Incentivizing Rural Waste Management - Game theoretic Analysis and Literature Review

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Note - Some of the research and data cited here might not be exactly in Indian context but they are mostly in the context of developing countries or highly populated countries like China due to lack of research data available .

Introduction

Solid Waste Management is a major issue in developing countries like India.The villages in general and those on the periphery of cities and towns in particular are at the frontline as far as indiscriminate and unmanageable waste generation is concerned. Though, solid waste generated in rural areas is predominantly organic and biodegradable, it is becoming a major problem as the waste generated is not segregated in-situ and is of the order of 0.3 to 0.4 million metric tons per day, as reported the Ministry of Drinking Water and Sanitation (MDWS), Government of India.The responsibility of solid waste management in villages lies on the shoulder of Gram Panchayat . It is the responsibility of Gram Panchayat to ensure proper door to door collection to ensure that the waste is segregated at the source and treated or disposed properly. The Swachh Bharat Mission (SBM-Gramin) launched by Honourable Prime Minister Shri Narendra Modi requires every Gram Panchayat to put in place a functional waste management . While some states like Tamil Nadu have done well and ranked 1 in Swachh Survekshan Gramin Awards 2019 there are many that are far from ideal for most of the village and even urban areas which lack the basic solid waste management system. In this paper first I will discuss guidelines proposed by the National Institute of Rural Development and try to discuss the implementability issues with the plan from a game theoretical perspective.

Solid Waste Management in Rural Areas (India) - Guidelines

(Source - http://nirdpr.org.in/nird_docs/sb/doc5.pdf)

Step – I: Preparation

This step involves conducting gram panchayat meetings , identifying infamous spots (dumping ground waste) educating the community through IEC campaigns and community preparation which involves distribution of buckets -

1. Green Bucket - kitchen refuse , leftover food and wet waste.
2. Blue Bucket - dry waste
3. Red Bucket - Hazardous waste like batteries , bulb

It is the responsibility of every household to do the primary segregation i.e. separate the waste into 3 categories.

Step – 2: Planning

This step involves -

1. Area Survey - estimating nature , type and quantum of waste generated .
2. Material Planning - vehicle for waste collection uniform and gears (jacket, gloves, cap, water bottle, first aid kit) for the workers, segregation shed, compost yard for wet waste, storeroom to lay in dry waste, tools and equipment.
3. Manpower Planning , Technical and Financial Planning

Box – 3: Income and Expenditure for a Solid Waste Management Project (It is worked out assuming that this project is for 300 Households)	
Items of Expenditure	**Possible Income Sources**
A. One-time Expenditure (Capital Cost)	1. Service charge
1. Baskets (900 numbers) - Green, Blue, Blue	2. Sale of compost items
2.Tricycles - 2	3. Sales of recyclables
3.Compost pit, segregation shed	4. Fine and penalties
4.Uniforms, gloves, gaps, whistle	
5.Tools & equipment	
B. Recurring Expenditure (Operational Cost)	
1. Supervisor Salary	
2. Sanitary Workers Salary	
3. Consumables / bleaching powder etc.	
4. Repair and maintenance	

Step - 3 Organising

1. Manpower - Recruiting Manpower . In some places rag pickers are recruited and paid minimum wage
2. Materials and Facilities - Setting up required facilities segregation sheds , uniform,tools , equipment
3. Technology - Vehicle for waste collection , technology used for treating wet waste , landfill
4. Funds - State Funds , NGOs
5. Coordination

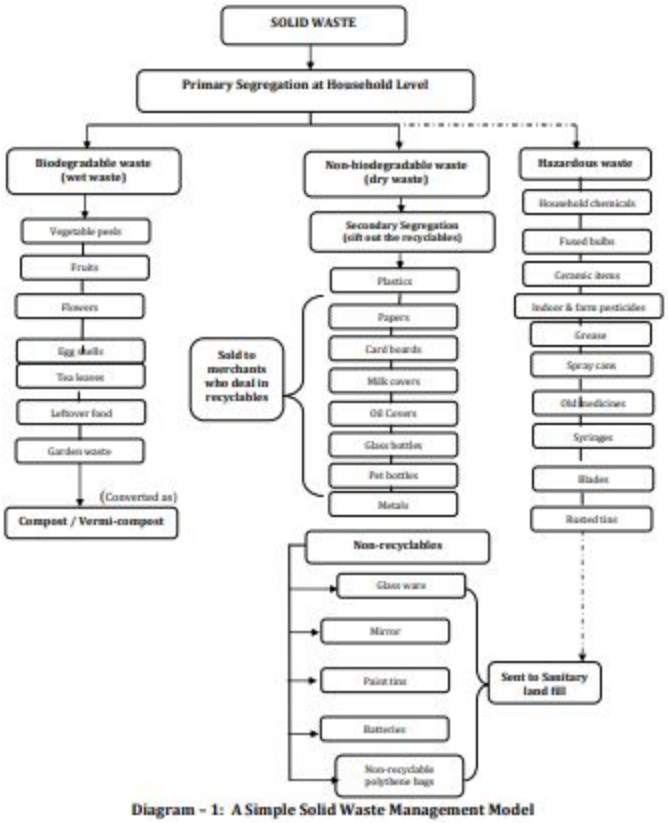

Diagram – 1: A Simple Solid Waste Management Model

Step - 4 Implementation

1. Segregation at Source - Primary segregation takes place at source namely at the household itself.It reduces load at secondary segregation otherwise it is unpleasant to work on wet waste that is 8 to 12 hours old.
2. Collection - The sanitation workers collect the waste from household
3. Secondary Segregation - The vehicles arrive at segregation sheds where recyclable items from non recyclables. Non Recyclables along with hazardous waste are dumped in landfills.
4. Facility for treatment and Treatment of waste
5. Service Charge collection - Service charge is collected from each house to meet the operational cost.The sanitation supervisor sits at the Gram Panchayat office daily to collect the service charge.

Step - 5 Monitoring and Correctives

This includes ensuring proper functioning and taking corrective measures wherever needed.

Game Theoretic Analysis of Above approach

There are mainly participants in the above model which includes Gram Panchayat , sanitation workers ,village participants or households . For the above model to be successful to be successful there should be enough incentive for all the participants to perform their duties . We assume that each agent is rational and selfish and tries to maximize its own utility . We will not consider emotional factors ,moral factors and human errors while calculating utilities . We will only consider monetary benefits and effort required to perform certain tasks. While there are past examples where communities have acted as good citizens but such examples are rare without strict and proper law enforcement which is difficult in developing countries like India where this is one of the major issues especially in rural areas.

Household

Incentives - Nil or fixed (say B)
Duties - Dispose off of the waste in three seperate bins after proper primary segregation , Cooperate with sanitation workers , Pay Service charge on a regular basis.
We define the utility of household as

$$U_{household} = -(ServiceCharge + effort_{PrimarySegregation})$$

Sanitization Workers

Incentives - Salary (Fixed say S)
Duties - Collect waste from the household ,Ensure proper primary segregation , Perform secondary segregation , Educate the household on the importance of primary segregation.

We define the utility of Sanitation worker as

$$U_{SanitationWorker} = Salary - (effort_{SecondarySegregation} + effort_{WasteCollection})$$

Gram Panchayat

Assumption - It is assumed that funds allocated will only be used for creating a solid waste management system in the village.

Incentives - Funds (Fixed say F) , Service charge , Income generated by recycling
Duties - Preparation , Formulate plan for effective waste management , Organisation , Implementation and monitoring .

We define the utility of Gram Panchayat as

$$U_{GramPanchayat} = Funds + ServiceCharges + Income_{Recycle} - (effort_{ProperImplementation} + effort_{Monitoring})$$

We do strategy analysis of two participants - household and sanitation workers . Let's assume that households are required to pay Service charge irrespective of if they do primary segregation and sanitation workers are required to collect waste from households therefore the strategy set of the household consists of two elements whether to do primary segregation or not . Similarly, the strategy set of sanitization workers consist of 2 elements whether to perform secondary segregation properly or not.

Let

$\lambda 1$ = Cost of doing Primary segregation

$\lambda 2$ = Cost of doing Secondary segregation

We will consider all other factors as zero since they are constant anyways.

Row - Household Column - Sanitation Worker

	Secondary Segregation	No Secondary Segregation
Do Primary Segregation	$-\lambda 1$, $-\lambda 2$	$-\lambda 1$, 0
No Primary Segregation	0 , $-\lambda 1 - \lambda 2$	0 , 0

Conclusions -

- Unless there is a fine imposed or other measures on the householder for not following proper segregation rules the householder will not properly segregate the waste as per table above as not segregating is a strongly dominant strategy for householder.

- Unless proper quality assurance and monitoring is maintained, a strongly dominant strategy for sanitation workers is to not follow proper protocols.Even if the sanitation workers do their job even then also they have to incur extra cost because of lack of primary segregation.

- As per the document mentioned above " Running an SWM unit is a time-consuming and long-drawn out task. Once started, it must go on and on. If left unattended for four-days, things will fall back as bad as how it was earlier.Therefore, the GP must constantly keep in touch with the community; the sanitation workers; and watch out the supportive income sources that help compensate the loss incurred in SWM etc. Poor coordination may result in ineffectuality, eventually resulting in unsustainability."

  The above statement explains that running a SWM is not an easy task requiring proper enforcement mechanism , man power , time and effort and even for gram panchayat is difficult to implement at a village with limited resources.

- The above discussions come to a major conclusion without proper intervention of gram panchayat the above model will not function properly which is not guaranteed .

Problem Statement - Design a model or mechanism to facilitate proper segregation and treatment of waste where each participant is accountable and earns profit by following the desired action.

Drawbacks of above approach -

- Lack of accountability - Since it is not possible to monitor each participant at step the system lacks accountability.

- No Incentive or low incentive for properly following the set protocols which requires effort on the part of the participant.
- Lack of Trust between the gram panchayat and householder
- Since everything is managed manually it requires a lot of time and effort most people are willing to put in.

Proposed Method -

(Source - https://www.sciencedirect.com/science/article/pii/S187661021930027X)

For simplicity and narrowing down of scope of problem the method is proposed in the context of farmers. The type of waste considered here is agricultural waste which is a subset of solid waste in rural areas . We consider two types of agricultural waste one which can be converted into energy and other into agricultural bi products like fertilizers though similar approaches can be applied in other cases. This approach might not be applicable for managing non recyclable waste.

Through this method we want to create a transparent and decentralized application where farmers and waste to energy plants can trade their waste in exchange for digital coupons or other services like energy or agricultural products like fertilizer.

- The farmers are required to register on application . Each farmer is connected to a digital blockchain wallet.
- Farmers are provided with special bags or containers containing unique qr code. Once the container is full enough the farmer can schedule pick up by scanning the qr code.
- Once sufficient pick up requests are available the plants send its transport to collect the waste. This is a typical case of Travelling Sales Problem where an efficient route needs to be set for pickup.
- The pick up staff scans the qr code after ensuring proper quantity of waste an instant transaction happens where the farmer receives digital coupons in his wallet.
- Each and every activity is recorded in the blockchain network.
- These coupons can be used to buy services like energy or fertilizer .

Stakeholders

Farmers -

- Duties -
    - Collection and separation of waste
    - Management of Digital coupons

- Incentives - Subsidised energy and fertilizer , Rid of hazardous waste

$$U_{Farmer} = DigitalCoupons - (effort_{segregation} + effort_{ManageCoupons})$$

Entrepreneurs -

- Duties -
    1. Collection of waste
    2. Maintaining waste to energy facilities
- Incentives -
    1. Low cost of attaining segregating waste
    2. Profit from surplus energy or fertilizer produced
    3. External investments and Government incentives
    4. Predictability and Accountability

$$U_{Entrepreneurs} = Profit + Incentives - (cost_{collection} + cost_{Operation})$$

Conclusions -

- As per the paper by David Zhang 100 percent of farmers were ready to segregate waste if they were provided with incentives like subsidised energy/fertilizer or digital coupons. The above equations suggest the same i.e if the value of digital coupons is greater than effort put in it is a strongly dominant strategy for farmers to segregate waste.
- While one or two villages might not be enough to cover the operational cost by economies of scale the model can be profitable for plant as well as is confirmed by the case study of Yitong System.
- Since all the transactions handled digitally through blockchain the model is transparent where each participant is accountable.

- Digital transactions lead to more efficiency and reduction of operational cost.

References -

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- Application of Blockchain Technology in Incentivizing Efficient Use of Rural Wastes: A case study on Yitong System - David Zang https://www.sciencedirect.com/science/article/pii/S187661021930027X
- An examination of incentive structures in recycling policy https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=17830&context=rtd