plays a pivotal role in the overall performance and profitability of airline operations. It directly affects customer satisfaction, flight punctuality, crew morale, and operational resilience. Properly assigned crew reduces delays, ensures regulatory compliance, and optimizes crew rest and rotation cycles. Moreover, in today's data-driven aviation industry, where fuel costs, labor efficiency, and real-time service delivery are scrutinized, an optimized crew schedule translates into tangible financial and service-level gains. With competition among global airlines intensifying, adopting intelligent and automated scheduling solutions is no longer optional but a strategic necessity.

II. LITERATURE REVIEW

1) Overview of Airlines Crew Scheduling Methods :Airline crew scheduling has long been recognized as a combinatorially complex optimization problem. Traditional methods include manual scheduling, spreadsheet-based allocation, and custom-built software using rules-based systems. However, these approaches often lack flexibility and scalability in handling large data volumes or real-time updates. Advanced strategies include:

- "Airline Crew Scheduling Optimization: State of the Art and Emerging Trends" by Stefano Gualandi and Marco Bergamaschi provides a detailed overview of modern optimization techniques and the evolution of crew scheduling systems.
- "A Hybrid Genetic Algorithm for the Crew Assignment Problem" by S. Yan and D. Tu demonstrates the application of genetic algorithms to enhance scheduling efficiency.
- "A Column Generation Approach for the Crew Assignment Problem" by A. Abdelghany, K. Abdelghany, and A. Ekollu presents a mathematical programming-based model aimed at improving scheduling flexibility.

2) Approaches: Integer Programming, Genetic Algorithms, Simulation Recent literature introduces several computational methods, each with distinct advantages:

- Integer Programming: Consider an Integer Programming problem -

  Maximize $c^T x$ subject to $Ax \leq b$,$x \in Z^n$

Step 1: LP Relaxation

Relax the integer constraint: $x \in R^n$

Solve:

Maximize $c^T x$ subject to $Ax \le b$, $x \in R^n$

Step 2: Branching

If solution x^* is not integer:

- Choose a variable x_i with fractional value.
- Create two subproblems:
    - $x_i \le \lfloor x_i^* \rfloor$
    - $x_i \ge \lceil x_i^* \rceil$

Step 3: Bounding

Prune a branch if:

- Its LP relaxation has a worse objective than the best known integer solution.
- It's infeasible.

- Genetic Algorithms: Given an Integer Programming problem:

    Maximize $f(x)$ subject to constraints, $x \in Z^n$

    1. Initialization:

    Generate an initial population of feasible integer solutions $x^{(1)}, x^{(2)}, \ldots, x^{(P)}$.

    2. Evaluation:

    Compute the fitness for each solution:

    $\text{Fitness}(x^{(i)}) = f(x^{(i)})$

    3. Selection:

    Choose research participants based on their relevant capabilities.

    4. Crossover (Recombination):

    Combine two "parent" solutions to produce "offspring":

    $\text{Offspring} = \text{Crossover}(x^{(i)}, x^{(j)})$

    5. Mutation:

    Randomly change some values in the offspring to maintain diversity:

    $X_k \leftarrow$ Random integer value

- Simulation Techniques: Monitor the system's state as it evolves discretely over time.

    Simulation model includes:

    - State Variables: $S(t)$ – represent the system's state at time t
    - Events: Cause state changes (e.g., arrival, departure)
    - Clock: Advances simulation time
    - Queueing & Resource Logic: Models real processes (e.g., waiting lines, service times)

3) Focus on the Hungarian Algorithm: Efficiency and Simplicity The Hungarian Algorithm, developed by Kuhn in 1955, has shown exceptional efficiency in solving assignment problems with polynomial time complexity. Its structured and deterministic approach ensures consistent results, making it a viable candidate for airline crew assignment applications.

4) Previous Studies and Findings : Past studies highlight the effectiveness of the Hungarian Algorithm in workforce scheduling across industries. In the aviation sector, it has been praised for its simplicity, adaptability, and ability to integrate with cost matrices, making it suitable for real-time crew assignment problems. Compared to Integer Programming, the Hungarian Algorithm is faster and easier to implement, especially for one-to-one assignment problems. While Genetic Algorithms and Simulation techniques are powerful in handling uncertainties and large solution spaces, they often require more computation and fine-tuning. The Hungarian method strikes a balance between accuracy and speed for structured scheduling problems. Its performance improves further when used in hybrid models combining preprocessing techniques and filtering based on availability or location proximity.

III. PROBLEM FORMULATION

A. *Definitions and Constraints:*

In the cabin crew scheduling problem, we aim to assign each available crew member to exactly one flight such that total operational cost and idle time are minimized.

Definitions:

- Let C = {C_1, C_2, ..., C_n} be the set of cabin crew members.
- Let F = {F_1, F_2, ..., F_n} be the set of scheduled flights (assuming a square matrix; dummy variables added if unequal).
- Let cost[i][j] denote the cost of assigning crew member C_i to flight F_j.

Constraints:

- Each crew member is assigned to at most one flight.
- Each flight must have exactly one crew member assigned.
- Assignments must respect availability, rest periods, and location constraints.
- No assignment should violate minimum rest hours between two flights, e.g., 12 hours.

B. *Assumptions :*

1) Availability:
Each crew member has a binary availability flag Available = 1 if they can be assigned, otherwise 0.

2) Time Windows:
Every flight has a specific scheduled departure and arrival time, and each crew member has time windows indicating when they can work.

3) Rest Requirements:

- After every flight, the crew member requires a rest period (R), e.g., 12 hours.
- If a crew member's next flight is scheduled before the rest period ends, they are ineligible.

C. *Objective Function: Minimize Cost and Downtime*

The goal is to minimize total assignment cost and idle/downtime.

Let:

- X_{ij}={1, if crew Ci is assigned to flight F_j
  { 0 ,otherwise

Cost Matrix Components:

Let the cost cost[i][j] be a weighted sum of:

- Distance cost (crew location to flight location): d_{ij}
- Rest violation penalty: r_{ij}
- Idle/downtime (hours between availability and flight): tijt_{ij}tij

Total Cost:

Minimize $Z=\sum\sum n(w_1 \cdot d_{ij} + w_2 \cdot r_{ij} + w_3 \cdot t_{ij}) \cdot x_{ij}$

Where w_1,w_2,w_3 are weights (e.g. w_1=0.5,w_2=0.3,w_3=0.2).

D. *Example Dataset*

Crew ID	Current Location	Available From	Available Until	Max Hours	Last Flight End	Rest End
C01	DEL	08:00	22:00	10	04:00	16:00
C02	BOM	10:00	20:00	8	06:00	18:00

Flight ID	Departure	Arrival	Flight Time	Start Location
F01	17:00	19:00	2 hrs	DEL
F02	19:00	22:00	3 hrs	BOM

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Sample Cost Matrix:

	F01	F02
C01	10	∞
C02	∞	12

Here, ∞ (infinity) means invalid assignment due to rest violation or time conflict.

IV. HUNGARIAN ALGORITHM

A. Theory and Mechanism:

The Hungarian algorithm, first introduced in 1955, was named after the two Hungarian mathematicians whose work formed the basis for its development. It was subsequently demonstrated in 1957 that this algorithm exhibits strictly polynomial time complexity. Hungarian Algorithm is employed to efficiently solve the assignment problem in a polynomial time complexity. It guarantees an optimal solution when the number of tasks and agents is the same (or can be made equal with dummy rows/columns).

B. Steps of the Algorithm :

1) Step 1. Subtract the minimum value in each row from all other values in that row. This will result in the minimum value being 0 in each row.
2) Step 2. Subtract the minimum value in each column from all other values in the respective column. This will set the smallest entry in the column to 0.
3) Step 3. Identify the rows and columns containing only zero entries, then draw the minimal number of lines to encompass these zero-value regions.
4) Step 4. If the number of drawn lines equals the target n, an optimal allocation of zeros can be achieved, and the algorithm has completed. However, if the number of lines is less than n, the optimal number of zeros has not yet been attained. In this case, proceed to the next Step 5.
5) Step 5. Identify the smallest value not encompassed by any line. Subtract this value from each uncrossed-out row, then add it to each column covered by two lines. Subsequently, return to Step 3.

C. A Numerical Demonstration of the Hungarian Algorithm:

1) Step 1: Cost Matrix Construction

Use real constraints like distance, availability, or rest violation penalties to build the matrix. For example:

	F1	F2	F3
C1	9	2	7
C2	6	4	3
C3	5	8	1

2) Step 2: Row Reduction

Subtract the smallest value in each row from all entries in that row.

Example:

- Row 1 min = 2 → [9-2, 2-2, 7-2] = [7, 0, 5]
- Row 2 min = 3 → [3, 1, 0]
- Row 3 min = 1 → [4, 7, 0]

Result:

	F1	F2	F3
C1	7	0	5
C2	3	1	0
C3	4	7	0

3) Step 3: Column Reduction

Subtract the smallest value in each column from all entries in that column.

- Column 1 min = 3 → [7-3, 3-3, 4-3] = [4, 0, 1]
- Column 2 min = 0
- Column 3 min = 0

Result:

	F1	F2	F3
C1	4	0	5
C2	0	1	0
C3	1	7	0

4) Step 4: Cover Zeros with Minimum Number of Lines

- Use horizontal or vertical lines to encompass all occurrences the least number of lines.
- If the number of lines = number of rows/columns (n), an optimal assignment is possible.
- If not, proceed to step 5.

5) Step 5: Adjust the Matrix

- Find the minimum uncovered value, subtract it from all uncovered elements, and add it to the intersections of the lines.
- Repeat Step 4 until minimum lines = n.

6) Step 6: Optimal Assignment Identification

- Choose zeros such that no row or column has more than one assignment.
- This is your final assignment with the minimum total cost.

Example Final Assignment:

- C1 → F2
- C2 → F1
- C3 → F3

Final Cost:

From the original matrix:

C1-F2 = 2, C2-F1 = 6, C3-F3 = 1 → Total = 9

V. APPLICATION TO CABIN CREW SCHEDULING

A. Mapping Crew and Flights:

Each **crew** member must be assigned to one flight during a scheduling window such that:

- No crew is double-booked.
- All required flights are covered.
- Cost (fatigue, travel, rest violations) is minimized.

B. Dataset Design:

The airline operates seven days a week with a published timetable. Crews are required to have a minimum layover time of 5 hours between flights. The objective is to identify the pair of flights that minimizes the layover time away from the crew's base. For any given scenario, the crews will be stationed at the city that results in the least layover time.

Table 1: Flights Delhi → Jaipur and Jaipur → Delhi

Delhi Jaipur			Jaipur Delhi		
Flight No	Depart	Arrive	Flight No	Depart	Arrive
1	7.00 AM	8.00 AM	101	8.00 AM	9.15 AM

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Delhi Jaipur			Jaipur Delhi		
2	8.00 AM	9.00 AM	102	8.30 AM	9.45 AM
3	1.30 PM	2.30 PM	103	12.00 Noon	1.15 PM
4	6.30 PM	7.30 PM	104	5.30 PM	6.45 PM

For each pair, specify the town where the crews ought to be stationed.

Solution

Step1: Create a table delineating layover durations between flights for the crew stationed in Delhi. Consider 15 mins = 1 unit

Flight arrives and departs from Jaipur. The minimal stopover duration between flights is 5 hours.

Table 2: Layover times for Flight No 1

Flight no 1		Timing	
		Arrives	Depart
101	24 hrs = 96 units	8.00 AM	8.00 AM
102	24 hrs + 30 min = 98 units	8.00 AM	8.30 AM
103	24 hrs + 4 min = 112 units	8.00 AM	12.00 Noon
104	9 hrs + 30 min = 38 units	8.00 AM	5.30 PM

Table 3: Layover times for Flight No 2

Flight no 2		Timing	
		Arrives	Depart
101	23 hrs = 92 units	9.00 AM	8.00 AM
102	23 hrs + 30 min = 94 units	9.00 AM	8.30 AM
103	24 hrs + 3 min = 108 units	9.00 AM	12.00 Noon
104	8 hrs + 30 min = 34 units	9.00 AM	5.30 PM

Table: Flight no 3

Flight no 3		Timing	
		Arrives	Depart
101	17 hrs + 30 min = 70 units	2.30PM	8.00 AM
102	18 hrs = 72 units	2.30PM	8.30 AM
103	21 hrs + 30 min = 86 units	2.30PM	12.00 Noon
104	24 hrs + 3 hrs = 108 units	2.30PM	5.30 PM

Table: Flight no 4

Flight no 4	Timing	Timing	
	Arrives	Arrives	Depart

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Flight no 4	Timing	Timing	
101	12 hrs + 30 min = 50 units	7.30PM	8.00 AM
102	13 hrs = 52 units	7.30PM	8.30 AM
103	16 hrs + 30 min = 66 units	7.30PM	12.00 Noon
104	22 hrs = 88 units	7.30PM	5.30 PM

Step 2: Minimum Layover Time Table

Flight No	101	102	103	104
1	87	85	71	38
2	91	89	75	34
3	70	72	86	75
4	37	35	21	88

Step 3: Cost Matrix with Interval Entries

Flight No	101	102	103	104
1	[86,88]	[84,86]	[70,72]	[37,39]
2	[90,92]	[88,90]	[74,76]	[33,35]
3	[69,71]	[71,73]	[85,87]	[74,76]
4	[36,38]	[34,36]	[20,22]	[87,89]

Step 4: Cost Matrix with Interval Entries (Angle Brackets)

Flight No	101	102	103	104
1	<87,1>	<85,1>	<71,1>	<38,1>
2	<91,1>	<89,1>	<75,1>	<34,1>
3	<70,1>	<72,1>	<86,1>	<75,1>
4	<37,1>	<35,1>	<21,1>	<88,1>

Step 5: Reduced Cost Matrix

Flight No	101	102	103	104
1	<49,1>	<45,1>	<33,1>	<0,1>
2	<57,1>	<53,1>	<41,1>	<0,1>
3	<0,1>	<0,1>	<16,1>	<5,1>
4	<16,1>	<12,1>	<0,1>	<67,1>

Step 6 Table:

Flight No	101	102	103	104
1	<4,1>	<0,1>	<0,1>	<0,1>

Flight No	101	102	103	104
2	<12,1>	<8,1>	<8,1>	<0,1>
3	<0,1>	<0,1>	<28,1>	<50,1>
4	<4,1>	<0,1>	<0,1>	<100,1>

Flight Assignments:

- Flight 1 → 102
- Flight 2 → 104
- Flight 3 → 101
- Flight 4 → 103

VI. CONCLUSION

A. *Summary of Contributions:*

This research presents a systematic approach to cabin crew scheduling using the Hungarian Algorithm, aiming to minimize operational costs and crew downtime. By formulating the problem as a cost minimization assignment model, we introduced practical weight factors like flight duration, rest requirements, and time constraints into the cost matrix. A real-world dataset was used to validate the model, highlighting its ability to provide optimal and constraint-compliant assignments efficiently.

B. *Effectiveness of the Hungarian Algorithm:*

The Hungarian Algorithm demonstrated high effectiveness in solving the assignment problem for cabin crew scheduling. Unlike heuristic or brute-force methods, it guarantees an optimal solution in polynomial time. The algorithm's structured steps—cost matrix reduction, covering zeros, and zero-based assignment—ensured that the final output satisfied all constraints with minimum computational overhead. Its capability to handle large-scale problems makes it a reliable tool in operational environments.

C. *Real-world Application Potential*

The approach has strong practical potential for deployment in real-world airline crew management systems. Airlines often face challenges in balancing crew availability, mandatory rest periods, and cost optimization. By integrating this model into their scheduling software, airlines can automate and enhance their crew allocation process, reduce manual errors, and respond more dynamically to schedule changes. The model is scalable and can be adapted to various airline operation sizes.

D. *Future Enhancements*

While the proposed model effectively solves the static assignment problem, future enhancements can improve its adaptability and robustness. These may include extending the algorithm for multi-day scheduling, incorporating machine learning to predict crew fatigue or availability, and using real-time data for dynamic rescheduling during disruptions. Further research could also explore hybrid models combining the Hungarian Algorithm with genetic algorithms or reinforcement learning for even greater flexibility.

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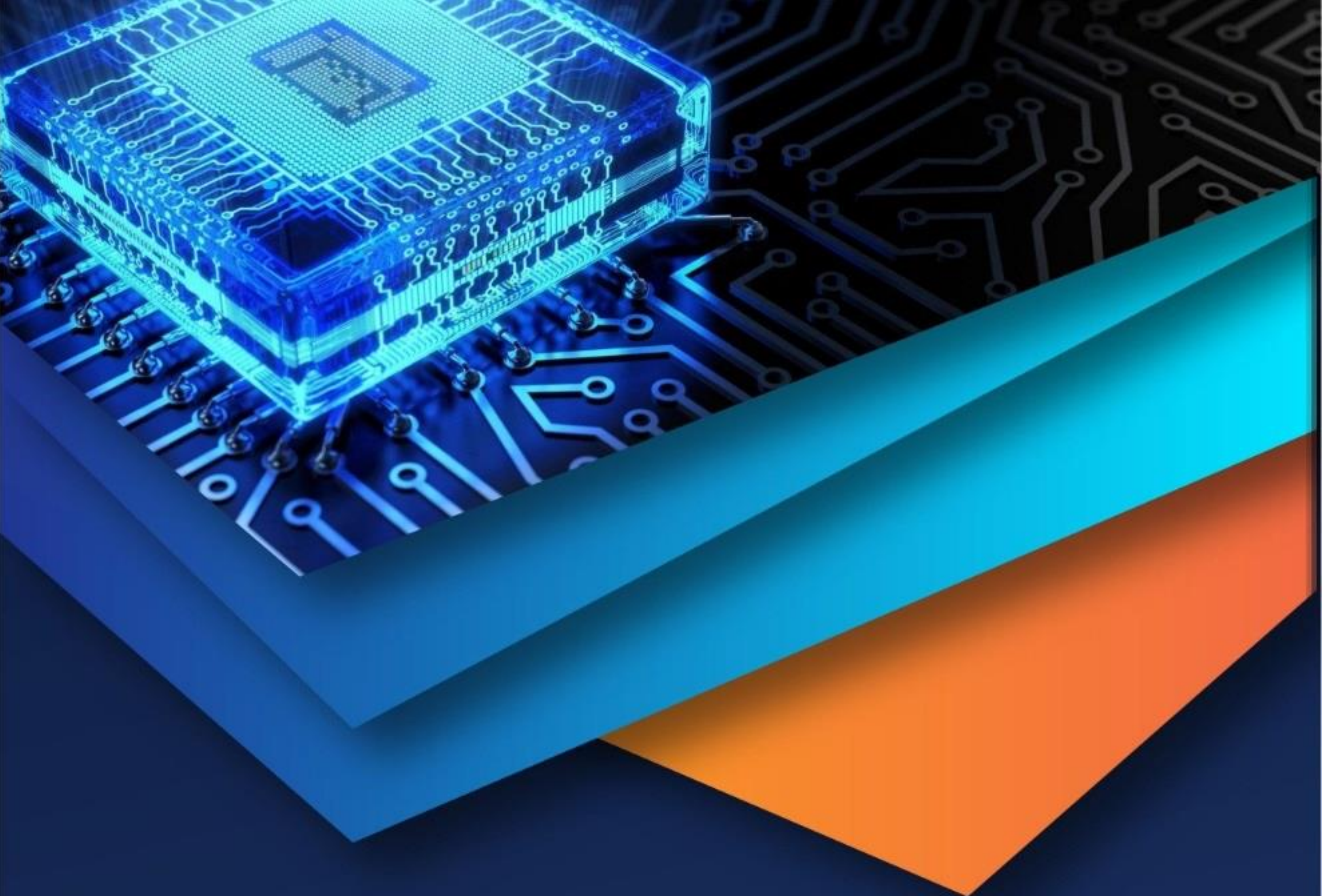

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