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Municipal Solid Waste Model Development through Binary Coding

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ABSTRACT

Municipal Solid Waste management involves many stages like Generation, Source storage, Collection, Storage, Transportation, Processing and Disposal. Further, Municipal Solid Waste management can be divided into two major components, i.e. Collection and Transportation Plan and the Disposal Plan. In order to account for all possible combinations, a Binary coding approach has been suggested. To focus on the best process there is a need to develop a generic model. Different Models have been attempted with all possible combinations of activities of Solid Waste Management. The process of elimination was carried out through the application of two/ two analytical matrix. The final model was narrowed down for the best Collection and Transportation (CaT) plan and Disposal Plan by the process of elimination with the help of two/ two analytical matrix. The combination of CaT plan and disposal plan need to be subjected to the ground realities for sustainability. The prevailing Government Rules and regulatory compliance checks can further give a direction for the most feasible MSW Model typical models could be generated by taking different possible combinations.

Key words *: Municipal Solid Waste Management, Model Development, Collection and transportation Plan, Disposal plan, Binary Coding, Two/Two Matrix.*

Introduction

The process of management of solid waste begins with waste generation and ends at the point of disposal of waste. The whole process can be divided into seven basic stages i.e. 1-Generation of Waste, 2-Source Storage, 3-Primary Collection, 4-Secondary Storage, 5-Transportation of waste, 6-Processing of waste and 7-Disposal of waste. Municipal Solid Waste Management can be condensed into four important components, collection, transportation, processing and disposal of the waste[1]. Collection and Transportation can be clubbed together to call it Collection and transportation (CaT) Plan, whereas processing and disposal can be clubbed together and it can be called Disposal Plan.

Literature Review

The core objectives of sustainable waste management practices can be listed as to safeguard the health related aspects of the people, protect the environment, and to conserve the essential resources. In order to achieve these objectives, often the decision makers apply various integrated strategies that such as effective collection, transportation, treatment, recycling, and disposal of wastes (Al Sabbagh *et al*., 2012). It was in the late 1960s, when various decision support models were first applied for effective management of waste. In the beginning, these

concepts, majorly focused on individual functional elements, such as collection routes or facility locations (Tanskanen, 2000), followed by focussing on the entire waste management systems by the 1980s Computer-aided decision support began in the 1980s (Banar *et al.*, 2009)[2].At present, many published assessment methods for waste management systems are quite advanced and sophisticated because waste management is considered a strategic sector of public service (Coelho *et al.*, 2019). The high goal to provide sustainability as a balance between society, economy, and ecology requires an integrated approach. Hence, for an evaluation of the many effects of waste management systems, it is necessary to consider all of the processes involved (Diaz and Warith, 2001-2003).

The management of waste become complex and the facilities provided cannot cope with the increasing demand and needs. Therefore, best approach need to be implemented immediately while considering environmental, social and economic aspects (Aye and Widjaya, 2006). The drivers of sustainable waste management were clarified by Agamuthu *et al.* (2009), which include human, economic, institutional and environment aspect. The study suggests that each driving group should be considered in local context as managing solid waste for a particular society may differ from the others. For example, waste managers in Africa need to tackle some issues including, lack of data, insignificant financial resources, vast different of amount and waste types between urban and rural area, lack of technical and human resources, low level of awareness and cultural aversion towards waste (Couth and Trois, 2010). On the other hand, problems faced among Asian countries differ with two distinct groups; developed and developing countries. While some of the countries are having specific national policy on solid waste management, some others experience problems such as increasing urban population, scarcity of land, services coverage area, inadequate resources and technology, and so on (Shekdar, 2009). The differences in managing solid waste not only vary between countries but also among areas in the same country. Integrated Sustainable Waste Management (ISWM) system was then introduced in 1995 to improve earlier system that neglect unique characteristics of a given society, economy and environment (van de Klundert, 1999). For example, European countries had applied various system assessment tools and engineering models to create sustainable communities, manage resources efficiently, taping innovation potential of the economy, ensuring prosperity, environmental protection and social cohesion in their SWM system. The waste management system should be dynamic and continuous based on new insights and experiences. Therefore, Model Development is necessary to effectively handle the MSW issue.

Methodology

The methodology adopted is to develop a generic framework through a Binary Coding process. SWM has many processes and activities. If a particular activity is carried out, it is assigned code '1', otherwise it is assigned code '0'. This framework should be able to explain all possible variations of MSW practices carried out in different cities. After the MSW model is developed, it is further screened by a decision-making technique i.e., the two-by-two matrix.

Model Development Through Binary Coding

The generic Waste Disposal Model is developed with the help of Binary Coding. If a particular activity is carried out, it is assigned code '1', otherwise it is assigned code '0'. The Binary Coding method would be a generic frame work to contain all possible combinations. The combination will include all the seven stages of waste disposal activities like generation of waste, source storage of waste, collection of waste, intermediate storage, transportation to processing unit, processing of waste and final disposal of waste.

1. Generation of waste – The generation of waste can take place in households, hotels, commercial institutions, temples or other such institutions etc.
2. Source storage of waste – Once the waste is generated and dropped on the floor, it becomes a litter. If it is dropped into a bin, it is called source storage. While storing it in a container, if they are segregated based on dry waste or wet waste, it is called source segregation. Source segregation can be expanded to Two Bin model, or Three Bin model based on principles of segregation. Source segregation helps in easy recycling of waste.
3. Collection of waste – Collection of waste can be carried out though 'Door to door' collection or by 'Street sweeping'. In some case, the waste producer may take the waste to the kerbside bin and

drop the waste there. The collection can be either manual or mechanised. Push cart or auto trippers can be used for door-to-door collection. Mechanised sweeping machines can be used for street sweeping.

4. Intermediate storage – This is the intermediate storage which takes place before the municipality removes the garbage for further processing or disposal. The garbage is stored in a kerbside litter bin or in a collection centre. This acts as a buffer storage to accommodate two or three days of storage. But it is prone to nuisance because it is exposed to animals, other vectors posing health hazards. The advantage of intermediate storage is that the ragpickers get access to the garbage before it is moved for disposal. Proper bin storage is necessary to maintain health and hygiene.
5. Transportation of waste – This transportation takes place for further processing. The garbage is transferred to a processing centre or a transfer centre, before it is moved to the dumping yard. Usually, bigger vehicles or sometimes trains are used to save fuel cost or reduce traffic congestion.
6. Processing of waste –Processing of waste is required for recycling, material recovery or making them ready for further activities. Segregation, mechanical shredding, pelletizing or composting. The garbage is subjected to treatment and processing. The treatment process can be mechanical material recovery, shredding, palletizing (refuse derived fuel), or composting. Maximum volume reduction may take place during processing of waste.
7. Disposal of waste – The scientific disposal of waste after processing is through landfilling. Sometimes the waste may be sent directly for landfilling without processing. The best way is to send only those items that can't be recycled. The landfills should be scientifically designed to prevent ground water contamination and control the methane.

At the stage 1 and 2 the waste remains with the waste generator, i.e. with the house hold or with the institution producing the waste. From the stage 3 through 7 the waste may move from the waste generator to the service provider i.e. the ULB (Urban Local Body). In rare cases, it may so happen that the waste generator may carry out all the 3 through 7 stages.

Different Models were chalked out with all the possible situations that could take place in the SWM (Solid Waste Management) process based on the occurrence/ non-occurrence of a particular activity. Using the above technique a total of 17 typical models could be generated by taking different possible combinations.

Model – 1

In this model, the waste is not stored at the source, where it is directly disposed of on the street or any vacant place around the place of generation. For example, the garbage may be tossed on the highway from a moving vehicle, dropped into the storm water drain or burnt on the site. It is nothing but littering and creates unhygienic environment and environmental pollution due to natural decay. This model shows that there is no city service provided to the residents. This is commonly seen in the small semi-urban towns without a ULB.

Model – 2

In the second model, the waste is collected and stored in a bin at the source. But, it is not collected by the ULB, therefore, the garbage is dumped indis-

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
1	0	0	0	0	0	0	(Indiscriminate disposal) Street Dumping or dumping in the storm water drains Or burning it on site (Open burning is neither processing nor a disposal technique)– no city service	- Unhygienic environment, mostly in urban sprawls, Slums - no employment generation or material recovery - Zero Cost to ULB - High environmental cost

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
2	1	0	0	0	0	0	Household burying garbage inside premises Or Household burning garbage inside premises or on the road side (Open burning is neither processing nor a disposal technique)	- depends on availability of space inside premises - Difficult in Apartments - no employment generation or material recovery - Zero Cost to ULB - High environmental cost

criminately on the road or in the vacant place (vacant neighbour's plot). The owner may bury the garbage inside a pit within the premises or burn it. When the organic waste is buried in the back yard, it is called back yard composting. This model has no solution for inorganic wastes. If the inorganic waste is burnt, it causes severe air pollution. This practice may be carried out by some individual household in small towns without a functional ULB. This model shows that there is no city service provided to the residents.

Model – 3

In this Model, the owner stores the waste in a bin at the source, and there is no collection from the door. The owner takes it to the kerb side vacant place and disposes it there. There after the garbage is not collected and it is subjected to natural decay. Sometimes it finds its way into the storm water drains. Or, it may be burnt by local residents, which causes severe air pollution. The leachate from the decaying matter may cause water pollution. This model is prevalent in the peripheral areas of a small town, where the residents are aware of the kerbside disposal, but the ULB does not provide the collection (or low frequency) of garbage from the transit points.

Model– 4

In this Model, there is no door to door collection. The owner drops the garbage in the kerbside litter bin or open garbage point. In intervals the garbage is picked up by vehicle and disposed in the disposal yard without processing. The disposal yard is either sanitary land fill or an open dumping yard. This is practiced in most of the ULBs, without door to door collection facility.

Another variation is collection from the apartments by trucks and transported to dump yards. Some material recovery takes place while collecting from the apartment community bin.

Model – 5

In this Model, the owner transports the garbage to the dumping yard and disposes the garbage. It takes place in western countries for yard wastes and toxic wastes. Huge transportation cost due to independent movement of garbage.

Model – 6

Here, the owner takes the recyclables to the processing unit, which may be a kawadiwala and disposes

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
3	1	0	1	0	0	0	Individual Dumping at the Kerbside – no collection but burning after some days of storage(Prevalent in small towns without a functional ULB)	- Unhygienic surrounding - No cost to ULB - High environmental cost

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
4	1	0	1	1	0	1	Individual Dumping at the kerb side bin – picked up by compactor machine and transported to dump yard (Practiced in Delhi) - Collection from apartments by trucks and transported to Dump yard (Practiced in Bangalore)	- Cost to ULB for kerbside collection and transportation to dump yard - Some employment generation for door to door collection by private persons - Some material recovery while collecting from door to door

the waste. Or it can be vice-e-versa, i.e. kawadiwala collecting it from the household. The organic part of the waste is composted. This model does not have the solution for the non-valued inorganic waste.

Model – 7

Here, the individual drops the waste at the processing unit, may be a composting unit and the processing unit after composting, goes for landfill of the compost rejects. In US the toxic waste, e-waste is collected at specific collection centres and individuals are directed to dispose ofsuch wastes in those centres.

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
5	1	0	0	0	0	1	Individual transporting and dumping in the dump yard- landfill site	- Huge cost of transportation- no employment generation or material recovery- Zero Cost to ULB- High environmental cost (Open dumping and transportation)

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
6	1	0	0	0	1	0	Individual dumping recyclables in the processing unit – Kawadiwala or Kawadiwalas collecting from house holds - Individual going for back yard composting	- Mostly taking place in urban areas for recyclables - Employment generation and material recovery- Back yard composting for organic degradable and non-degradable for Kawadiwalas, except for non-valued wastes- Zero Cost to ULB

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
7	1	0	0	0	1 Composting, Recyclable recovery)	1(Open Dumping by kawadiwala)	Individual dumping at processing unit- after processing the reject is disposed off	- Why the individual should dump at own cost?- This is necessary for toxic wastes, bio-medical wastes, battery, tube lights, computers, thermom-eters, etc.- Zero Cost to ULB

Model – 8

This model represents, indiscriminate dumping, but street sweeping without push cart transportation to kerbside storage. On the other hand, the garbage is burnt at the road side or left to decay. This pollutes the environment through burning or choking the drains. The ULB bears the cost of street sweeping only.

Model- 9

This Model represents, indiscriminate dumping and street sweeping with push cart. The collected waste

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
8	1	1	0	0	0	0	Street dumping- Street sweeping without push cart – Open road side dumping – Open Burning (Most prevalent in small towns and poor municipalities)	- Collection through street sweeping and dumping or burning after sweeping - Cost to ULB for street sweeping - Cost will depend on the frequency of service - High environmental cost

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
9	1	1	0	1	0	0	Street dumping- Street sweeping with push cart – Open kerbside dumping – Open Burning (Most prevalent in small towns and poor municipalities)	- Collection through street sweeping and dumping or burning after sweeping - Cost to ULB for street sweeping - Cost will depend on the frequency of service - High environmental cost

is dumped on the kerb side and mostly burnt. This practice is most prevalent in the small towns and poor municipalities. It causes high environmental cost for open burning and health hazards due to exposure to different vectors. ULB bears the cost for street sweeping and kerb side dumping.

Model – 10

This Model has a negative element of indiscriminate dumping. The garbage is collected through street sweeping and directly hauled through another vehicle to the dump yard. The cost of ULB is street sweeping and transportation to the dump yard. If the disposal is open dumping, it will cause environmental pollution.

Model – 11

This Model is the most prevalent model. It can have two variants, in one variant, there can be street dumping, street sweeping with push cart to kerb side storage and finally transportation to disposal yard. In the other variant, it can be door to door collection with push cart to the kerb side storage yard, from where, the garbage is transported to Disposal yard. It will have high environmental cost if the storage on the kerb side is longer and the disposal is open dumping. Otherwise, with sanitary landfill and regular kerbside disposal, the model is more appropriate. Cost to ULB will be high, if door to door collection is provided. This is more practised in the district headquarter towns. The ULB focus is more on street sweeping, with temporary storage and thereafter, the garbage is transported from temporary storage to the disposal yard and the final disposal is made through open dumping.

Model- 12

This is an advanced model, practiced in Western countries. The waste is collected door to door through a compactor machine and transported directly to the disposal yard. The advantage of the model is that there is no temporary storage at the

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
10	1	1	0	Two stage	0	1	Street Dumping – Street sweeping with push cart (No storage) – transportation – open dumping (Better version is dumping in a sanitary landfill)	- Collection through street sweeping and no storage after sweeping but hauled directly to dump yard- cost to ULB for street sweeping, transportation to dump yard- cost will depend on the frequency of service- High environmental cost

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
11	1	One stage One Type	1	Two stage	0	1	Street Dumping – Street sweeping with push cart to kerbside (Storage) – transportation – is recommended) Or door to door collection with push cart to kerb side (Storage) (No street sweeping) – transportation – Open dumping (sanitary landfill is recommended)	- Collection through street sweeping (Or door to door) and storage after that at kerbside- cost to ULB for street sweeping, transportation to dump yard- cost will depend on the frequency of service- High environmental cost

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
12	1	1	1	1	0	1	Door to door collection with compactor machine and transported to Open dumping - No storage	- Collection through one stage of Door to door and directly transported to dump site - Less Employment generation - No material recovery

kerb side. Disadvantage is that there is no material recovery and low employment generation.

Model – 13

This is also prevalent model with door to door collection and street sweeping. Garbage is stored at the kerb side bin and then transported to disposal yard. There is no Processing of the waste and therefore, no material recovery. The environmental pollution is caused by open storage due to open dumping (if practiced). This model is commonly practiced in most urban areas of India.

Model – 14

This model is similar to Model 13 except there is an introduction of a transfer station. The waste collected from door to door and street sweeping is stored at the kerb side. Thereafter, it is transported

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
13	1	Two stage	1	Two stage	0	1	Door to door collection and street sweeping with push cart to kerb side (Storage)-transportation – Open dumping (sanitary landfill is recommended) (most commonly practiced in urban areas of India)	- Collection through two stages of Door to door and street sweeping and one storage after that prior to transportation to dump site - Employment generation - No material recovery - High environmental cost for open dumping

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
14	1	Two stage	Two stage	Two stage	0	1	Door to door collection and street sweeping to kerb side (Storage)-second storage at transit point transportation – Open dumping (most commonly practiced in urban areas of India)	- Introduction of transfer station helps in compaction and reduction in the transportation cost. - Location of transfer station can be optimized to reduce waste hauling distance - Suitable for multiple waste disposal

to a transfer station, where the waste is transferred to a bigger carrier or a compactor machine. There is a volume reduction at this stage so that the hauling cost is reduced. The city traffic congestion is also reduced due to movement of fewer large carriers than number of small carriers. The waste is disposed at the disposal yard. The transfer stations can be suitably located in the city to optimize the hauling distance from the kerbside to the transfer station. This model is more advanced and should be adopted by big cities and metropolitan areas, where the distance to disposal yard is too long. Secondly, this is most suitable for decentralized and sectoral method of waste disposal, where the city can have multiple disposal yards at different corners of the city.

This Model has no street sweeping but introduces a processing unit. The waste from door to door collection is transported to the kerb side storage and then it is transferred to a processing unit. The processing unit can be a composting unit or a waste to energy plant. After processing, the process rejects, like compost rejects or the ash residue is sent to disposal yard. Disposal in a sanitary landfill is recommended. The advantage of the model is material recovery, less land requirement for landfilling which is

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
15	1	One	One	Two	One stage comosting or WTE (West to Energy	1 (Disposal of compost reject or ash residue)	Door to door collection with push cart to kerb side (Storage)- transportation to processing unit – Open dumping of rejects (sanitary landfill is recommended)	- Advantage of material recovery - less land requirement for sanitary landfilling - Less environmental pollution - more cost to the ULB for the erection and maintenance of the processing unit, which can be privatized

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
16	1	Two stage	One stage	Two stage	Composting for some waste and WTE to some other waste	Scientific Landfill	Door to door collection with push cart to kerb side and also street sweeping to kerbside (Storage)- transportation to processing unit – Open dumping of rejects (sanitary landfill is recommended)	- Advantage of material recovery - less land requirement for sanitary landfilling - Less environmental pollution - more cost to the ULB for the erection and maintenance of the processing unit, which can be privatized

due to material recovery or burning, as the case may be. In case of composting, the volume reduction is by 25% and in case of incineration the volume reduction is 90%. The model is environmentally less polluting. But, it causes extra cost to the ULB due to erection and maintenance of the processing unit.

This Model has an additional feature over the Model -15, i.e. street sweeping. The door to door waste collection and street sweeping is stored at the kerb side and then transported to the disposal yard. The extra cost to the ULB is the additional street sweeping cost. The advantage of the model is similar to Model 15.

Model – 17

This is an advanced model over the Model 16, and it is called 'Bin Free' model. The door to door collection and street sweeping is carried out with push cart. The waste from the push cart is directly transferred to a waiting truck/tractor and transported to the processing unit. After processing, the process reject is sent for land filling. The advantage of the model is that there is no kerbside storage and city looks clean. The disadvantage of the model is that there is no facility for buffer storage in the city to meet any exigencies. The citizens need to hand over the waste at a particular timing of door to door collection.

Categorisation of Models Based on 'Collection and Transportation

Seventeen models generated through binary coding can be characterized into 4 basic groups. The group 1 which is characterized by 'indiscriminate dumping and Street Sweeping', group 2 characterized by 'community bin dumping', group 3 characterized by 'door to door primary collection' and the last group being the 'handle ones' group.

Group No.1-'Indiscriminate dumping and street sweeping'

This group contains model Nos.1,8,9 &10 (Table 1). The model No.1 has no city service. In this case, the waste sensitivity of resident is low. Indiscriminate

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	Consequences
17	1	Two stage	0 "Bin Free"	Two stage	Composting for some waste and WTE to some other waste	Scientific Landfill	Door to door collection with push cart and street sweeping is transferred to a waiting lorry, which is transported directly to the processing unit – Sanitary landfilling of process reject	- Clean look of the city - Less health hazard - But, no buffer storage in the city

Table 1. 'Indiscriminate dumping and street sweeping'

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model
1	0	0	0	0	0	0	(Indiscriminate disposal) Street Dumping or dumping in the storm water drains Or burning it on site
8	1	1	0	0	0	0	Street dumping- Street sweeping without push cart – Open road side dumping – Open Burning
9	1	1	0	1	0	0	Street dumping- Street sweeping with push cart – Open kerbside dumping – Open Burning
9	1	1	0	1	0	0	Street dumping- Street sweeping with push cart – Open kerbside dumping – Open Burning

dumping has to be accompanied by street sweeping. The model No.8, 9 have street sweeping and in model No.10 the garbage is transported to open dumping. These models are practiced in ULB having low financial capability or they are observed in urban slums and low priority colonies. The other characteristic is that it is a multi-handling process with low scores on environmental factors.

Group No.2- 'Community bin dumping'

This category contains the model Nos. 3, 4 and 11 (Table 2). In model 3 the individual does the dumping at the community bin but there is no city service to clear the community bin. In model No.4 the garbage from the community bin is removed and transported to disposal yard. In case of model No.11, the garbage is collected through street sweeping to the kerbside storage bin and then transported to disposal site. This process is practiced by many ULBs where there are significant budgetary constraints. This model is less capital intensive. It requires high waste sensitivity on the part of residents to use the community bin. Other characteristic is that it is a multi-handling process, but facilitates waste recovery by providing access to rag pickers.

Group No.3- 'Door to Door Primary Collection'

This group includes model Nos.11, 13, 14, 15 and 16 (Table 3). In this model the primary collection is made through door to door collection either with the help of push cart or with the help of a mechanized auto tripper. This process is costlier than the community bin model. It gives better waste management services to the citizens. It is a multi-handling process. The amount of waste recovery depends on the provision for access to the rag pickers. Manual method of door to door collection generates high employment and gives higher possibility of waste recovery.

Group No.4- 'Handle once'

This group includes model Nos.2, 5, 6, 7, 12 and 17 (Table 4). The biggest advantage of this model is that the wastes are handled only once. It is directly collected from the door side in a mechanised compactor machine or auto tripper and disposed at the disposal yard. There is no intermediate storage of waste between the collection and disposal. Another sub-classification in this group is model 2, 5, 6 & 7 in which case the individual disposes the waste at the processing unit, or at the disposal yard or through backyard composting. In this case, there is zero cost to the ULB, but it demands high level of waste sensitivity on the part of the citizen. The compactor machine door to door system has its disadvantage of poor material recovery and low employment generation. This model has high technical inputs and they are capital intensive.

Application of Two/ Two Analytical Matrix

Two/Two Analytical matrix can be applied to the above four basic Collection and Transportation Plan (CaT Plan)to analyse and choose the model with the best fit through the process of elimination.Similarly, disposal plans which may have four or five dominant options can be analysed with the same two/

Table 2. 'Community bin dumping'

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model
3	1	0	1	0	0	0	Individual Dumping at the Kerbside – no collection but burning after some days of storage
4	1	0	1	1	0	1	Individual Dumping at the kerb side bin – picked up by compactor machine and transported to dump yard- Collection from apartments by trucks and transported to Dump yard
11	1	One Stage	1	Two stage	0	1	Street Dumping – Street sweeping with push cart to kerbside (Storage) – transportation – open dumping or door to door collection with push cart to kerb side (Storage) (No street sweeping) – transportation – Open dumping

Table 3. Door to door primary collection'

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	
3	1	0	1	0		0	0	Individual Dumping at the Kerbside – no collection but burning
11	1	One Stage	1	Two stage		0	1	Street Dumping – Street sweeping with push cart to kerbside (Storage) – transportation – open dumping Or door to door collection with push cart to kerb side (Storage) (No street sweeping) – transportation – Open dumping
13	1	Two stage	1	Two stage		0	1	Door to door collection and street sweeping with push cart to kerb side (Storage)- transportation – Open dumping
14	1	Two stage	Two stage	Two stage		0	1	Door to door collection and street sweeping to kerb side (Storage)- second storage at transit point
15	1	One stage	One stage	Two stage		One stage composting or WTE	1 (Disposal of compost reject, ash residue)	transportation – Open dumping Door to door collection with push cart to kerb side (Storage)- transportation to processing unit – Open dumping of rejects
16	1	two Stage	One Stage	Two stage		Composting or WTE	Scientific Landfill	Door to door collection with push cart to kerb side and also street sweeping to kerbside (Storage)- transportation to processing unit – Open dumping of rejects

Table 4. 'Handle once'

Model No	Source Storage	Collection	Storage	Transportation	Processing	Disposal	SWM Model	
2	1	0	0	0		0	0	Household burying garbage inside premises Or Household burning garbage inside premises or on the road side
5	1	0	0	0		0	1	Individual transporting and dumping in the dump yard- landfill site
6	1	0	0	0		1	0	Individual dumping recyclables in the processing unit – Kawadiwala or Kawadiwalas collecting from house holds- Individual going for back yard composting
7	1	0	0	0		1 (Composting, Recyclable recovery)	1 (Open Dumping by kawadiwala)	Individual dumping at processing unit- after processing the reject is disposed off
12	1	1	0	1		0	1	Door to door collection with compactor machine and transported to Open dumping
17	1	Two Stage	0'Bin Free'	Two stage		Composting or WTE	Scientific Landfill	Door to door collection with push cart, street sweeping is transferred to a waiting lorry, which is transported directly to the processing unit – Sanitary landfilling of process reject

two matrix method as a result of which the two/two analytical matrix will lead to the selection of the best disposal option. Clubbing together the two chosen options, i.e. the CaT and the disposal plan would form the complete model of SWM for the city. A diagrammatic representation (two/two analytical matrix) indicating the relationship between the CaT plans with respect to ULB capability and waste sensitivity is given in Figure 1.

Sensitivity of the individual respondent towards waste plays a crucial role in determining the selection of model option. High sensitivity to waste is indicated by activities like making source storage, walking up to the community bin, avoiding street littering. Coupled with high sensitivity another strong component of waste management is the ULB capability. Keeping the high sensitivity factor intact the ULB has either a high or low capability towards waste management. A combination of high sensitivity and high ULB capability leads to options like individual dumping at kerbside picked up by compactor and transported to dump yard – community bin model . Similarly high sensitivity coupled with low capability leads to the following alternatives: back yard composting, individual dumping at disposal yard or at street corner site.

Likewise, low sensitivity to waste is indicated by typical activities like no source storage, street littering, street dumping, no recycling. However, low sensitivity combined with high ULB capability has

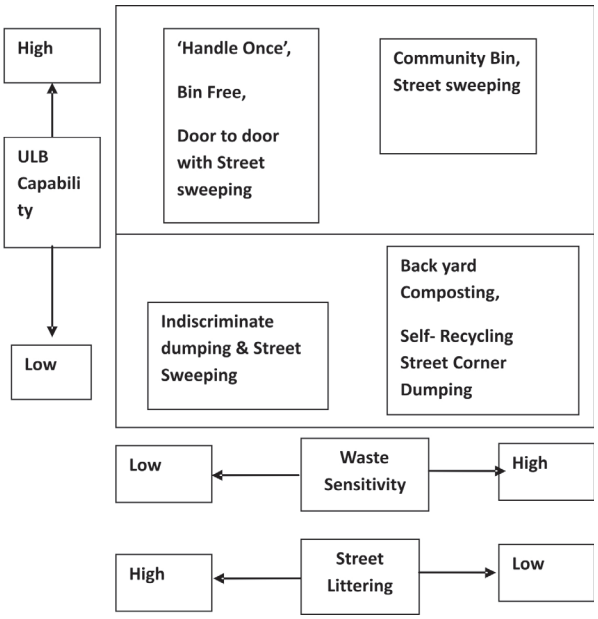

Fig. 1. Two / Two Analytical Matrix of CaT Plan

choices like door to door compactor collection, bin free system, door to door collection with push cart along with street sweeping. However, low sensitivity and low ULB capability is the only combination having limited scope for waste management. It results in activities like street dumping and street sweeping.

Assuming that the ULB has high capability and sensitivity fluctuating between high and low, there are several other options to choose from. A diagrammatic representation (two/two matrix) reflecting the relationship between CaT plans and influence of factors like multiple or 'handle once', material recovery, cost factor, technical factor and environmental factor is given in the Fig. 2.

The ULB capacity remaining constant at high, a host of factors can be instrumental in deciding the optimum CaT plan. With reference to the cost factor there can be two viable Model options, one capital intensive and the other, low capital intensive. The high cost model refers to one of the best fit models with door to door compactor collection and waste being 'handled once'. This model uses sophisticated technology and is environment friendly, provides primary collection, but without the scope of material recovery. The alternative high cost model is door to door auto tripper or push cart collection (bin free model), which has the disadvantage of multiple handling, but is technically oriented, being environmental friendly, with the scope of material recovery.

The relatively low cost model refers to community bin disposal with regular clearance. Though the obvious drawback of this model is that it is not en-

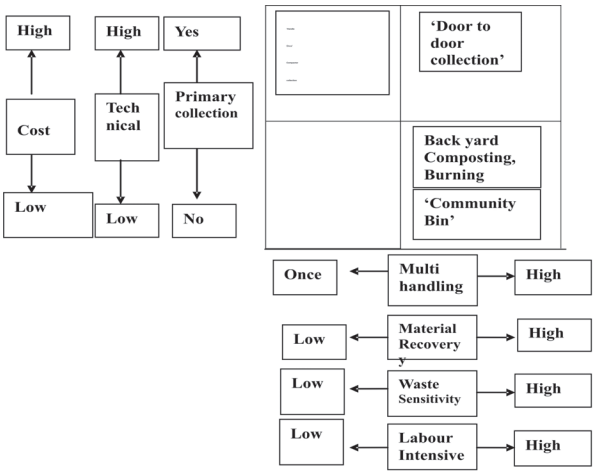

Fig. 2. Two / Two Analytical Matrix for ULB with High Capacity

vironmentally sensitive, it has the advantage of being based on low technical orientation and has scope for material recovery. Another advantage of a low capital intensive model is that it is labour intensive. Large employment generation is an advantage of the low cost model, which needs to be considered in developing countries.

The above picture holds true for most metros and rich municipalities. However, India has a fair share of financially starved municipalities, which requires low cost models. The following diagrammatic representation reflecting the relationship between CaT plans and factors like cost, technical input and environmental aspect is given in Figure 3.

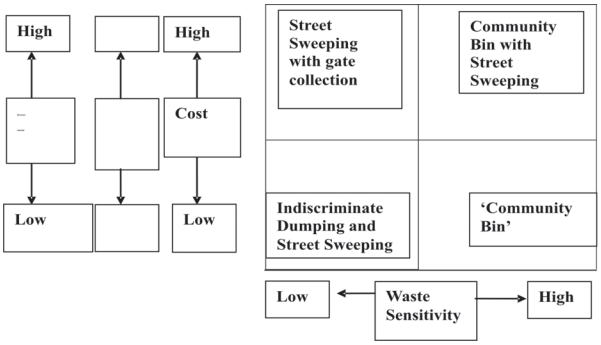

Fig. 3. Two / Two Analytical Matrix for ULB with Low Capacity

Among the low cost model options, a relatively higher end model is street sweeping coupled with garbage collection (to be deposited near the gate/ garbage dropped into the push cart). Another higher end model is community bin collection with regular street sweeping. These two model options have the advantage of moderate technical input and moderate sensitivity to environment. The low end low cost model is street corner dumping with intermittent clearance or street dumping and intermittent street sweeping. These options have negligible technical inputs and lack environmental concern. However, the lower end models are labour intensive, rather than capital intensive. Further, these models of multiple handling of waste offer greater chances of material recovery, due to more access to the waste by rag pickers or the waste workers.

It is important to note that if waste sensitivity of the population is low and provided the ULB has the capability, it is preferable that the municipality should adopt higher waste management models to keep the city clean and vice-versa.

Decision Making for Processing and Disposal Technique Selection

Most popular methods in disposal technologies are the following[1]:

1. Composting
2. Waste To Energy / Fuel
3. Bio-methanation
4. Sanitary Land-filling

The decision maker should keep in mind that there can be disruptive technologies in waste management and the new one's may replace the old . Therefore, the maturity of the technology, feasibility (proven technology), etc. should be studied and discussed well before freezing a specific technology.

The criteria which affect the decision for different technologies are as follows:

1. Volume of waste generation (Economies of scale)
2. Availability of land
3. Type of waste (mixed or segregated)
4. Funding options (Incentive)
5. Material Recovery (Processing)

Two/ Two Matrix Analysis (Processing and Disposal)

A two/two matrix tries to superimpose all the above factors and simplifies the decision making process. The matrix is placed at Fig. 4.

Availability of Land

Availability of land is a very crucial factor for adopting a specific disposal technology. It is difficult to find out and demarcate enough land in big cities for

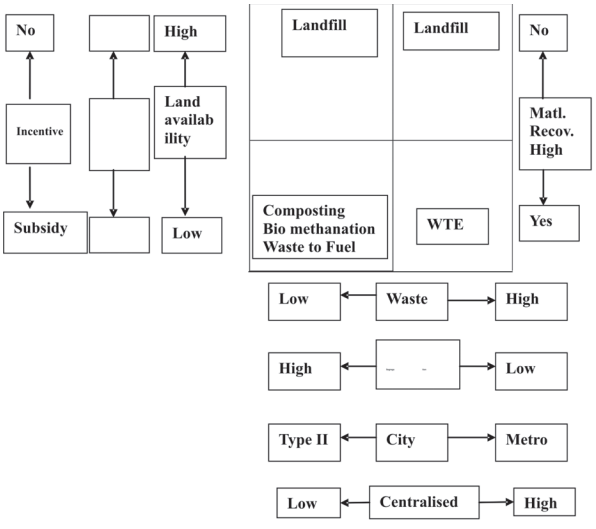

Fig. 4. Two / Two Matrix of Disposal Plan

waste disposal. Secondly the cost of land is exorbitant in big cities. When there is less availability of land, waste to energy path is most suitable because volume reduction is almost 90%[2]. The land filling can be taken up only when the land availability is high. Therefore, availability of land decides the selection of disposal of technology.

Types of Waste

When the waste segregation is low, it indicates that the waste is mixed waste. The most suitable disposal technology for mixed waste is either waste to energy or land filling. On the other hand, when segregation is high through source separation, the preferred options are composting or bio-methanization for degradable component and land filling for non-degradable waste. When there is no source segregation, even segregated transportation of waste can help in treating different categories of waste differently. For example, the waste from the vegetable market should go to the compost yard and waste from apartments should not go to compost yard; rather it should go for land-filling directly. Composting of mixed waste is risky due to contamination of the compost by toxic elements.

Incentive

In waste disposal practices the incentives are available through carbon trading and subsidies by Ministry of New and Renewable Energy for Waste to Energy plants. Whereas, in the carbon trading fund can be available on a continuous basis, in subsidy of MNRES it is a one-time grant, and power purchase at a higher price is a continuous support. This may help for the sustainability of the project. No such incentive is available for land filling activities. Therefore, if the urban local body wants to avail the incentives, they should go for waste to energy or composting process.

Material recovery

There is no material recovery in the land filling process, whereas through composting, bio-methanation or waste to energy, there is recovery of recyclable material or energy from the waste respectively. Depending on the option for material recovery, decision makers may choose either land filling or waste to energy/ bio-methanation / composting process.

Volume of waste generation

The volume of waste generation is important as it decides the economies of scale. When the volume of waste is high, the ULB can go for a number of disposal options, like land-filling, composting or waste to energy (more 400 capital MT per day). Therefore, the big cities and metros can go for any kind of disposal option whereas, the small towns and type –II cities where the waste generation is less than 350/ 400 MT cannot opt for waste to energy option, unless they cluster with other nearby cities to make waste to energy plant viable. So, small towns can go for composting or land filling options. In another variation, the big cities can also adopt decentralized waste disposal methods by having multiple facilities. They can divide the cities into a number of smaller sectors and based on the volume of waste generation, they can have different facilities like waste to energy, land filling, composting etc. This will also reduce the future risk due to any disruptive technology.

Conclusion

In order to arrive at the specific MSW model selection, it is necessary to follow a series of steps. At first, all the possible models were prepared and compiled through a process of binary coding. The series of models were grouped into four basic models based on 'collection and transportation' combination. Those basic models were 'indiscriminate dumping and street sweeping', 'community bin dumping', 'door to door primary collection' and the last one , "handle once". The process of elimination was carried out through the application of two/ two analytical matrix. The final model was narrowed down for the Collection and Transportation (CaT) plan. Similarly, for the Processing and Disposal plan, the same process of elimination was used with the help of two/ two analytical matrix. This process gave us the best disposal plan. Finally, the combination of CaT plan and disposal plan need to be subjected to the ground realities for sustainability. The prevailing Government Rules and regulatory compliance checks can further give a direction for the most feasible MSW Model.

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