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A Development of Multi-Stakeholder Game Model for Analysis of Preferences of Hazardous Substances Computers or Hazardous Substances Free Computers-Based On Incentive Mechanism

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Abstract: The tremendous growth in use of electronics devices and services, faster change of technology had left the world with a threat of deterioration in environmental conditions and human health as the waste of electronic devices which contains hazardous substances is not managed properly and disposed of after the end of their life. The aim of this paper is to survey the game theory modeling to the computer waste management and presents a framework for analysis of the behavior of manufacturer and consumer in hazardous substances free and hazardous substances strategies by considering cost difference. This paper proposed a scheme to decide which strategy is better suited, gaining the maximum profit and also the profit allocation of each stakeholder. Results suggest that the HSF computers can be a preferred choice of the manufacturers as well as consumers and also suggest that applying return back schemes with some incentives to the consumers and penalty to those who do not follow the prescribed procedure for discarding computer waste could be very useful to discourage the land disposal of the computer waste.

Keywords: Computer waste management, Extended producer responsibility fee, Game theory, Return back scheme.

I. INTRODUCTION

Electronics waste commonly known as e-scrap, is the trash we generate from surplus,broken and obsolete electronic devices.We are creating e-waste at a rapid rate as there is increase in use of electronic devices, frequent innovations in IT sectors and faster change of technology.Some of the most commonly replaced electronics include cell phones (replaced every 22months), desktop computer (replaced every 2 years), portable music players (replaced every 2/3 years), DVD player (replacedevery 4/5 years), printer (replaced every 5+ years), and televisions (replaced every 10+ years). So, with very short useful life, these electronics transition into e-waste at a rapid pace.Every year millions of electronic devices such as mobile phones, TVs, computers, laptopsand tablets reach the end of their useful life.These wastes are generated globally in large quantities and in most case, are not managed properly. These days computer has become most common and widely used gadget in all kinds of activities ranging from schools, residences, offices to manufacturing industries. E-toxic components in computers could be summarized as circuit boards containing heavy metals like lead and cadmium; batteries containing cadmium; cathode ray tubes with lead oxide and barium; printed circuit boards, cables and plastic casing containing brominated flame-retardants; poly vinyl chloride coated copper cables and plastic computers; casings that release high toxic dioxins and furans when burnt to recover valuable metals; mercury switches and others. Basel Action Network (BAN) estimates that the 500 million computers in the world contain 2.87 billion kgs of plastics, 716.7 million kgs of lead and 286,700 kgs of mercury. So these are extremely dangerous to human health and the environment as the lead can contaminate the ground water from landfills and if the tube is crushed and burned, it emits toxic fumes into the air. Acids and sludge obtained from melting computer chips if disposed on the ground causes acidification of soil. These toxic substances affects nervous system, brain development of children, accumulates in kidney and liver, causes reproductive and developmental problems, damage immune system, increase chances of lung cancer, skin disease. 20 to 50 million metric tons of e-waste are disposed worldwide every year. In 2007, the US Environmental Protection Agency stated that more than 63 million computers in the US were traded in for replacements or discarded..So disposal requires special treatment to prevent the leakage and dissipation of toxics into the environment.

Rapid technology change, low initial cost have resulted in a fast growing surplus of computers and electronic components around the globe. Today 15% of electronic devices and equipment are recycled in US Technical solutions are available but in most cases a legal framework, collection system, logistics and other services need to be implemented before applying a technical solution. The US Environmental Protection Agency estimates 30 to 40 million surplus PCs classified as hazardous household waste would be ready for end-of-lifemanagement in the next 5 years. The US National Safety Council estimates that 75% of all personal computers ever sold are now surplus electronics. There are many regulatory initiatives as the established producer responsibility organization is SWICO mainly handling information, communication and organization technology. In 2001, Arkansas enacted the Arkansas computer and electronic solid waste management act, which requires that state agencies manage and sell surplus computer equipment, establishes a computer and electronics recycling fund and authorizes the department of Environmental Quality to regulate or ban the disposal of computer and electronic component in Arkansas landfills. Electronic Device Recycling Research and Development Act distributes grants to universities, government labs and private industries for research in developing projects in line with e-waste recycling and refurbishment. According to report by UNEP titled, " Recycling-from E-waste to Resources" the amount of e-waste being produced- including mobile phones and computers could rise by as much as 500 percent such as India. According to National Environmental Management Act 1998 and National Environmental Management Waste act 2008, any person in any position causing harm to the environment and failing to comply with the waste act could be fined R10 Million or put into jail or receive both penalties for their transgressions.

Recycling e-waste with suitable techniques is necessary to protect the air, soil and water and thus to protect health and environmental risk. Computer waste management system needs to have clear objectives and policies to manage them properly. As a computer contains many hazardous substances, if these hazardous substances computers are replaced with hazardous substances free computers , a manufacturer has to select the product design strategies that are economic as well as environmentally friendly. As HSF materials are more costly than the HS materials. Hence replacing the HS computers with HSF computers will have significant impact on the overall cost of the computers.This paper implements certain strategies to compensate the increased cost of the computer for the stakeholders as they are contributing towards reducing the environmental risks at the time of end-of-life disposal of the computer. The computer waste management system should develop a clear role for the manufacturer and the consumer, including incentive to consumer in case of return back, penalty to consumer in case of land disposal and incentive to the manufacturer in case of HSF computer and no incentive in case of HS computers.

aim of this paper is to set the strategies in such a manner that the overall profit of manufacturer and the cost paid by the consumer should remain in balance. This study applied the game theory between manufacturer and consumer by considering two strategies each.

II. LITERATURE REVIEW

As a computer system has different components and because of hazardous material composition, their disposal in inappropriate manner is problematic. These hazardous materials can pollute ground water if disposed on the land, can pollute air if burned or leach into the soil. So manufacturing of HS computers can be changed into the HSF computers to reduce the environmental issues. To operate the computer waste management system financial resources are provided for collection, recycling and disposal in many countries. In some countries land disposal of the e-waste are not allowed. Forslind (2005) stated that European parliament passed a directive requiring its member countries to institute an EPR fee for the end of life. There are several studies that analyzes the implementation of EPR fee for e-waste. According to Greenpeace (2008), in India return back scheme for e-waste is in its growing stage. HCL, WIPRO, Nokia, Acer, Motorola, LG are practicing the return back scheme. Wang et. al. (2010) applied the game theory to create a mixed strategy game model of the manufacturer and the supplier. Ying-Ying et al. (2009) studied the price decisions and incentive mechanism of the three levels RSC model including manufacturer, a maintenance centre, retailer. Casey et al. (2007) reported the application of game theory to the life cycle of bottle packaging and presents a framework for an analysis of the choice between refillable and disposable bottles. Sinha-Khetriwal et al. (2005) has reported that collectors pay the customers for their old appliances for strong recycling network and in 2009 report about ARF which producers pay at the time of sale. Barari et al. (2012) developed a two player synergetic alliance with the focus on maximizing economic profits by leveraging the product's greenness.

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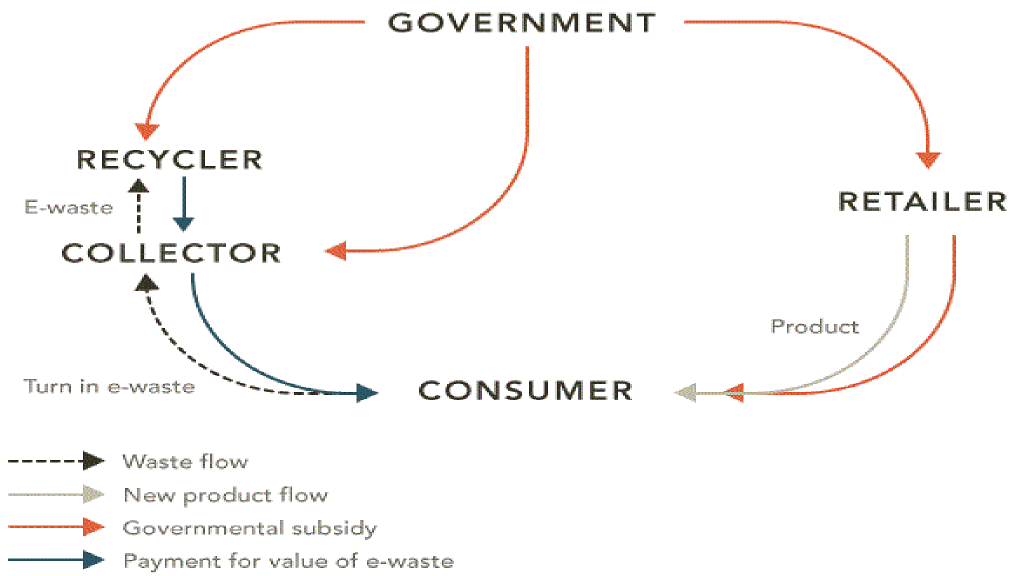

Figure 1: Material and financial flows of e-waste.

For successful management of computer waste, market based e-waste strategies around the globe should be adopted by implementing the various policies that are experienced by different countries. In this paper a game model for the manufacturer and the consumer is used for finding a set of Nash-equilibrium strategies which motivate them to recycle the HSF computers. Material and financial flows of e-waste in India are shown in fig. 1. Collectors pay consumers for their old appliances which are in demand. Government gives incentive to manufacturer for HSF computer.

A. Game model for manufacturer and consumer

An extensive form game is a specification of a game in game theory which represents the sequencing of player's possible moves, their choices at every decision point, the information each player has about the other player's moves when he makes a decision and his payoffs for all possible game outcomes. The manufacturer has two strategies: uses HS or uses HSF material in manufacturing of the computers. The manufacturer can give incentive to the consumer for return back products. The manufacturer can charge EPR fee from the consumer for EOL management of computer waste in case of HS computers and can be relaxed in the case of HSF computers. The consumer may have two strategies for its computer waste: either to choose land disposal or return back to manufacturer.

Payoffs formulation for stakeholders: EPR (E_P) from the consumer, incentive from government (I_{GM}) and selling price of recycled material (S_R) at disposal of computer waste are positive payoffs to manufacturer. The collection charges (C_C), recycling fee (R_F) and incentive to the consumer (I_{MC}) in case of return back for disposal of computer waste are negative payoffs to the manufacturer. Incentive from manufacturer (I_{MC}) in case of return back is positive payoff to consumer while transportation cost (T_C), EPR (E_P) and penalty to the government (I_{GC}) for land disposal of computer waste are negative payoffs for the consumer for both HSF and HS computers.

Payoff of the manufacturer:

$$\Pi_M = E_{P\,jk} - C_{C\,jk} - R_{F\,jk} - I_{MC\,jk} + I_{GM\,jk} + S_{R\,jk} \quad \textbf{(1)}$$

Payoff of the consumer:

$$\Pi_C = I_{MCjk} - T_{C\,jk} - E_{Pjk} - I_{GC\,jk} \quad \textbf{(2)}$$

Where j = 1 or 2, k = 1 or 2 as each player selects its single strategy at a given time.

B. Assumptions

The following assumptions have been made for the construction of these equation (1&2):

1) EPR fee will be paid by the consumer only in case of HS computer.

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2) Government will provide incentives to manufacturer for manufacturing the HSF computers and no incentive for HS computers to encourage the manufacturer for producing HSF computers.
3) Incentive will be given to consumer by the manufacturer only in the case, when the consumer selects the return back strategy to discourage the land disposal.
4) Selling price of recycled material will be taken by the manufacturer.
5) The consumer will pay the penalty charged by the government when the consumer selects the land disposal strategy to minimize the land disposal of the waste. Penalty in case of land disposal of HS computer is higher in comparison with HSF computer.
6) Manufacturer will pay the recycling fee of the computer waste.
7) Manufacturer will pay the collection charges of computer waste only in the case when the consumer selects the land disposal strategy.
8) The transportation cost will be paid by the consumer in the case of return back option.
9) There is no upper limit on the capacities of the collection, reuse, treatment and disposal facilities.

The assumed values of various parameters are shown in the table 1for both HSF and HS computers.

Parameters	HS Computer	HSF Computer			
		X_1 = 5% of cost	X_2 = 10% of cost	X_3 = 15% of cost	X_3 = 20% of cost
Assumed extra cost of HSF computer (X)	-	of HS computer	of HS computer	of HS computer	of HS computer
Cost of computer(US$)	400	420	440	460	480
EPR (E_P)	6%	0%	0%	0%	0%
Incentive to manufacturer from government (I_{GM})	0%	Y_1%	Y_2%	Y_3%	Y_4%
Recycling Fee (R_F)	4%	2%	2%	2%	2%
Incentive return to consumer From manufacturer (I_{MC})	4%	Z_1%	Z_2%	Z_3%	Z_4%
Resale price of recycled Material (S_R)	2%	6%	6%	6%	6%
Penalty to consumer in land Disposal by government (I_{GC})	6%	2%	2%	2%	2%
Transportation cost (T_C)(US$)	44	4	4	4	
Collection charges (C_C)(US$)	44	4	4	4	

Values gven in % are in % of cost of the respective computer.

Table 1 Parameter Values in the Game Model.

The values of Y_1, Y_2, Y_3, $Y_4$and Z_1, Z_2, Z_3, Z_4 have been found for assumed cost differences (X_1, X_2, X_3, X_4) using a two stakeholder non-cooperative extensive game with manufacturer and consumer as players. GAMBIT software has been used for generating game trees for non-cooperative game for two stakeholders.

III. RESULTS AND DISCUSSION

The Nash-equilibrium strategies with respective payoffs for manufacturer and consumer are shown in table 2.

Cost of computer and cost difference (US$)(a)	% of cost of HS computer (b)	Policy (c)	EPR (6% of cost of HS computer (US$) (d)	Manufacturer Nash equilibrium strategy(e)	Payoff (US$)(f)	Consumer Nash equilibrium strategy(g)	Payoff (US$)(h)	Extra cost paid for HSF (US$) (i)=(a)-(d)	Total extra cost paid for HSF (US$) (j)=(i)-(h)

HS=400 X_1=5 I_{GM1}=1.6% 24 HS 0 RB -12 -4 8

HSF=420 I_{GM2}=1.8% 24 HSF 0 RB 20.36 -4 -24.36

Cost difference or HS 0 RB -12 -4 8

C=20I_{GM3}=2.0% 24 HSF 0.84 RB 20.36 -4 -24.36

I_{MC1}=5.6% 24 HSF 0.84 RB 19.52 -4 -23.52

I_{MC2}=5.8% 24 HSF 0 RB 20.36 -4 -24.36

or HS 0 RB -12 -4 8

I_{MC3}=6.0% 24 HS 0 RB -12 -4 8

E_P = 5.8% 24 HSF 0RB 20.36-4 -24.36

E_P = 6.0% 24HSF0RB 20.36-4 -24.36

Or HS0RB -12 -48

E_P = 6.2% 24HS0.8RB -12.8 -4 8.8

HS=400 X_1=10 I_{GM1}=10.4% 24 HS 0 RB -12 1628

HSF=440 I_{GM2}=10.6% 24 HSF 0 RB 60.2416-44.24

Cost difference or HS 0 RB -12 1628

C=40 I_{GM3}=10.8% 24 HSF 0.88 RB 60.2416 -44.24

I_{MC1}=14.4% 24 HSF 0.88 RB 59.3616 -43.36

I_{MC2}=14.6% 24 HSF 0 RB 60.2416 -44.24

or HS 0 RB -12 16 28

Cost of computer cost and cost difference HSF (US$)(a)	% of cost of HS computer (b)	Policy (c)	EPR(6% of cost of HS computer (US$) (d)	Manufacturer Nash equilibrium strategy(e)	Payoff (US$)(f)	Consumer Nash equilibrium strategy(g)	Payoff (US$)(h)	Extra cost paid for HSF (US$) (i)=(a)-(d)	Total extra paid for (US$) (j)=(i)-(h)

I_{MC3}=14.8% 24 HS 0 RB -12 162 8

E_P = 5.8% 24 HSF 0 RB 60.2416 -44.24

E_P = 6.0% 24 HSF 0 RB 60.2416 -44.24

Or HS 0 RB -12 1628

E_P = 6.2% 24 HS 0.8 RB -12.8 16 28.8

HS=400 X_1=15 I_{GM1}=18.6% 24 HS 0 RB -12 3648

HSF=460 I_{GM2}=18.8% 24 HSF 0 RB 100.88 36 -64.88

Cost difference or HS 0 RB -12 3648

C=60 I_{GM3}=19% 24 HSF 0.92 RB 100.88 36 -64.88

I_{MC1}=22.6% 24 HSF 0.92RB 99.96 36 -63.96

I_{MC2}=22.8% 24 HSF 0 RB 100.88 36 -64.88

or HS 0 RB -12 3648

I_{MC3}=23% 24 HS 0 RB -12 36 48

E_P = 5.8% 24 HSF 0 RB 100.88 36 -64.88

E_P = 6.0% 24 HSF 0 RB 100.8836 -64.88

Or HS 0 RB -12 3648

E_P = 6.2% 24 HS 0.8RB -12.8 36 4 8.8

HS=400 X_1=20 I_{GM1}=25.8% 24 HS 0 RB -12 56
68

HSF=480 I_{GM2}=26% 24 HSF 0 RB 140 56 -84

Cost difference or HS 0 RB -12 56
68

C=80 I_{GM3}=26.2% 24 HSF 0.96 RB 140 56 -84

I_{MC1}=29.8% 24 HSF 0.96 RB 139.04 56 -
83.04

I_{MC2}=30% 24 HSF 0 RB 140 56 -84

Cost of computer cost and cost difference HSF (US$)(a)	% of cost of HS computer (b)	Policy (c)	EPR(6% of cost of HS computer (US$) (d)	Manufacturer Nash equilibrium strategy(e)	Payoff (US$)(f)	Consumer Nash equilibrium strategy(g)	Payoff (US$)(h)	Extra cost paid for HSF (US$) (i)=(a)-(d)	Total extra paid for (US$) (j)=(i)-(h)

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		or HS	0	RB	-12	56	68
I_{MC3}=30.2%	24	HS	0	RB	-12	56	68
E_P = 5.8%	24	HSF	0	RB	140	56	-84
E_P = 6.0%	24	HSF	0	RB	140	56	-84
		Or HS	0	RB	-12	56	68
E_P = 6.2%	24	HS	0.8	RB	-12.8	56	68

Table2 Results of Nash equilibrium strategies.

The Nash equilibrium strategies and their payoffs for manufacturer and consumer are obtained by game tree that is generated by GAMBIT software. The game tree for one of the case as I_{GM3} =19% for X_3= 15% is shown in fig. 2. The payoffs for strategic moves are shown at their terminal nodes. The probabilities of selecting each of the actions are displayed above the respective branch of the game tree.

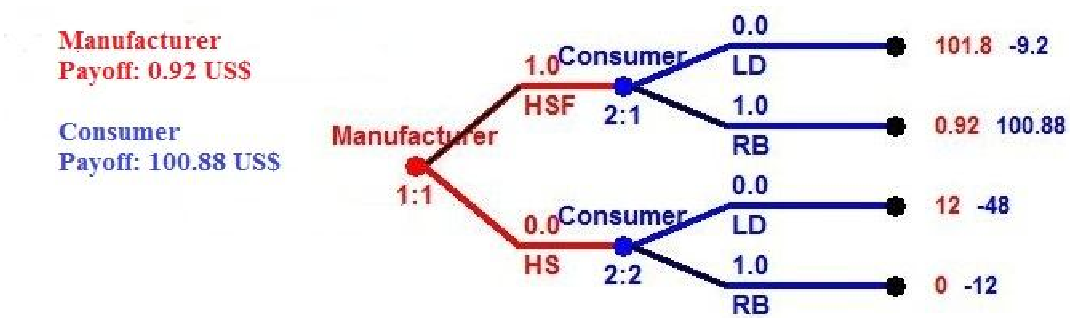

Figure 2 Extensive game tree for I_{GM3} =19% for X_3= 15%.

A. EPR(E_P)

From table 2 it can be seen that the manufacturer will not prefer the production of a HS computer and select HSF computer production if EPR is less than or equal to 6% of the cost of the HS computer. If EPR is more than 6%, the manufacturer's choice will be HS computer production.

B. Incentive to manufacturer from government (I_{GM})

From table 2 it can be seen that, for X_1 =5%, at I_{GM1}= 1.6% the Nash equilibrium strategies are HS and RB with payoffs of 0 and -12 US$ for manufacturer and consumer respectively. At I_{GM2}= 1.8% the Nash equilibrium strategies are HSF or HS and RB with payoffs (0 and 20.36US$) and (0 and -12US$) and at I_{GM3}= 2% the strategies are HSF and RB with payoffs of 0.84 and 20.36US$ respectively for manufacturer and consumer. It shows that if the incentive to manufacturer from government is equal to or more than 1.8% of the cost of the HSF computer, the manufacturer's profit remains same or increases and consumer gets the payoff of 20.36US$. So the manufacturer will prefer the manufacturing of HSF computers in place of HS computers if the incentive from government is atleast 1.8% of the cost of a HSF computer for a cost difference of 5% of the cost of a HS computer. Similarly if these incentive to manufacturer are 10.6%, 18.8% and 26%, the payoffs of manufacturer remains the same (0US$) for both HS and HSF computers, whereas the payoffs to the consumer are 60.24, 100.88 and 140US$ respectively. The extra cost paid by the consumer for a HSF computer are 16, 36 and 56US$ respectively, for cost differences of 10, 15 and 20%. This implies that the consumer recovers the extra cost paid for the HSF computer.

C. Incentive return to consumer from manufacturer (I_{MC}):

It can be seen from table 2 that for X_1 =5%, the Nash equilibrium strategies at I_{MC3}= 6% are HS and RB with payoffs of 0 and -12US$ respectively, for manufacturer and consumer. It shows that the manufacturer will prefer to produce HS computes if the incentive to consumer from manufacturer for a HSF computer is 6%. At I_{MC1}= 5.6%, the Nash equilibrium strategies are HSF and RB with payoffs 0.84 and 19.52US$ respectively for the manufacturer and consumer. At I_{MC2}= 5.8%, the Nash equilibrium strategies are HSF or HS and RB with payoff (0 and 20.36US$) and (0 and -12US$). This suggests that for a cost difference of 5% of the cost of a HS computer, the manufacturer will prefer HSF computer manufacturing and the consumer will prefer the HSF computer to return back to the manufacturer at its EoLif the incentive to consumer from manufacturer is less than or equal to 5.8% of the cost of the HSF computer. Similarly, for a cost difference of 10,15 and 20%, the manufacturer will prefer HSF computer manufacturing and the consumer will prefer the HSF computer to return back to the manufacturer at its EoL if the incentive to consumer from manufacturer is 14.6, 22.8 and 30% of the cost of the HSF computer.As at these incentives, the payoffs to the manufacturer remains same 0US$.For both HS and HSF computer manufacturing, whereas the payoff to the consumer are 60.24, 100.88 and 140US$ respectively. The extra cost paid by the consumer for a HSF computer are 16, 36 and 56US$ respectively for cost difference of 10, 15 and 20%. This implies that with these incentives the consumer can recover the extra cost paid for a HSF computer.

IV. CONCLUSIONS

In this paper a game model has been presented by considering manufacturer and consumer as a player, having each strategies for replacing the HS computer by HSF computer without compromising their profits. This study sets better policies to promote return back, reuse and recycling for reducing the environmental risk and human health related issues. To encourage the recycling of computer waste the government can impose penalty on the land disposal of computer waste. In this study, this penalty has taken more in the case of land disposal of HS computers in comparison with the land disposal of HSF computers. The government can provide incentive to manufacturers for producing the HSF computers and no incentive for producing HS computer. To promote return back strategy the manufacturer can give some incentive to the consumer. In this paper, this incentive has taken more for a HSF computer in comparison with HS computer to attract the consumer towards the HSF computer. Manufacturer can impose an EPR to the consumer at the time of purchase of a HS computer, while there should be no EPR for a HS computer.

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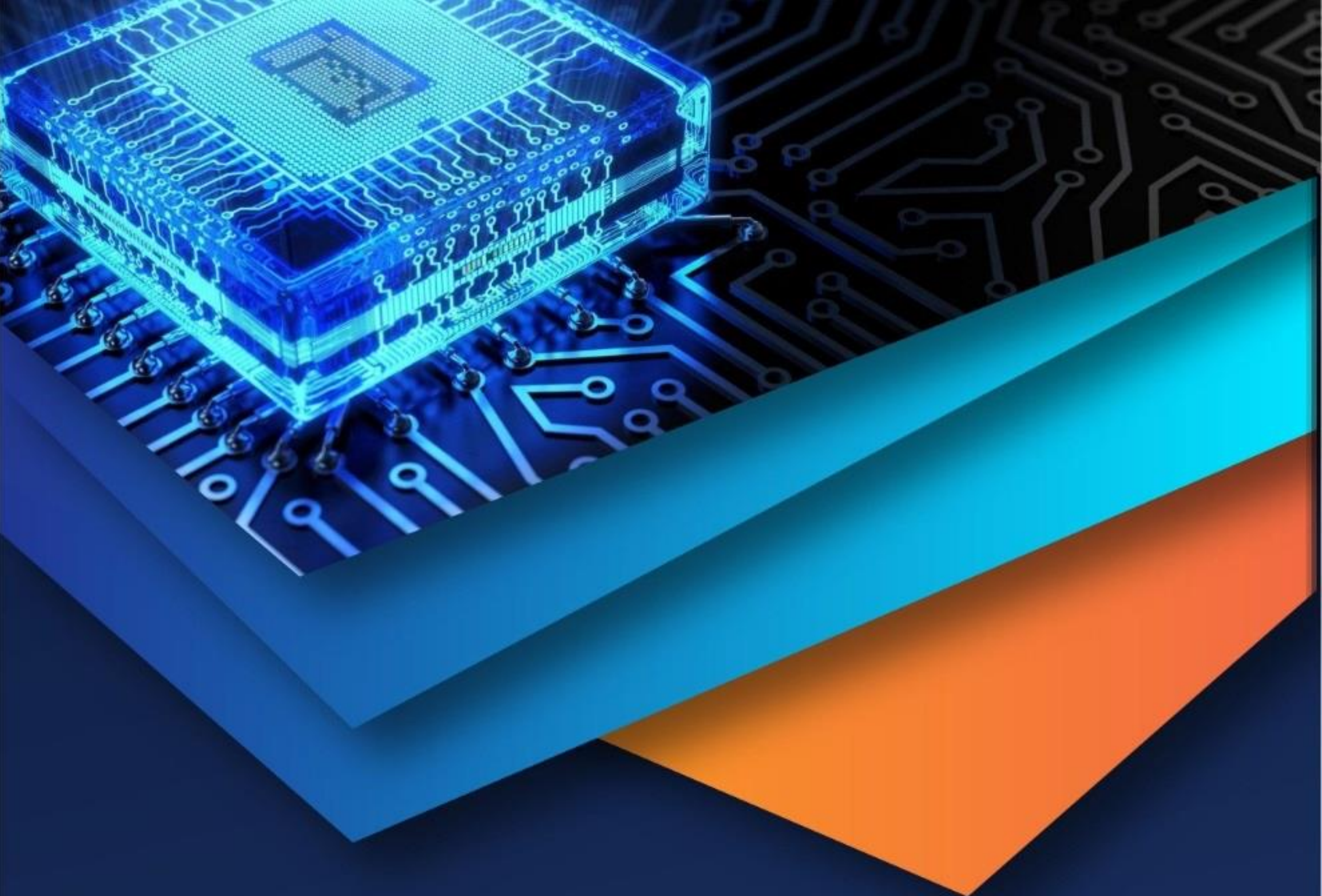

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