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# Game-theory approach to optimize waste management

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*Abstract:* - **Waste management helps to evade undesirable short term and long-term effects of waste disposal. It must follow approved guidelines that take into considerations the social, environmental, and technical aspects of sustainability. Game theory is a developing science of strategy, or at least the optimal decision-making of independent decisions as it involves the study of human conflicts and cooperation within a competitive situation which often lack in other methods. The formal application of game theory requires knowledge of the details like identity of independent actors, their preferences, what they know, which strategic acts they are allowed to make, and how each decision influences the outcome of the game. Depending on the model, various other requirements or assumptions may be necessary. Stakeholders relevant to the problem scenario, their respective strategies, and parameters which influence their payoff are identified.. The payoffs of the game were calculated considering both direct cost and external cost. The game was played for a hypothetic scenario .Different games taking different combination of players were played. Best strategy for each player has been identified. In many cases coalition offered a better payoff. It has been found that a proper logical formulation of payoff is essential for reliable results**

**Index Terms— Solid waste, Game-theory, Decision making; Competition; Cooperation; Waste management planning**

## 1. INTRODUCTION

Modern life-style with its emphasis on consumption and disposal has brought in its wake the acute problem of Waste Management across the globe. The problem is aggravated due to pressure on land space on our planet. Unscientific handling of wastes degrades the urban environment and causes health hazards .World faces major environmental challenges associated with waste generation and inadequate waste collection, transport, treatment and disposal. Current system in many countries cannot cope with the volumes of waste generated by an increasing urban population, and this impact on the environment and public health.[12],[21],[56],[67] The waste management criteria are mostly common but vary in parameters and reliant on the social-economic, environmental requirements, size and physical topography of respective communities. In many of the methods priority is given for technical parameters where socio-economic-environment aspects are of least concern. Game theory overcomes this problem. Game theory is the formal study of conflict and cooperation. Game theoretic concepts apply whenever the actions of several agents are interdependent. These agents may be individuals, groups, firms, or any combination of these. The concepts of game theory provide a language to formulate structure, analyze, and understand strategic scenarios.(Theodore L. Turocy, 2001).In this regard Game Theory provides optimal result for waste management. the optimum solution to the waste management problem is mainly focused on multiobjective, multicriteria, and multistakeholder context[3],[29]]. According to [41] waste management deals with situations where waste producers and waste processors are involved. The producers need to dispose of all the waste and the processors want to fill their capacity. For the efficiency of this process, the right decisions need to be made. This decision-making situation is further denoted as the waste management game with waste processors and waste producers as its players.

The objective of waste processors is to maximize their income by achieving the optimal combination of the amount of the processed waste and the charge for this processing. Assuming the waste processors already standing, and hence with no way to change the capacity, their only tool is the gate fee setting. For any setting, however, a reaction of other processors is expected. Waste producers, on the other hand, aim to minimize their outcome. These aspects are seldom considered in conventional methods. In existing studies only direct costs are taken into account for payoff formulation. This may not result in reliable equilibrium strategies. So indirect costs are also included in present study

## APPLICABILITY OF GAME THEORY

The internal consistency and mathematical foundations of game theory make it a prime tool for modeling and designing automated decision-making processes in interactive environments. As a mathematical tool for the decision-maker the strength of game theory is the methodology it provides for structuring and analyzing problems of strategic choice. The process of formally modeling a situation as a game requires the decision-maker to enumerate explicitly the players and their strategic options, and to consider their preferences and reactions. The discipline involved in constructing such a model already has the potential of

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providing the decision-maker with a clearer and broader view of the situation.
The object of study in game theory is the game, which is a formal model of an interactive situation. It typically involves several players; a game with only one player is usually called a decision problem. The formal definition lays out the players, their preferences, their information, and the strategic actions available to them, and how these influence the outcome. Games can be described formally at various levels of detail. A coalitional (or cooperative) game is a high-level description, specifying only what payoffs each potential group, or coalition, can obtain by the cooperation of its members. What is not made explicit is the process by which the coalition forms. As an example, the players may be several parties in parliament. Each party has a different strength, based upon the number of seats occupied by party members. The game describes which coalitions of parties can form a majority, but does not delineate, for example, the negotiation process through which an agreement to vote en bloc is achieved.
Cooperative game theory investigates such coalitional games with respect to the relative amounts of power held by various players, or how a successful coalition should divide its proceeds. This is most naturally applied to situations arising in political science or international relations, where concepts like power are most important.

In optimization most of the problems are multi criteria, multi decision problems. In conventional optimization methods, while converting problem attributes to a single function, a perfect cooperation is assumed among decision makers. The individual priorities are seldom considered. But in game theory these priorities are taken into consideration in a way that, individual decisions are affected by other's payoff and decision. This self-optimizing attitude determines the resultant strategy.
According to Rajendra Kumar Kaushal [45] Game theory can help to provide some planning, policy, and design insights that would be unavailable from other traditional systems engineering methods. Another advantage of game theory over traditional quantitative simulation and optimization methods is its ability to simulate different aspects of the conflict, incorporate various characteristics of the problem, and predict the possible resolutions in the absence of quantitative payoff information. Often non-cooperative game theory methods can help to resolve the conflict based on the qualitative knowledge about the players' payoffs .This enables handling of the socioeconomic aspects of conflicts and planning, design, and policy problems when quantitative information is not readily available. In general, game theory results are closer to practice because this method better reflects the behaviors of the involved parties, something often neglected by conventional optimization methods for solving multi-criteria, multi-stakeholder decision-making problems.

## METHODOLOGY- GAME FORMULATION

The basic methodology of game theory approach in non-cooperative game is presented in Fig 1..Each step is crucial for the proper functioning of game. Among the given steps most critical one is payoff calculation. For cooperative game payoffs have to be calculated for different coalitions using shapelyvalue.

### 1. Stakeholder identification

Consider an example problem of landfill site selection where stakeholders are in conflict in terms of technical and economic feasibility. Here a scenario is assumed in which a Local Self Government (LSG) is taking care of landfill construction while government is only a regulator. So there can be four stake holders namely government, LSG, waste generators and people living nearby who got directly affected by waste disposal..

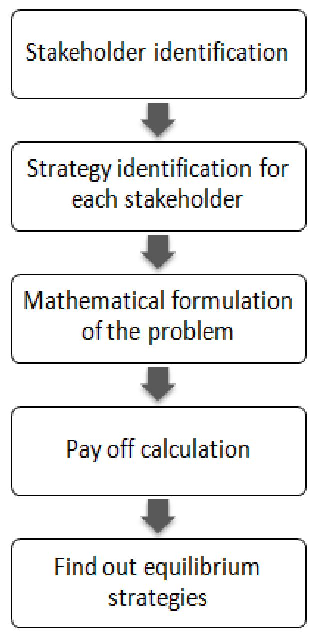


*Fig 1: Basic methodology of game theory*

### 2. Strategy identification

Strategies are the actions that each stake holder is supposed to take. In case of waste management there are number of strategies each stakeholder can take. Strategies are mutually exclusive. But when there are more strategies, the game will be complicated. So in this study number of strategies have been limited into two for each stakeholder. They are given in table 1 .The government can have two strategies. First one is the subsidy to the LSG for the regular operations. This can be a fixed percentage of upfront costs and operating costs of landfill. Another one is penalty for the misconduct of regular operations.

**Table 1: strategies of each stakeholder**

| Strategy | Government | LSG | Waste generator | Public |
|---|---|---|---|---|
| 1 | Subsidy | Compensate public | Pay Landfill levy | Cooperate |
| 2 | Penalty | Waste to energy | Go for alternate method | Non cooperate |

LSG also have two strategies. One is to compensate the public for the dis-amenities.Secondly repay the environmental cost through waste to energy conversion**.**
Waste generators have two strategies. Either pay landfill levy or go for alternate waste disposal options.
The people living nearby may either cooperate or non-cooperate with the landfill. Their cooperation is subjected to the additional social benefits like road, education outreach etc. that they may get through the upcoming project provided that there is no visible dis- amenities. On the other hand noncooperation is related to harmful effects like property value depreciation, environmental contamination, etc.

### 3. Mathematical formulation of the problem

For mathematical formulation consider a hypothetical case with following assumptions.
The landfill's footprint is square with dimensions of 110m and is a little over 9 acres including side slopes. Because of sloping, the final surface grades needing cap and cover are approximately 10 acres. Similarly, the bottom of the landfill needing a liner and leach ate system is 5 acres. Total acres of landfill construction (cap and liner) are 15. Let the total combined generation of solid waste be 500 tons/day. The major source being domestic, contributed by nearly 100,000 households. Let the number of people who get directly affected be 500. For the proper functioning of game certain assumptions have to take. They are as follows :Government will give subsidy only if LSG is willing to compensate Waste generators will pay landfill levy only if there is no other alternative availableLSG will buy user fee only in case of landfill use .Public living nearby will cooperate only if there is compensation Subsidy will be given by the government to the LSG only in case in which the customer chooses the land-disposal. Penalty will be charged by the government only in the case in which public non-cooperates.

### 4. Payoff formulation

Pay off formulation is very crucial in case of waste management. Here we are considering both direct and external cost. They are given below.
In order to calculate the payoff of each stake holder the following data are taken Construction cost = 15 Cr. Operation and maintenance cost =80 Cr.Total direct cost = 95 Cr. =**Dc**
Subsidy by government:-Let the subsidy be 40 % of total cost = 38 Cr = **Gs**
Penalty by government:-Penalty will be imposed if there is misconduct from the authority. Penalty can be monetized as the difference between total coat of landfill and opportunity cost. Opportunity cost refers to a benefit that a person could have received, but gave up, to take another course of action. Stated differently, an opportunity cost represents an alternative given up when a decision is made.
Penalty = total cost of landfill - opportunity cost
Assume that a 6 story shopping complex having carpet area of 50000sq.ft is constructed instead of landfill .the opportunity cost for this would be as shown below.
Construction cost of building @ Rs.3000/ sq.ft =3000x50,000 =15 Cr.Expected average rent per month = Rs. 100/sq.tft/month Assuming 90% occupancy,monthily income as rent = 0.45 Cr. Total rent obtained per annum = 5.4 Cr. Assuming a discount rate of 8% cost of capital = 1.2 Cr
Net return from shopping complex=5.4-1.2 = 4.2 Cr. Equivalent capital cost assuming 8% discount rare= 52.5 Cr = opportunity cost =**Oc**
Pay off in case of penalty = Dc-Oc =42.50Cr = **Gp**
*Compensation by LSG :-*
Physical impact cost of water and emissions are only considered here as compensation. For other impacts the cost of respective treatment technique has to take in to account.
*Physical impact cost of water:-*
The physical impact cost contributed by the landfill for suspected water quality deterioration can be taken as cost of water supply borne by the government for the public living nearby. Assume a daily demand of 1 lakh liters supplied through 20 tanks having capacity of 5000l. Cost of 20 tank @ 12000/tank = 2.4 lakhs Labor charge including transportation cost = 1.5 lakh Cost of pipes and other fittings = 2.5lakhs
Total cost of installing tanks = 6.4 lakh Cost of chlorination of water be 0.1 Rs/L Total cost of chlorination per day= 100000x0.1= 10000 .Total cost of chlorination per year = 36.5 lakhs Total cost = 42.9 lakhs.The equivalent capital cost at a discount rate of 8% = **5.36 Cr = Cc**
*Physical impact cost of emissions :-*

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Waste generated per day =500 tons. Waste generated per year = 182500 tons. Assume that 30% of waste is undergoing composting, the net carbon emissions in Metric Tons of $CO_2$Equivalent, (calculated by waste carbon calculator, university of Texas(Sharp, 2016)) is 600.As per STANFORD news(THAN, 2015) , Estimated social cost of carbon dioxide emissions per ton is 220 $. It is equivalent to around 15000 rupees. So annual cost will be around 1 crore. The equivalent capital cost at a discount rate of 5 % = 20Cr**(Ce)** .Total physical impact cost will be = 20 +5.36 = 25.36Cr **= Cp**

*Waste to energy conversion:-*

According to a study conducted by *Envis*(Ministry of Environment, 2016) , the average power potential per ton of MSW, in India is nearly 0.017 MW.So 500 tons of MSW can

| **Three player game** | | | | | |
|---|---|---|---|---|---|
| LSG | | PUBLIC | | GOVERNMENT | |
| **Strategy** | **Payoff** | **Strategy** | **Payoff** | **Strategy** | **Payoff** |
| 1 | 159.71 | 1 | 71.76 | 1 | 33.76 |
| 1 | 79.21 | 1 | 71.76 | 2 | 71.76 |
| 1 | 81.42 | 2 | -6.53 | 1 | -44.53 |
| 1 | 0.92 | 2 | -6.53 | 2 | 35.97 |
| 2 | 230.55 | 1 | 19.26 | 1 | 33.76 |
| 2 | 166.76 | 1 | 19.26 | 2 | 71.76 |
| 2 | 152.26 | 2 | -6.53 | 1 | -44.53 |
| 2 | 71.76 | 2 | -6.53 | 2 | 35.97 |

produce nearly 205920 kWh of renewable electricity.

By taking Rs 6 / KWh (assuming 150-200 units in a month .based on KSEB norms), total cost of electricity would be 12.35 lakhs. So annual turnover will be **45.05 Cr=Cw**

*Waste generator - Landfill levy :-*

Waste generator has to pay landfill levy if there is no other alternative available. Land fill levy might be a fixed percentage of total cost of landfill (including direct cost and external cost). In this case we are assuming Rs. 3000/ ton, so that, per day income for 500 ton = 0.15Cr .Annual income =54.75 Cr =$\mathbf{W_L}$

*Cost of alternate disposal options:-*

Here we are considering incineration as an alternative.

*Cost of incineration:-*

Consider an incinerator having capacity 100 kg/ hr. work for 10 hr. a day .So in order to incinerate500t , 500 units of incinerators are needed. Cost of incinerators @ 20 lakh/ unit, for 500numbers. = 10 Cr. Installation cost + operation and maintenance cost = 5Cr..Equivalent capital cost at a discount rate of 8% = 62.5 Cr.Total cost of incineration = 72.5 Cr = **Wi**

*Public pay off :-*

People's cooperation is subjected to 'Enough compensation from authority', 'Emissions are within limits' and 'No

$$\emptyset_1 = (1-1)!(3-1)!/3![v(1) - v(\emptyset)] + (2-1)!(3-2)!/3![v(12) - v(2)] + (2-1)!(3-2)!/3![v(13) - v(3)] + (3-1)!(3-3)!/3![v(123) - v(23)] \quad (5)$$

$$\emptyset_2 = (1-1)!(3-1)!/3![v(2) - v(\emptyset)] + (2-1)!(3-2)!/3![v(12) - v(1)] + (2-1)!(3-2)!/3![v(23) - v(3)] + (3-1)!(3-3)!/3![v(123) - v(13)] \quad (6)$$

$$\emptyset_3 = (1-1)!(3-1)!/3![v(3) - v(\emptyset)] + (2-1)!(3-2)!/3![v(13) - v(1)] + (2-1)!(3-2)!/3![v(23) - v(2)] + (3-1)!(3-3)!/3![v(123) \quad (7)$$
$$- v(12$$

aesthetic discomfort' .The actual pay off of cooperation has to find out based on WTP (willingness to pay) of people for different attributes. However in this case we are equating it to opportunity cost **(Pc)**. Noncooperation has a direct relationship to physical impact cost **(Pn).**.Now defining another term, say **Ec** (environmental cost ), which is nothing but the difference between waste to energy conversion ,and physical impact cost . Ec= Cw- Cp= 19.26 Cr

Based on these calculations, the payoff function for each stake holders are given below.

**Government:Gp- Gs+Ec+Pc-Pn** (1)

**LSG:Gs+ Cw- Cp-Gp-Pn+Pc+$\mathbf{W_L}$+Dc** (2)

**Waste generator: -$\mathbf{W_L}$ – Wi** (3)

**Public: Pc- Pn+Ec** (4)

**5. Finding out equilibrium strategies**

Games can be played between two players ,three players or four players. But in case of two players only non-cooperative game is possible. a cooperative game is also possible if there are more than two players. Here it has shown an example of three players.

***Non –cooperative game:***

A non-cooperative game is one in which players are unable to make enforceable contracts outside of those specifically modeled in the game. Hence, it is not defined as games in which players do not cooperate, but as games in which any cooperation must be self-enforcing

The stakeholders in three players game are LSG, Public and Government. The strategies and respective payoffs in a non-cooperative game are shown in table 1

***Table1: Pay off matrix for game between LSG , Public and Government***

***Cooperative game:-***

Cooperative game theory assumes that groups of players, called coalitions, are the primary units of decision-making, and may enforce cooperative behavior. Consequently, cooperative games can be seen as a competition between coalitions of players, rather than between individual players. Analysis in cooperative game theory is centered on two major issues: coalition formation and distribution of wealth gained through cooperation (N. X. Jia, 2003). In cooperative game every stakeholder wants to obtain maximum benefit in coalition. For that a rational allocation of profit is needed. Shapely values are used as a tool for reasonable allocation.
For three player game the set of coalitions are {(1),(1,2),(1,3),(1,2,3},{(2),(1,2),(2,3),(1,2,3},{(3),(1,3),(2,3) , (1,2,3}, where 1, 2, 3 represents LSG ,public, Government respectively. Along with this defining another coalition {(Φ)} , which is related to empty coalition.
As described earlier, the shapely value is given by the formula

$$\Psi_{pi}(N,v)=\sum \frac{|s|!(|N|-|s|-1)!}{|N|!}\left(v(s)-v(S\{p_i\})\right),\ s \subseteq N$$

LSG &Public, LSG & Government and Government & Public has shown in table 2 , table 3 and table 4
A cooperative game can also be defined with a characteristic cost function $\{v:2^N \rightarrow R\}$ satisfying $\{v(\Phi)=0\}$. In this setting, players must accomplish some task, and the characteristic function *v* represents the cost of a set of players accomplishing the task together.
The Characteristic functions values from three players game are given below
*v(1,3) = 264.31 , v (2) = 19.26*
*v(1,2)= 186.02 , v(3) = 71.76*
*v(2,3)= 105.52, v(1) = 159.71*
*v(1,2,3 ) = 283.57*
Equilibrium strategies of each game have been found out using solution concepts of game theory. In most of the cases Players got different payoff in non-cooperative and cooperative game. Pay off from a cooperative game is valid if and only if, it is better than that from non-cooperative game. The equilibrium pay off thus obtained from each game has discussed in the following sections.

## RESULTS

Nash equilibrium for three player game of LSG, Public and government, suggest that penalty for government, waste to energy conversion for LSG and cooperation for public as equilibrium strategies with respective pay offs of Rs.166.76 Cr, Rs.19.26Cr and Rs. 71.76 Cr.

**Table 2:coalition I : LSG and PUBLIC vs GOVERNMENT**

| | | | GOVERNMENT | |
|---|---|---|---|---|
| | **Strategies** | | **1** | **2** |
| | **1** | **1** | 231.47 | 150.97 |
| | **1** | **2** | 74.89 | -5.61 |
| LSG+ PUBLIC | **2** | **1** | 249.81 | 186.02 |
| | **2** | **2** | 145.73 | 65.23 |

| | | LSG+ PUBLIC | | | |
|---|---|---|---|---|---|
| | **Strategies** | **1 1** | **1 2** | **2 1** | **2 2** |
| GOVERNMENT | **1** | 33.76 | -44.53 | 33.76 | -44.53 |
| | **2** | 71.76 | 35.97 | 71.76 | 35.97 |

Here $v(s)$ represents the payoff for respective coalition.
For three player game the shapely values will be as follows.
And
$\emptyset_1+\emptyset_2+\emptyset_3=$ v(123) (8)
In three players, coalition can be either between LSG & Public or LSG & Government or Government & Public. In a cooperative game, when the stakeholders cooperate to form some coalitions, it is certain that different stakeholders will obtain different profits in their coalitions. it does not imply that all stakeholders can obtain their maximum profits in the same coalition. Cooperation between any players is allowed in the present study. The payoff matrix for coalition between

The equilibrium pay off for LSG is less compared to highest pay off in two player game. Public and government also got a lesser payoff than two player game. For public reduction is more. This may be due to the interlinking of government strategy to both Public and LSG.
Equation number in parentheses. To make your equations
As stated earlier different coalitions are possible in three player game. Payoffs in non-cooperative and cooperative games (based on characteristic functions)after Shapely value allocation using Equations (5), (6), and (7), respectively, has been presented in table 5. From the table it is clear that for LSG a coalition with government is the most favored option

 

as it gives higher payoff than non-cooperative game. The difference in payoff is about 10Crore. For public a coalition with government gives better pay off than in non-cooperative game. This is in line with our stated assumptions. For government a mutual coalition with LSG and Public seems to be the better option. In that case payoff is16.5 crore which is

**Table 3: coalition II : LSG and GOVERNMENT vs PUBLIC**

| | | | PUBLIC | |
|---|---|---|---|---|
| | **Strategies** | | **1** | **2** |
| LSG+ GOVERNMENT | **1** | **1** | 193.47 | 150.97 |
| | **1** | **2** | 36.89 | 36.89 |
| | **2** | **1** | 264.31 | 238.52 |
| | **2** | **2** | 107.73 | 107.73 |

| | | LSG+ GOVERNMENT | | | |
|---|---|---|---|---|---|
| | **Strategies** | **1 1** | **1 2** | **2 1** | **2 2** |
| PUBLIC | **1** | 71.76 | -6.53 | 19.26 | -6.53 |
| | **2** | 71.76 | -6.53 | 19.26 | -6.53 |

**Table 4: coalition III : PUBLICandGOVERNMENT vs LSG**

| | | | LSG | |
|---|---|---|---|---|
| | **Strategies** | | **1** | **2** |
| PUBLIC+ GOVERNMENT | **1** | **1** | 105.52 | 143.52 |
| | **1** | **2** | -51.06 | 29.44 |
| | **2** | **1** | 53.02 | 91.02 |
| | **2** | **2** | -51.06 | 29.44 |

| | | PUBLIC+ GOVERNMENT | | | |
|---|---|---|---|---|---|
| | **strategies** | **1 1** | **1 2** | **2 1** | **2 2** |
| LSG | **1** | 159.71 | 81.42 | 230.55 | 152.26 |
| | **2** | 79.21 | 0.92 | 166.76 | 71.76 |

**Table 5: Pay off in different coalitions for three player game**

| **PLAYERS** | **COALITION 123** | **COALITION 12** | **COALITION 13** | **COALITION 23** | **NON-COOPERATIVE GAME** |
|---|---|---|---|---|---|
| LSG | 172.471666 | 163.235 | 176.13 | 159.71 | 166.76 |
| PUBLIC | 22.8516666 | 22.785 | 19.26 | 26.51 | 19.26 |
| GOVT. | 88.2466666 | 71.76 | 88.18 | 79.01 | 71.76 |

more than that in non-cooperative game.

The variation in payoff of each stakeholder in different coalitions along with non-cooperative game is shown in fig 2,3,4 .For each players, best possible coalition has given in table 6

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*Fig 4: Variation in payoff for LSG in different coalitions*

**Table 6: best coalition**

| Stakeholder | Best coalition |
|---|---|
| Government | 123 |
| LSG | 13 |
| Public | 23 |


*Fig 5: Variation in payoff for public in different coalitions*


*Fig 5: Variation in payoff for govt. in different coalitions*

## CONCLUSION

This study discusses the possibility of identifying most favored strategy for key stakeholders involved in landfill diversion. Equilibrium strategies have been identified by comparing the non-cooperative and cooperative games among them using game theory. The study of the noncooperation game points out that the Nash equilibrium for strategies varies as the number of player changes. This may be due to the variation in payoff as the number increases. Analysis of cooperative game among the stakeholders using the Shapley value approach gives an overall idea of variation in payoff as the coalition changes. In some cases cooperation will bring more profits to them. The grand coalition may not suit each stakeholder in every case, so the player will have to search for better suited coalitions. Optimal cost allocation mechanism will bring the best possible payoff for all stakeholders. This study also reveals the need of considering the relative importance of strategies in order to have a better payoff. Independent decisions often results in strategies which are not up to the mark in financial and environmental performance. The results for stakeholders also verified the principle that cooperation is better than competition among the stakeholders. The example problem demonstrates the applicability of the proposed method for finding optimal strategies

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