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Optimizing and Analyzing the Cost of Collection andTransportation of Solid Waste Using GIS

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Abstract: This study aimed to analyze the cost of the waste collection and transportation system of zone 2 ward 95, Kanpur. Population growth, rapid economic development and urbanization have led to an increase in the generation of solid waste. For this purpose, the maps of collection routes and locations of waste storage were drawn using Arc & QGIS software. According to the GIS maps software, the main waste collection cost was supplying human resources and fuel charges. Transfer stations are an integral part of present-day municipal solid waste management systems. The main criteria used to decide on the location of a transfer station has traditionally been the minimization of transport costs since it is cheaper to transport great amounts of waste over long distances in large loads than in small ones. Municipal solid waste (MSW) has been produced since the establishment of mankind. Solid wastes are wastes generated due to human and animal activities and are unavoidable by-products of human activities. Routing is one of the main components of solid wastemanagement to optimize of collection route and reduce travel distance which could reduce disposal costs. Waste collection and transport can generate up to 70% of the MSW system costs. Separate collection of recyclables or organic waste raises the costs of waste collection. The proper estimation and monitoring of waste collection costs are essential to define the most cost-effective waste collection system. This has become a critical issue for every MSW company aimed at providing their services in the best possible way.
Keywords: MSW, Vehicle Route, ArcGIS, QGIS, Collection & Transportation, etc.

I. INTRODUCTION

The recent increase in the production of different types of waste in various quantities and qualities is due to industrialization. Preserving the health of human beings and the environment and also raising the efficiency in all stages of solidwaste management is a cause of the consideration of new waste management systems in metropolises. In this framework, policies and scientific strategies have been applied to develop programs and effective solutions for the collection, transportation, and disposal of solid waste. The main components of municipal solid waste management include production, storage, transportation, processing, recycling, and disposal which are connected and thus should be systematically linked so that uniformunits can be used. The efficiency of the waste management program should be based on health, economy, and environmental engineering aspects. The collection stage is the most difficult part of solid waste management, especially in megacities. One of the most effective factors in waste management is the cost of waste collection and transportation which constitutes about 50% to 70% of the total cost of solid waste management programs. Through the application of plans, advice, and optimized route management of the waste collection system, such costs can be drastically reduced Therefore, optimization of solid waste collection routes in an urban area is important where a significant amount of the time is spent loading and unloading as well as driving. Optimizing collection services is still depending on the knowledge of local conditions such as one-way streets and road construction by the collection teams. Efficiency and effectiveness are two indicators of a system's performance. While efficiency indicators define the relationship between a system's input resources and output products or services, effectiveness indicators measure a system's ability to meet its objectives. In other words, efficiency indicators show how efficiently a company utilizes the contracted budget for the collection and transportation of municipal waste.

II. MATERIAL AND METHODS

A. Study Area

Kanpur is a major industrial town of Uttar Pradesh, the northern state of India. This town is situated on the south bank of river Ganga, located 80 km west of Lucknow, the state capital. It is also known as the industrial capital of the state. According to the 2011 census, Kanpur Nagar district has a population of 4,581,268, roughly equal to the nation of Costa Rica or the US state of Louisiana. This gives it a ranking of 32nd in India (out of a total of 640). The district has a population density of1,449 inhabitants per square kilometre (3,750/sq. m). Its population growth rate over the decade 2001-2011 was 9.72%.

For the purposes of this routing optimization, study carried out it ranges from latitude 26.463672° N and longitude 80.345146° E. Dumping quantity is 70% waste collected disposed to disposal site.

Fig-1: Location of transfer stations to MSW Plant (Google Earth)

The Arc & Q Map module was routes for the basic functions of GIS problem solving, namely Dijkstra algorithm to find the shortest route with the network analyst tool of this module carrying out the actual analyses. System analyst tool can carry out a variety of different analyses including the production of network data sets in single or multiple modes, identification of optimal route using one network data set, developing a model for route analysis, transportation of a series of orders using a vehicle fleet, network analysis using traffic data and specification of most suitable sites. ArcGIS 10.4 & QGIS software was used for the GIS method employed in this study. The database of the network topology software for the neighbourhood of the optimization study was processed, and the road restrictions, like direction, speed limits were identified.

B. Vehicle Routing Problem

Vehicle routing problem is an optimization problem that aims to find best route between the location and transfer station to dumping site. There may be only one vehicle in the problem, or there may be more than one vehicle. Although the purpose of determining the best route is generally to find the shortest distance for the routes, a different problem can also be defined for different purposes such as minimizing the route of vehicle. Usually, constraints of the problem are related to the vehicles, the customers or the process. Due to these factors or constraints, several types of VRP have been introduced.

C. GIS

Geographic information systems are utilized in multiple technologies, processes, techniques and methods. They are attached to various operations and numerous applications that relate to: engineering, planning, management, transport. Showing spatial datafor a specific plan of purposes from this current reality. Creating, visualizing, and managing networks is an important part of GIS. Many types of physical infrastructure such as roads, railways, and utilities can be modelled as networks with lines and nodes - with properties attached to them. This tutorial will teach how road networks are commonly modelled and apply some styling techniques to visualize the routing properties. We willalso use QGIS built-in tools for network analysis that to find the shortest path between 2 points along with the network.

D. QGIS

QGIS functions as geographic information system (GIS) software, allowing users to analyse and edit spatial information, in addition to composing and exporting graphical maps. QGIS supports raster, vector and mesh layers. Vector data is stored as either point, line, or polygon features. Multiple formats of raster images are supported and the software can geo- reference images. QGIS can display multiple layers containing different sources or depictions of sources. In order to prepare printed map with QGIS, Print Layout is used. It can be used for adding multiple map views, labels, legends, etc.

1) *Identification Of The Layers:* In the given drawing, there were many layers such as pipeline, contour, road and housing layers. With referencing with the Google Earth Image and Arc Map, user can identify the road layers needed for data analysis. Finally, non-spatial data such as road name and length of each road were added.
2) *Creating Network Database:* A Network Dataset was created from the feature sources that participated in the network. It incorporates an advanced connectivity model that can represent complex scenarios, such as multimodal transportation networks. It also possesses a rich network attribute model that helps model impedances, restrictions, and hierarchy for the network.
3) *Creating Network Database:* Arc-GIS-NA is an extension that provides network-based spatial analysis including routing, travel directions, closest facility and service area analysis. The NA is able to find efficient travel routes for the trucks during solid waste collection. In order to solve the route optimization, distance criteria and collection time by the truck (regardless to time spent in traffic) were considered and generated. The final output was an optimal solution in terms of distance criteria. After setting the stop points, the optimized routes for solid waste collection were produced. The stop-points were numbered automatically by Network Analystin the order that they were visited.
4) *Service Design (definition of the routes):* The best possible routes for solid waste collection were identified based on the information obtained with the help of the GIS regarding the possible routes, and having taken into account the restrictions to the road conditions and topography. The routes were chosen in a way that the resources used for the collection, the length of the route and the time taken to complete the collection are minimized.

E. Solid Waste Management

Waste management or waste disposal includes the processes and actions required to manage waste from its inception to its final disposal. This includes the collection, transport, treatment and disposal of waste, together with monitoring and regulation of the waste management process and waste-related laws, technologies and economic mechanisms. Waste can be solid, liquid, or gas and each type have different methods of disposal and management. Waste management deals with all types of waste, including industrial, biological, household, municipal, organic, biomedical, and radioactive wastes. In some cases, waste can pose a threat to human health. Health issues are associated with the entire process of waste management. Health issues can also arise indirectly or directly. Directly, through the handling of solid waste, and indirectly through the consumption of water, soil and food. Waste is produced by human activity, for example, the extraction and processing of raw materials.

F. Transfer and Transport

The transfer of waste from the smaller collection vehicles to the larger transport equipment. Solid waste transfer stations are facilities where solid waste, mainly municipal solid waste (MSW), is unloaded from collection vehicles or containers for reloading into larger, long-distance vehicles for transport to landfills or other permitted solid waste facilities for final disposal. Facilities that move the solid waste from one mode of transportation to another, such as road, can also be considered transfer stations SW that quickly decomposes, such as food waste, must be removed from a transfer station by the next day. Recyclables may be stored in containers for a longer period of time. Combining several truckloads of waste into a single shipment reduces trips to and from the disposal site, saving communities money on labour and transportation.

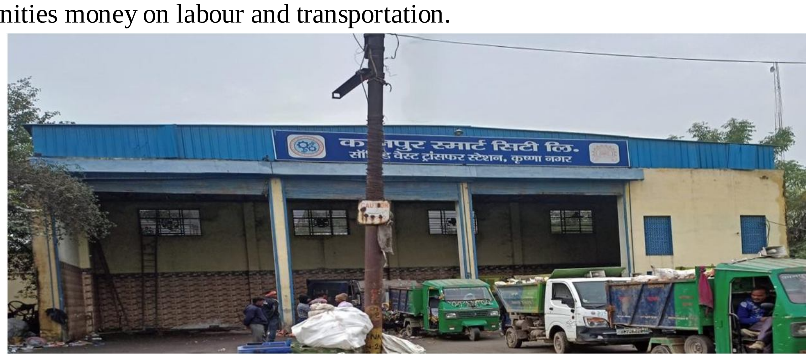
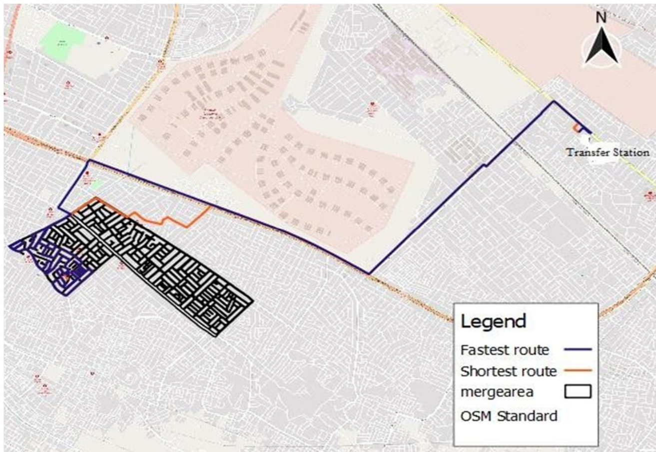


Fig-2: Transfer Station of zone 2

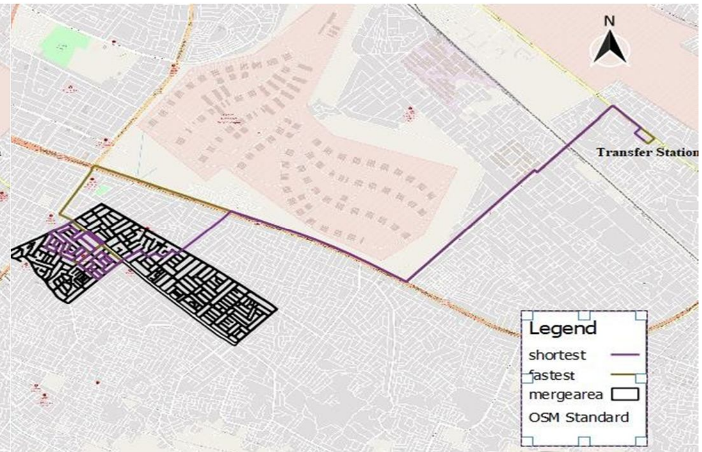
The private companies are contracted, for the collection of household solid waste and transportation to landfill disposal sites by the Municipality, number of labour's and waste trucks assigned to the task of collection and transportation, the contract budget, the mean location (study area) to disposal site.

G. Optimal Path Between Waste Collection Points to Transfer Station



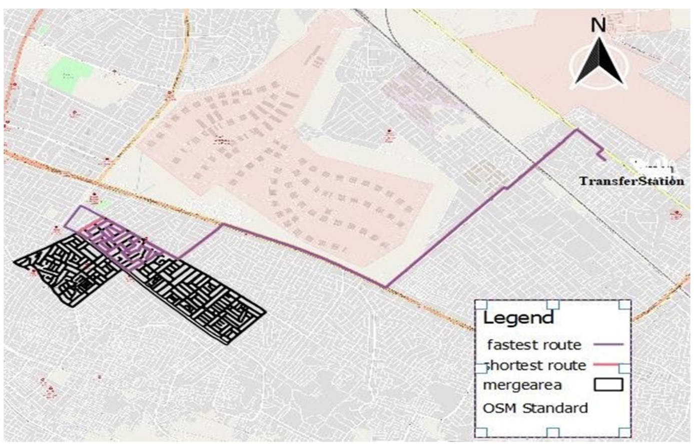
……13.09Km ……11.63Km

Fig- 3: Optimized solid waste collection vehicle route.



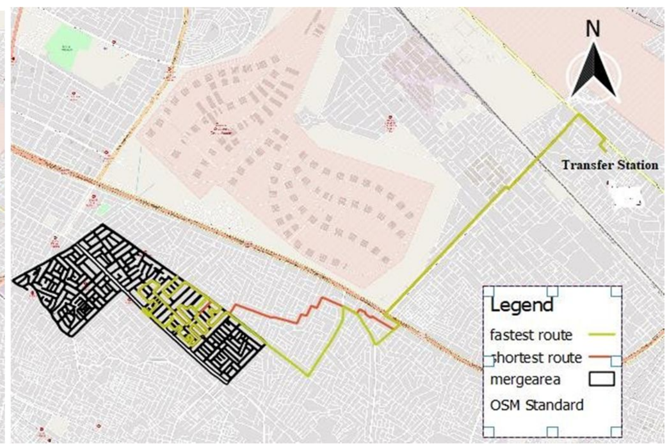
…12.05Km 10.45Km

Fig-4: Optimized solid waste collection vehicle route.



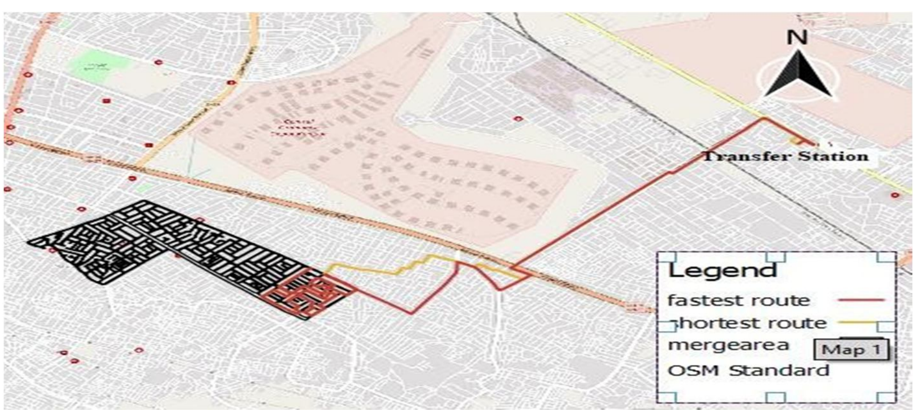
…11.65Km …….10.75Km

Fig-5: Optimized solid waste collection vehicle route.



…..11.29Km 10.23Km

Fig:-6: Optimized solid waste collection vehicle route.



…9.79Km ……9.22Km

Fig-7: Optimized solid waste collection vehicle route

All above figure to optimized solid waste collection vehicle route and two route are founded fastest & shortest route then alsofind the transportation cost of solid waste collection in below-

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H. Data Collection

Transportation cost:

Desired ward 95, zone 2. Five Working vehicles (Tata ace) are allotted for the ward. And each vehicle covers 780-800 houses.Each vehicle has 1 driver, 2 helper and 1 IEC member.

1) Quantity of waste generated/collected: 400 kg/day
2) Vehicle speed- vehicle stoppages and halts: (average) Mileage of vehicle 8 km/ltr.
3) Salary of driver (INR per month): 8800
4) Salary of helper (INR per month): 8800
5) Salary of IEC member (INR per month): 12000
6) Total cost of per vehicle in a month-maintenance of vehicle + salary (2 helper + 1 driver) + fuel = 35,900/- approx...

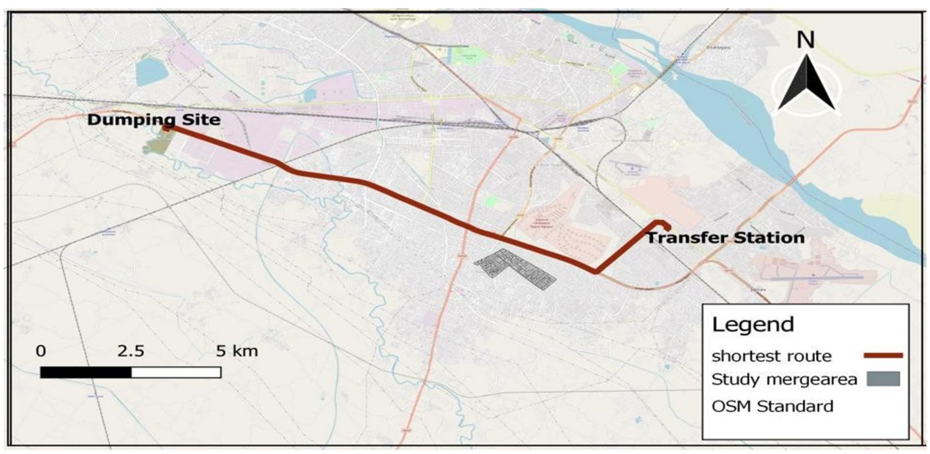
Sources: Nagar Nigam Kanpur

III. RESULTS AND DICUSSION

A. Optimize Waste route Between the Transfer stations to Dumping site Plants

……18.82Km

Fig-: 8 Fastest optimized solid waste collection vehicle route



……..16.63Km

Fig-: 9 Shortest optimized solid waste collection vehicle route

Table1: Results from the approach by comparing current distance (Km) v/s optimized distance (Km)

Vehicle	Destination Point	Practicing distance(Km)	Optimized distance (Km)	Saving distance (Km)
ST	Dumping site	18.82	16.63	2.19

The QGIS network analyst tool was applied by making the ward number 95 as a starting point of vehicle transfer station to Dumping site as a destination as shown in Fig 9. The shortest route was found as 16.63 km (optimized distance), compared to 18.82 km (existing route distance).

B. *Estimating Transportation Cost:*

Transportation cost of MSW includes cost of vehicle, cost of fuel, salaries of driver and helper and operation and maintenance cost of Vehicles. Transportation cost is calculated with the reference to “Municipal Solid Waste Management on a Regional Basis by Ministry of Urban Development Government Of India”.

Calculating desired ward 95, zone 2. Five Working vehicles (Tata ace) are allotted for the ward. Each vehicle has 1 driver, 2 helper and 1 IEC member.

Table2:No. of vehicle required

Waste transported vehicle per day	No. of Vehicles required	No. of Drivers required	No. of helpers required	IEC Member
400 kg	5	5	10	5

Table3:Cost of fuel (fastest)

Vehicles		Total Distance covered by Vehicle (km)	Diesel required per day (litre)	Cost of Diesel per day (INR)	Cost of diesel per Month (INR)	Cost of diesel per Annum (INR)
S1	TS	13.09	1.64	147.6	4428	53136
S2	TS	12.05	1.51	135.9	4077	48924
S3	TS	11.65	1.46	131.4	3942	47304
S4	TS	11.29	1.41	126.9	3807	45684
S5	TS	9.79	1.22	109.8	3294	39528
Total		57.87	7.24	651.6	19548	234576

Table4: Total cost of Transportation (per annum)

Total Waste to be transported	Cost of fuel (INR)	Salaries of worker (INR)	Cost of Maintenance (INR)	Total Cost (INR)
400 kg/d	234576	1776000	138000	2148576

Table5: Cost of fuel (optimized)

Vehicles		Total Distance covered by Vehicle (km)	Diesel required per day (litre)	Cost of Diesel per day (INR)	Cost of diesel per Month (INR)	Cost of diesel per Annum (INR)
S1	TS	11.63	1.454	130.86	3926	47112
S2	TS	10.45	1.306	117.54	3526	42312
S3	TS	10.75	1.344	120.96	3629	43548
S4	TS	10.23	1.278	115.02	3451	41412
S5	TS	9.22	1.153	103.77	3113	37356
Total		52.28	6.54	588.15	17645	211740

Table6:Cost of per vehicle worker Salaries

Total Wasteto be Transported	NO. of Drivers Required	Salary per month (INR)	No. of Helpers required	Salary per month (INR)	IEC member	Salary per month (INR)	Total salary permonth (INR)	Total salary perAnnum (INR)
400kg/d	1	8800	2	8800	1	12000	29600	355200

Cost of one vehicle worker Salaries= 29,600 Cost of five vehicles workers Salaries= 1,48,000

Table7:Total cost of Transportation (p

Total Waste to be transported	Cost of fuel (INR)	Salaries of workers (INR)	Cost of Maintenance (INR)	Total Cost (INR)
400 kg/d	211740	1776000	138000	2125740

Based on the obtained information, the total daily collected solid waste is 400kg/d. And 5 vehicles were specified to collect all produced waste from study area. Waste collection and transportation operations are carried out specific direction. Waste collection and transportation routes were designed using Arc & QGIS software and also calculating cost effectiveness of solid waste transportation.

IV. CONCLUSIONS

In this study, an optimization was developed using the QGIS tool in order to improve the efficiency of the collection and transportation of waste of ward 95, zone 2 in Kanpur. The location area of the transfer station to the dumping site were modelled separately to find respective optimized transportation routes for solid waste management. This study finds the reductions in haul distance as 2.19 for location. The present study attempted to analyze the collection and transportation costs of municipal solid waste from location of study area to transfer station. Here GIS based optimal model is developed and used to trace the least cost. This minimum cost is with respect to distance efficient collection path in transferring the solid waste to the open dumping ground. With different transfer station and associated minimum paths could be adopted as it saves around 25 thousands (approx.) on Solid waste management.

V. ACKNOWLEDGMENT

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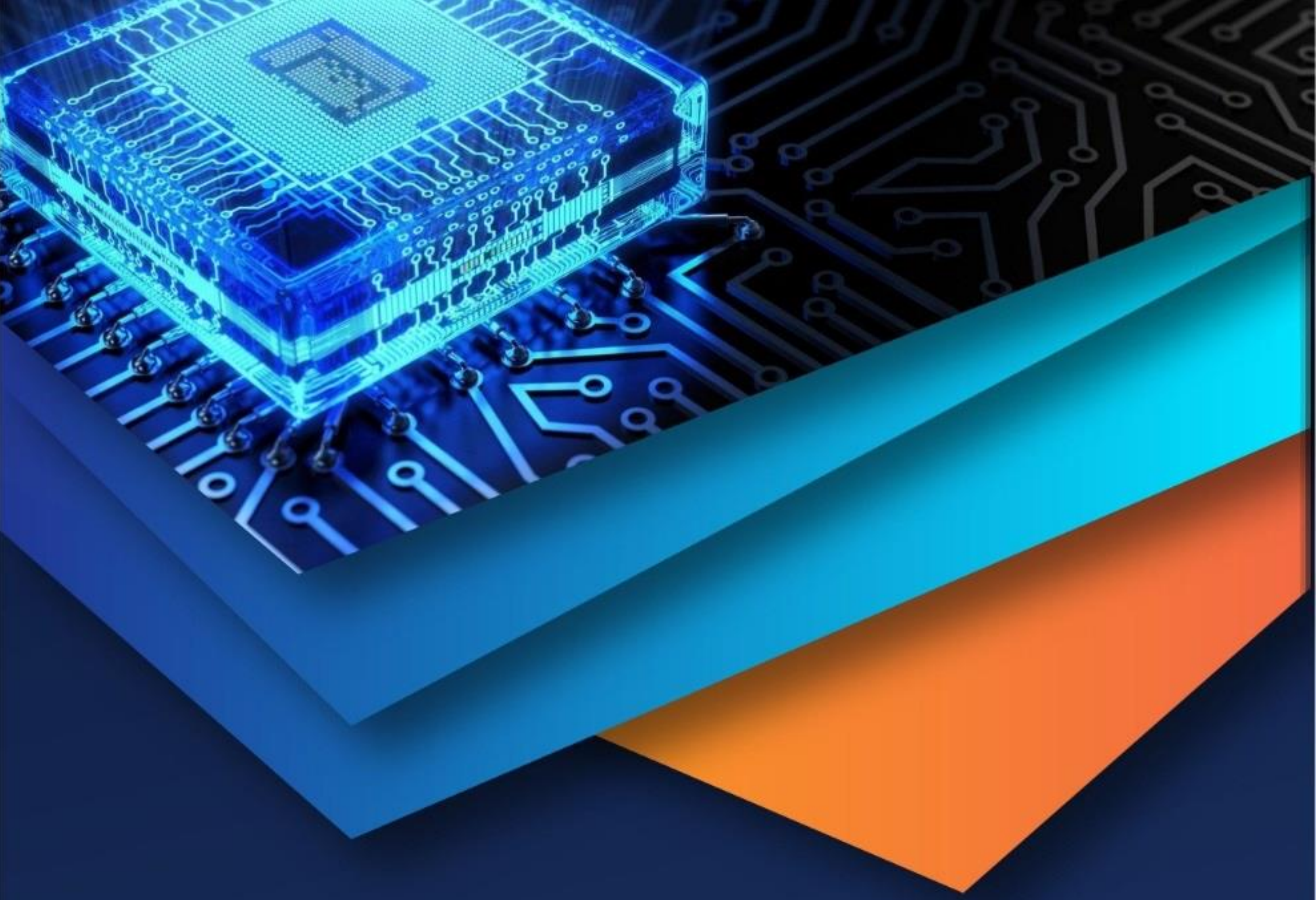

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