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The Threshold Target Approach to Waste Management in Emerging Economies: Pragmatic, Realistic, Appropriate

Manfred Fehr
Federal University at Uberlândia
Brazil

1. Introduction

Municipal solid waste is a commodity resulting from human endeavor and will always exist in the world's cities. The rate of production is commonly reported on a per-person-per-day basis, which implies that it will grow together with the population. In the not too distant past, waste was conceived of as a nuisance that could be removed by collection followed by tipping at a site not visible to the population: a landfill at best. This concept of a landfill as waste receiver has been challenged in recent decades for reasons of space availability and of collateral effects on soil, water and air. World summits have addressed the topic of waste within the general subject of sanitation, and have set targets for the gradual expansion of collection services to urban residents. Specifically, the directives resulting from the World Summit on Sustainable Development (WSSD 2002) asked to halve by the year 2015 the proportion of people not served by sanitation. Global intellectual movements such as the Zero Waste International Alliance (ZWIA 2009) have gone much further in their quest for sustainable waste management. In fact, several cities have adhered to those movements by passing local legislation that requires gradual reduction of waste disposal until reaching a zero waste situation within a timeframe in the order of fifteen years. Against this background of increasing demand for results, city administrators face enormous management challenges.

Although waste is produced and handled everywhere in the world, different countries are moving at different speeds to set and meet waste management targets. Southern countries in general are at the stage of moving from dumpsites to landfills, whereas Northern countries are already phasing out the landfills by efficient recycling and mechanical-biological pretreatment procedures. As a consequence, the management challenges differ, and appropriate solutions need to be developed for different groups of countries. Waste collection service is not yet universal in Southern countries. Consequently, expanding it as required by summit directives fatally implies more landfill space. This underlines the argument of different speeds and different directions. Landfills are still increasing in the South, whereas they are already decreasing in the North. Different countries at present are on different sides of the turning point, which represents complete collection service. Along comes the zero waste movement and sets the pace with pioneering cities towards eliminating waste altogether. The basic argument of the present study is that the move

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sought by the zero waste movement is only realistic when it starts beyond the turning point, i.e. in Northern countries. Very few cities of the developing world are prepared at this time to make such a move, almost a utopia to them. They need a viable alternative to zero waste, which will allow them to set intermediate targets on the long journey to sustainable waste management. The present study is designed to provide those intermediate targets.

Waste management research by this author in Brazil has identified thresholds for different components of municipal waste that are suitable for landfill diversion targeting. What is a threshold in this context? It represents the percentage of each waste component that can be moved through the reverse logistics chain by market forces without the necessity of public funds. This is a new concept in waste management. Once the threshold is known, it becomes the natural target for landfill diversion within a timeframe to be established by the municipal administration. The quantity of the waste situated beyond the threshold is left as a future challenge to be tackled in due time. The utopia has been eliminated, and the financial bottleneck of the city budget has been bypassed. By way of examples, the research has identified the threshold for domestic waste as 67% and that for construction debris as 90% of collected quantity. The methods used for determining the thresholds are described, and administrative procedures for reaching the threshold targets are outlined. The procedures include, but are not restricted to, the following activities: Establish the threshold for each waste component and create local legislation to enforce the corresponding separation at the source. Create incentives for reverse logistics operators to absorb the material made available by source-separation with possible use of funds liberated by reduced landfilling. Design landfill capacity only for waste produced beyond the threshold. Put municipal waste management activities into the hands of marketing and accounting professionals.

Even without the pretension to reach zero waste, the challenges for cities of emerging economies are enormous. This study is a modest contribution to meeting the challenges.

The success or failure of urban waste management may be viewed as an indicator of sustainability.

Indicators have meaning if they incorporate a mixture of physical, economic and social data that evaluate changes in time and promote actions. Many measurable indicators for the state of development of a nation or country have been proposed and applied. Two of them are officially used by the United Nations to classify countries. They are the Gross National Product and the Human Development Index. The former only has meaning when applied to a nation, and even so has its shortcomings. The industrial and service outputs are not necessarily sustainability indicators. Large quantities of throw-away products that increase required landfill space contribute to the gross national product, but are not representative of a sustainable society (Kanitz 2006).

The Human Development Index, apart from being applied to countries, is also used to classify cities within a country. It measures the life expectancy, the frequency of school attendance, the degree of literacy, the infant mortality rate and the average individual income. All of them are considered indicative of the general state of living standard, and are perfectly appropriate for a municipal context in terms of determining the degree of sustainability.

The measure of relative quality of life is included in the Mercer Index that classifies the World's cities according to the parameters of security, health services, basic sanitation, air pollution, education and transport facilities (Report 2004).

Perhaps the most widely known sustainability indicator at present is the Ecological Footprint that measures the energy and material consumption of a society in terms of land area required to satisfy the demand (Rees 1996).

In 2004, this author's team proposed a specific set of indicators for urban sustainability that may be determined by local diagnosis and continuous data collection (Fehr et al 2004). As they are meant to identify absolutely defined situations, they may also be referred to as identifiers. Table 1 is reproduced from that paper to illustrate the degree of quantification aimed at.
The present study describes research carried out to more closely qualify the third identifier in Table 1: Landfill diversion of solid waste is in excess of 70%. After evaluating the present solid waste situation in a city, the study pursued the objective to define a threshold value of diversion, which separates results possible with private initiatives from results achievable only with public intervention.

Population growth is under control.
The public transportation system is of high quality.
Landfill diversion of solid waste is in excess of 70%.
All liquid effluents are treated.
Air quality is monitored.
Fresh water demand is monitored and controlled.
The public education system has high student and teacher satisfaction
Public health care is accessible and of high quality.
Citizens are socially and politically active.
Energy supply and demand are monitored and controlled.
Public recreation areas are available in all sectors of town.
Rivers and creeks are under official protection.

Table 1. Basic municipal sustainability identifiers (Fehr et al 2004)

2. Materials and methods

It is acknowledged that the landfill is part of the ecological footprint in as much as it sets aside land area for depositing the city's refuse. The rate of deposit is appropriate to be used as a sustainability indicator, since it evaluates changes in time and promotes actions. To illustrate the change in time, the land distribution of the Planet may be invoked. In the year 2000, seven percent of the Earth's surface was deemed useful for agriculture, industrial activities and city dwelling, for a total of $36*10^6$ km^2, and there were $6*10^9$ people (Fehr 2003). The urban area proper occupied 5% of the arable land, or $1.8*10^6$ km^2, and the landfills, in turn, occupied 1% of urban area or $1.8*10^4$ km^2. The World's population is expected to level off at $10*10^9$ people around 2080 (Doyle 1997).
At this rate of population growth and trash production, a typical city will have to construct a new landfill every 16 years. The land occupied by landfills will thus reach 6% of urban area by 2080. The change in time is impressive. The urban terrain per person in 2000 was $1.8*10^6$ / $6*10^9$ = 300 m^2. In 2080 the urban terrain per person will be $1.8*10^6$ / $10*10^9$ = 180 m^2, of which landfills will occupy six percent or 11 m^2. This is the fatality resulting from constant waste management policies in the 80-year period. The urban area available for living will shrink from 300 - 3 = 297m^2 to 180 - 11 = 169 m^2 per person. As this sequence of events is a road sign to collapse, the landfill area, or alternatively the rate of landfill diversion of waste, is a strong candidate for sustainability indicator. How does this indicator promote action? With proactive waste management models, about 80% of urban waste may

today and in the near future be diverted from the landfills (Fehr and Calçado 2001). This means that landfill area would be maintained at 11*(1-0.8) = 2 m^2 or approximately one percent of urban terrain per person from 2000 to 2080. The indicator will allow for monitoring the progress and the success of the proactive waste management model.
The remainder of this chapter is dedicated to describing experiments carried out with the objective to build at least one possible version of the management model required. The relativity of sustainability comes into play here. If sustainability were considered a state function or a fixed condition, then a city could only be sustainable or unsustainable. If sustainability were considered a process, then intermediate or fractional approaches to sustainability could exist. In the case made here, if the city in question was sustainable in 2000 with one percent of its space dedicated to landfills, and the management model was applied successfully, the city would still be sustainable in 2080 with the same one percent of its space dedicated to landfills, other factors notwithstanding.
As the implementation of the model takes up time, the required landfill space will exceed one percent of urban area for a number of years and finally return to one percent and level off. The function of the indicator is to register this change in time in order to promote the corresponding actions. What is to be measured is the evolution of the fraction of urban waste diverted from the landfill and recycled as a function of time, and this fraction will be representative of the approach to sustainability related to urban waste, with 0.67 being a satisfactory starting target for domestic waste as will be explained shortly.
The threshold for landfill diversion was arrived at through research on urban waste composition for raw waste and for sorted waste. Tables were developed to show the evolution of waste production, waste collection and landfill diversion in the city with and without the use of threshold targeting. Threshold targeting is presented as a pragmatic tool for the development of waste management schemes.

3. Results and discussion

3.1 Household waste

The experiments carried out with household waste management identified a threshold for landfill diversion at 67% of total waste produced. The meaning of the threshold is as follows. The indicated diversion of 67% represents the maximum rate achievable with strictly private initiatives, or bottom-up management procedures, which may be either spontaneous or stimulated. In order to move above the threshold, intervention by the city administration is required. This leads directly to proposals for the diversion of the remaining 33% of city trash.
Existing management models for household waste were analyzed, but none evidenced a landfill diversion potential above the present value of 15% for selective collection of inert material in Brazil. A sharp paradigm shift was required to raise this potential to values above 70% and thus create the prospect of sustainable situations. The research led to the *Divided Waste Processing* (DWP) model as means to meet the challenge (Fehr & Calçado 2001). This model differentiates between humid and dry material in the waste stream, or in biological terms between biodegradable and inert material. Thus the model requires the use of only two recipients, one for each portion, and the collection and processing operations maintain them separated all the way to their respective destinations. Once the management model had been elaborated, tests of its functionality were initiated with the objective to demonstrate the landfill reduction achievable. Destinations of source-separated material

were animal feed and compost for the humid part, and informal reverse logistics for the dry part.

As the key to success is the correct source separation, the challenge was clearly educational and was faced and met as such. The research started in apartment buildings, was then extrapolated to a street, and recently arrived at the stage of using schools as multipliers of the model. In all those communities the model confirmed its consistency as it pointed to the same theoretical diversion potential of 83% even if to date this level has not been reached. This communication relates the experience gained, the arguments used with the communities and the results obtained with the active environmental education procedure. It opens up the prospect to amplify the application of the model to other sectors and eventually to the whole city.

The experiment described here is original in the sense that it is an entirely private initiative that takes the message of its results from the bottom upwards into the municipal administrative hierarchy. Traditional models follow the inverse direction.

In the first test community, the divided waste-processing model was functional in 60 apartments after 4 person-months of dedication. The humid and dry fractions of raw waste stabilized at 68% and 32% respectively. The behavior change was obtained and perpetuated by the building administrators through the constant communication of results. The effective participation rate of residents was above 80%. This level was considered excellent in a context where a completely new model with voluntary participation was applied. The behavior model of the participating families at present is as follows. In the apartments, all waste is rigorously separated into humid and dry parts. Each family uses a pail furnished by the administration to collect biodegradable waste for a day. At predetermined hours, the employees collect this pail. All inert waste is left at the collection point on each floor at any time of day and in any form of packaging. The employees transfer the contents of the pails to a barrel, which is taken away daily by a farmer who uses the material as animal feed. All inert material from the floors is transferred to a collection cart, which then is left at the disposal of selected waste retailers who take away approximately half of this material for their recycling businesses. What remains each day represents approximately 40% of all waste and is left at the curbside for official collection by the municipal vehicles that take it to the landfill.

In the second test community, the main factor of success was the insistence of the research team with the necessity of separation prior to collection. It happened that some residents did not separate their material for the programmed collection, and when questioned responded that the team had not visited them or left a message the day before. This example illustrates very well the difficulty of changing established thinking models.

In the work with the school communities, compost was prepared in the school yards from the source-separated biodegradable waste. The model turned out to be a powerful learning tool. All participating students now leave primary school with the baggage of practical experience of fabricating a useful product and with the conviction of having contributed their share to the reduction of the landfill. The compost is available for gardening in the school and in the neighborhood, and is introduced to the community as a product of what only a short time ago they used to call garbage.

In the case of domestic waste, the composition report is critical to setting diversion targets or thresholds. This is so because the composition of the waste depends on the amount of human intervention in its evolution. This research experimented with several stages of waste sorting and the corresponding compositions with the results reported in the following section.

Raw waste is what families discard in their waste baskets and leave for collection without any sorting effort. The analysis of this raw waste may yield three different types of composition reports. The first type of report results from the separation of raw waste into biodegradable material and biologically inert material. In the first test community this report produced the numbers shown in Table 2. The second type of report results from the separation of raw waste by substance. The same waste from the first community was analyzed for contained substances and produced the numbers shown in Table 3. The third type of report results from the separation of raw waste by utility. The same waste from the first community was analyzed for utility and produced the numbers shown in Table 4.

material	weight percent
biodegradable matter	68
biologically inert material	32

Table 2. Composition report by biodegradability for raw domestic waste

The evolution of the significance for decision making of the successive reports is apparent. The numbers in Tables 2 and 3 are basically of academic nature. They do not support waste management decisions on landfill diversion potential or educational efforts of source-separation. Table 4, to the contrary, supports such decisions. The educational effort required to reduce food waste by consumers is hidden in the lost food item. The landfill diversion potential may be read off Table 4 as 58+10+15=83%. This information is of utmost importance to the construction of a management model. It tells the administration that with an adequate model only 17% of present landfill capacity will be required in the long run.

material	weight percent
biodegradable matter	68
plastics	10
paper and cardboard	9
glass	4
textiles	3
metals	2
miscellaneous	4

Table 3. Composition report by substance for raw domestic waste

material	weight percent
food scraps to composting	58
lost food to further use	10
used packaging to recycle	15
trash to landfill	17

Table 4. Composition report by utility for raw domestic waste

There is however one basic shortcoming to all these reports, which is not visible to the unsuspecting observer but was identified by this research. All foregoing reports refer to raw waste. Consequently, no information is available on the success or failure of an effort to really separate the waste at the source into the categories listed. The indications derived for the municipal waste management model remain hypothetical. In order to advance, this research experimented with source-separation in the first test community for several months. Families were instructed to separate their waste into biodegradable matter and inert matter and deliver the two parts to the building administration for recycling. Containers were provided for the two types of waste, and the building employees collected them daily for screening. Instructions to various families were repeated to ascertain the procedure. After four months of experimentation, the following conclusions became available. It is impossible to obtain the collaboration of all families. An adhesion of 80% has to be considered excellent. The separation procedure at the source, even with the simple request of only two recipients, presents a heavy intellectual burden to most apartment dwellers. They do make an effort, but the success is only partial. Several items of waste end up in the wrong container. The building employees have to screen the delivered material and proceed with an additional separation before handing the sorted material over to reverse logistics operators. The result of this experiment was the two-step sorted-waste composition report shown in Table 5. In contrast to the previous reports, this one can be considered a management tool. It defines the landfill diversion potential as 67% of domestic waste, arrived at by experimental source-separation, and therefore this is a reliable number. The best raw waste composition report cited this potential as 83%, which would lead to erroneous decisions by waste managers. The trash item in Table 5 refers to material not separated at the source in spite of correct instructions and goodwill, as well as to items that are not recyclable at this time.

material	weight percent
biodegradable matter for composting	47
recyclable matter for reverse logistics	20
trash temporarily for landfilling	33

Table 5. Composition report for source-separated domestic waste

The key words in Table 5 are *source-separated* and *temporarily*. The former means that this composition represents the best separation result possible at this time in households, independently of the raw waste composition prevailing in the city. The latter means that the trash is not necessarily improper for recycling. It simply is not being separated at this time, thus opening targeting options to the municipal administration. Table 5 tells the administration that 67% of domestic waste can be recycled by private initiatives if the pertinent incentives were created. The remaining 33% represent the target for official intervention. Several options are available for diverting this material from the landfill. Some are obvious, as e.g. educational efforts to improve source separation, and policy tools to make more trash items attractive to reverse logistics. In the worst case, landfill capacity has to be provided to tip the 33% trash. This is the threshold mentioned at the beginning, and is the original contribution of this research to the science of waste management. As an indicator, the threshold of 67% landfill diversion, if reached, tells that the city administration has stimulated the private sector to contribute its maximum expected share to domestic waste recycling.

The expected waste movement at the stage where the threshold is reached is depicted on Figure 1. How can this stage be reached in practice? The proposal resulting from this research makes use of timeframes and annual targets that will lead to the threshold situation within those timeframes. The threshold target represents an intermediate stage between bulk tipping and "zero waste" offered to municipal administrations as a realistic and appropriate alternative to world summit directives. In order to illustrate the concept of timeframes and annual progress requirements, Tables 6, 7 and 8 will be explained now.

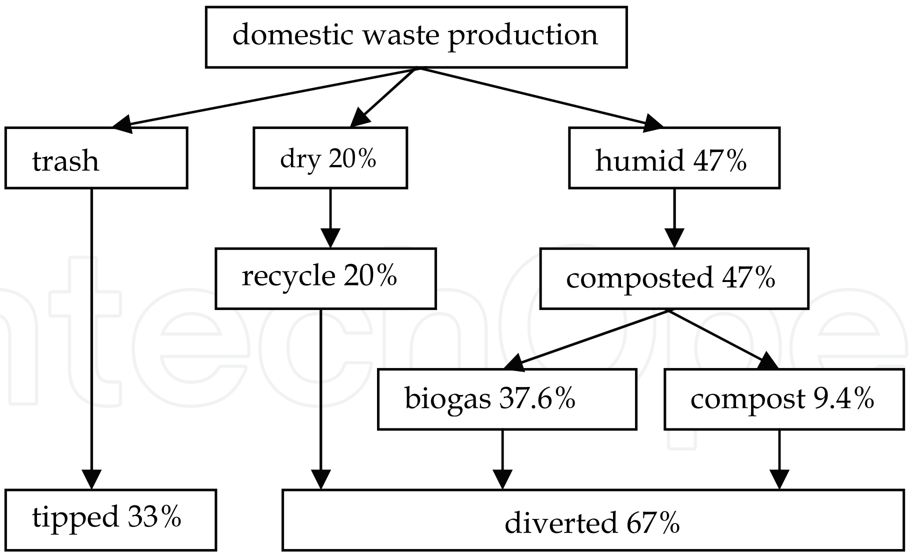

Fig. 1. Material movement of domestic waste at threshold situation

sequence of years	waste production preview kt/year	waste collection target according to WSSD directive kt/year	waste dumping target according to WSSD directive kt/year
0	182.5	146.0	36.5
1	183.8	148.4	35.4
2	185.1	150.8	34.3
3	186.4	153.2	33.2
4	187.7	155.7	32.0
5	189.0	158.2	30.8
6	190.3	160.7	29.6
7	191.6	163.3	28.3
8	193.0	166.0	27.0
9	194.3	168.7	25.6
10	195.7	171.4	24.3
11	197.1	174.2	22.9
12	198.5	177.0	21.5
13	199.8	179.8	20.0
14	201.2	182.7	18.5
15	202.6	185.7	16.9
16	204.0	188.7	15.3
17	205.5	191.8	13.7
18	206.9	194.9	12.1
19	208.4	198.0	10.4
20	209.8	201.2	8.6
21	211.3	204.5	6.8
22	212.8	207.8	5.0
23	214.3	211.1	3.1
24	215.8	214.5	1.2
25	218.0	218.0	0

Table 6. Production, collection and dumping targets from WSSD directives

Table 6 shows the base case of a municipality that adhered to the WSSD directive to halve, by 2015 (year 13) the proportion of residences not served by collection. In year 0 there were 500,000 inhabitants producing 1.0 kg per person per day of waste or 182.5 kilo tons (kt) per year. The collection service was available to 80% of the residences, which means that 182.5*0.8=146.0 kt were collected per year, and the remaining 20% or 36.5 kt per year were dumped by residents at unauthorized locations. The population and with it the waste production were increasing by 0.7% per year. The target set by the world summit required to reach 90% collection service by year 13. The necessary yearly collection expansion was found from equation 1

$$0.8 * x^{13} = 0.9 \qquad x=1.0091 \tag{1}$$

Considering the waste production increase of 1.007 per year, the resulting collection effort was defined as an annual increase of 1.0091*1.007.

As an example, for year 1 the production was 182.5*1.007=183.8 and the collection had to reach 146.0*1.007*1.0091=148.4 kt. The collection target for year 13 was set as $146.0*1.007^{13}*1.0091^{13}$ or 179.8 kt. This represents the required 90% of the 199.8 kt produced, with the remaining 10% or 20.0 kt being dumped.

Although the summit directive was satisfied, the exercise was extended at the same collection expansion until complete collection service would be reached. This occurred in year 25 (2027), when all waste produced would be collected and no more dumping would exist. This base case confirmed the following facts. In the city under study, it would take 25 years to reach complete collection if the service expansion required by the directive were extrapolated beyond year 13. In this model, all collected material is tipped at the landfill.

Table 7 shows the concept of threshold targeting. Here the collected material is partly tipped and partly diverted from the landfill. The city administration may choose any timeframe it deems reasonable to reach the target. In the example of Table 7 the timeframe was taken as

sequence of years	collection target from WSSD directive kt/year	threshold target for tipping kt/year	threshold target for diversion kt/year	progress of diversion %
0	146.0	146.0	0	0
1	148.4	140.8	7.6	5.1
2	150.8	135.3	15.5	10.3
3	153.2	129.5	23.7	15.4
4	155.7	123.7	32.0	20.6
5	158.2	117.4	40.8	25.8
6	160.7	111.0	49.7	30.9
7	163.3	104.4	58.9	36.1
8	166.0	97.6	68.4	41.2
9	168.7	90.4	78.3	46.4
10	171.4	83.1	88.3	51.5
11	174.2	75.4	98.8	56.7
12	177.0	67.5	109.5	61.9
13	179.8	59.3	120.5	67.0

Table 7. Tipping and diversion targets to reach threshold in 13 years

13 years. The first column repeats the waste collection requirement from Table 6. The next two columns illustrate how collected waste divides into tipping and landfill diversion.

The threshold to be reached in year 13 is the experimental value of 33% tipping and 67% diversion. Upon dividing 67% by 13 years, the annual diversion expansion is found to be 5.153846%. Excess significant digits are carried here to reduce round-off errors. As an example, the required diversion for year 1 is 148.4*0.05153846=7.6 kt, and the tipping rate has to be 148.4*(1-0.05153846)=140.8 kt. By the time year 13 is reached, the tipping rate would have been reduced to 179.8*(1-0.05153846*13)=59.3 kt or 33% of collected waste. The table shows the evolution of the diversion effort over the years and allows for precise targeting to reach the threshold within the chosen timeframe. No utopia is involved. The threshold value is experimental, and the required actions can be correctly dimensioned.

What are these actions? This research has contributed the most important one, namely promote source separation. The experimental work with the test communities showed that source separation drives reverse logistics, and not vice versa. The logistics for inert material is already in place and is completely private. It recycles all inert material conveniently separated at the source. The action of the public administration will be restricted to promoting source separation, either by local legislation or by educational campaigns. The model allows for ample time. Table 7 shows that 20% diversion is to be reached in year 4. This corresponds to the amount of inert material in the waste according to Table 5. Consequently, four years are available to divert all inert waste from the landfill by fostering source separation and stimulating reverse logistics: a reasonable task.

The logistics for biodegradable material is still incipient. It has to be developed within the remaining nine years. As the progress indicated in Table 7 is gradual, nine years are a reasonable period. Apart from stimulating more farmers to take away the biodegradable waste from restaurants and other commercial establishments, it will be necessary to support private composting facilities. There is no point in arguing that these facilities are not by themselves economically feasible. What has to be done is to dimension the savings resulting from reduced landfill construction and maintenance, and apply them to buying compost from the private operator at a price that will keep him or her in business. Other schemes may be invented. All depends on the creativity of the responsible administrators. What the threshold approach has provided is the realistic target for diversion. It has taken the guesswork out of waste management. Table 7 also implies result reporting. This is an essential part of modern waste management. It holds the public administration responsible for reaching the annual targets.

Another illustration of the use of this concept is presented in Table 8. It relates to a municipality that started to adhere to the summit directive in year 0 and progressed as planned until year 8, just as illustrated in Table 6. No diversion was considered until then. Starting in year 9, the administration decided to initiate threshold targeting. The tipping rate had been increasing as expected, but the outlook beyond year 8 called for gradual reduction. The timeframe chosen was 17 years until year 25, which was identified in Table 6 as the turning point where collection service would be complete. Following the threshold concept, from year 9 onward, the collected portion of waste was to be partly tipped and partly diverted, with the tipping rate reaching 33% by the end of the period.

The arithmetic for Table 8 is as follows. By dividing the threshold of 67% diversion by the period of 17 years, a yearly increase in diversion of 3.941176% was stipulated. Again, the excess significant digits have no meaning except for reducing round-off errors in the table. For year 9, the required collection from Table 6 was 168.7 kt, and the diversion was calculated as 168.7*0.03941176=6.6 kt. Consequently, the allowed tipping figure was found to be 168.7*(1-0.03941176)=162.1 kt. The dumping rate was not affected and continued as 25.6 kt/year from Table 6. Upon arriving at year 25, the tipping rate reached the threshold value of 33% of collected waste as follows: 218.0*(1-0.03941176*17)=71.9 kt.

sequence of years	popula tion	trash produ ced kt/year	trash collec ted and tipped kt/year	trash not collected and dumped kt/year	trash diverted from landfill kt/year	cumula tive landfill mass kt
0	500000	182.5	146.0	36.5	0	146.0
1	503500	183.8	148.4	35.4	0	294.4
2	507025	185.1	150.8	34.3	0	445.2
3	510574	186.4	153.2	33.2	0	598.4
4	514148	187.7	155.7	32.0	0	754.1
5	517747	189.0	158.2	30.8	0	912.3
6	521371	190.3	160.7	29.6	0	1073.0
7	525021	191.6	163.3	28.3	0	1236.3
8	528696	193.0	166.0	27.0	0	1402.3
9	532397	194.3	162.1	25.6	6.6	1564.4
10	536124	195.7	157.9	24.3	13.5	1722.3
11	539877	197.1	153.6	22.9	20.6	1875.9
12	543656	198.5	149.1	21.5	27.9	2025.0
13	547461	199.8	144.4	20.0	35.4	2169.4
13a	**547461**	**199.8**	**179.8**	**20.0**	**0**	**2274.6**
14	551294	201.2	139.5	18.5	43.2	2308.9
15	555153	202.6	134.5	16.9	51.2	2443.4
16	559039	204.0	129.2	15.3	59.5	2572.6
17	562952	205.5	123.8	13.7	68.0	2696.4
18	566863	206.9	118.1	12.0	76.8	2814.5
19	570861	208.4	112.2	10.4	85.8	2926.7
20	574857	209.8	106.0	8.6	95.2	3032.7
21	578881	211.3	99.7	6.8	104.8	3132.4
22	582933	212.8	93.1	5.0	114.7	3225.5
23	587014	214.3	86.3	3.1	124.8	3311.8
24	591123	215.8	79.2	1.2	135.4	3391.0
25	595261	218.0	71.9	0	146.1	3462.9
25a	**595261**	**218.0**	**218.0**	**0**	**0**	**4673.5**

Table 8. Evolution of landfill mass with threshold targeting from year 9. Bold face values show corresponding situation without threshold targeting.

Additionally, Table 8 provides information on population growth and cumulative landfill mass. The threshold targeting approach allowed for reducing the landfill mass by 26% with respect to the base case of Table 6 in spite of the 19% population and waste production increase during the period. Threshold targeting proved its utility as a management tool.

3.2 Construction and demolition debris (CDD)

In response to a diagnosis, the objective of the study required to construct a management model to efficiently handle construction and demolition debris in the city under study, and to determine the landfill diversion threshold of this waste as an indicator of sustainability.The city did not have a plan for integrated management of CDD. The Brazilian National Environmental Council regulated the handling practices of this material in 2002 through Resolution 307/2002 (CONAMA 2002), but this directive had not yet been implemented in the city. As a consequence, CDD were still collected at assigned locations throughout the city and taken to a CDD dumpsite.

The cited resolution classifies CDD into four categories, namely A, B, C and D. The definitions are as follows.

Category A: Debris that can be reused or recycled as aggregates for construction.
Examples: ceramic components, bricks, concrete, shingles, plasterboard.

Category B: Debris that can be recycled for uses other than in construction.
Examples: plastics, metals, cardboard, glass, wood.

Category C: Debris for which no recycling technologies are available.
Examples: gypsum and related material.

Category D: Hazardous or contaminated material.
Examples: thinners, solvents, oil, paint.

The resolution makes a distinction between small and large volumes of CDD to be taken care of, defined as deposited volumes of more or less than 2 m^3. The document asks for the establishment of networks of receiving points for small and for large volumes throughout the city, for the existence of a free telephone service by which residents may schedule waste pick-up for small volumes with the municipal administration, for the creation of a permanent Sector for CDD management within the administration, for effective supervision of all receiving points, and for environmental education programs directed to the population involved in CDD generation.

According to the document, the receiving points for small volumes have to be fenced, have to provide for separation of incoming waste into classes A, B, C and D, and have to keep records of quantities manipulated. All transfers of material from the receiving points to the CDD landfill are to be the responsibility of the public administration and are to be accompanied by transportation control sheets. Obviously, this standard procedure simply burdens the city’s tax payers with all expenses related to CDD.

In view of this questionable procedure, the author’s team decided against its recommendation to the city administrators. Instead, they developed a second option more realistic in terms of cost distribution and operating efficiency. The fundamental argument behind this new proposal is that private constructors produce the debris and have to carry the onus of disposal. The function of the municipal administration is to regulate, to supervise and to create the right incentives for private initiative, but not to run the system on tax money. The term "disposal" has to be redefined. The landfill is no longer an adequate place for deposit of CDD. Technology exists for reintegration of class A and B waste into the production chain. The management model needs to address them and stimulate recycling practices within the city. The traditional thinking model, which states that all services are provided free of charge by the public administration, has no place in a sustainable society. The collection and recycling operations have to be run as a business supported by private enterprise. Table 9 relates the cost and benefit distribution at various points in a privately operated system. Figure 2 provides information on material flow in the system.

income items	cost items
Deposit fee at small volume reception stations	Maintenance of small volume areas
Deposit fee at central large volume reception district	Transport from small volume reception stations to large volume district
Sale of class B residues to wholesalers	Transport of class C and D residues to landfill
Sale of recycled class A residues to construction projects	Operation of central large volume reception district and waste treatment
Sale of recycled material to public construction programs	Deposit fee at municipal landfill

Table 9. Economical balance for private waste handling model

The functionality of this model will be explained now. The final destination of collected residues received at any of the receiving stations is a treatment plant for type A residues, the municipal landfill for type C and D residues, and the reverse logistics chain for type B residues. All residues pass through the central reception district where they are separated and their destination is decided upon.

The whole system is operated by a private contractor and has to be financially self-sustaining. Table 9 indicates where the revenues will come from. It also shows where expenditures occur. The municipal administration does not interfere, except that it does buy recycled type A material for public works construction. This item may be negotiated with the system operator as a percentage of total recycled quantity.

All the receiving stations for small volumes are included in the enterprise, such that their operation is the responsibility of the contractor who may subcontract as convenient. All transportation is also part of the enterprise, but may also be subcontracted at will. Referring to Table 9, it is clear that the enterprise has to adjust the receiving fees at the various stations to values that will support the system. It will also have to pay the tipping fee at the municipal landfill. This is an important stimulation for the contractor to maintain a high level of recycle.

All small and large construction and demolition operators have to pay the reception fee at the receiving stations. This is the main new thinking model to be indoctrinated to the community. Heretofore people were used to discard their debris free of charge. The municipal bylaw, which will legally support the model, will have to insist on high fines for clandestine deposits in order to discourage them. The removal of this kind of degree of freedom is the heart of the system. The transportation of small volumes to the receiving stations is the responsibility of the rubble producers.

Large construction companies have to haul their debris to the central reception district where they pay the deposit fee. This central district is the heart of the model. It is at this point that all received material is separated and forwarded to its respective destination.

The number of small volume receiving stations in the city will be decided by the contractor and negotiated with the municipal administration who may rent publicly owned land for this application.

The market is expected to take care of operating details in the system such as the equipment and manpower available at the receiving stations and the central district and the intensity of the sorting procedure. The contract of the system's operator with the municipal administration will set the boundary conditions for the functioning parameters such as

capacity adjustments as required and the disclosure of balance sheets to justify the receiving fees.
The diagnosis showed the following contribution of each category to the composition of CDD: A = 75%, B = 15%, C+D = 7% and E = 3%, where E refers to contamination by biodegradable items during the collection process. As materials of categories A and B are potentially recyclable, their sum of 90% represents the diversion threshold achievable by private operators. The management model for the city will be designed to approach this number within an established timeframe, just as was done for domestic waste.

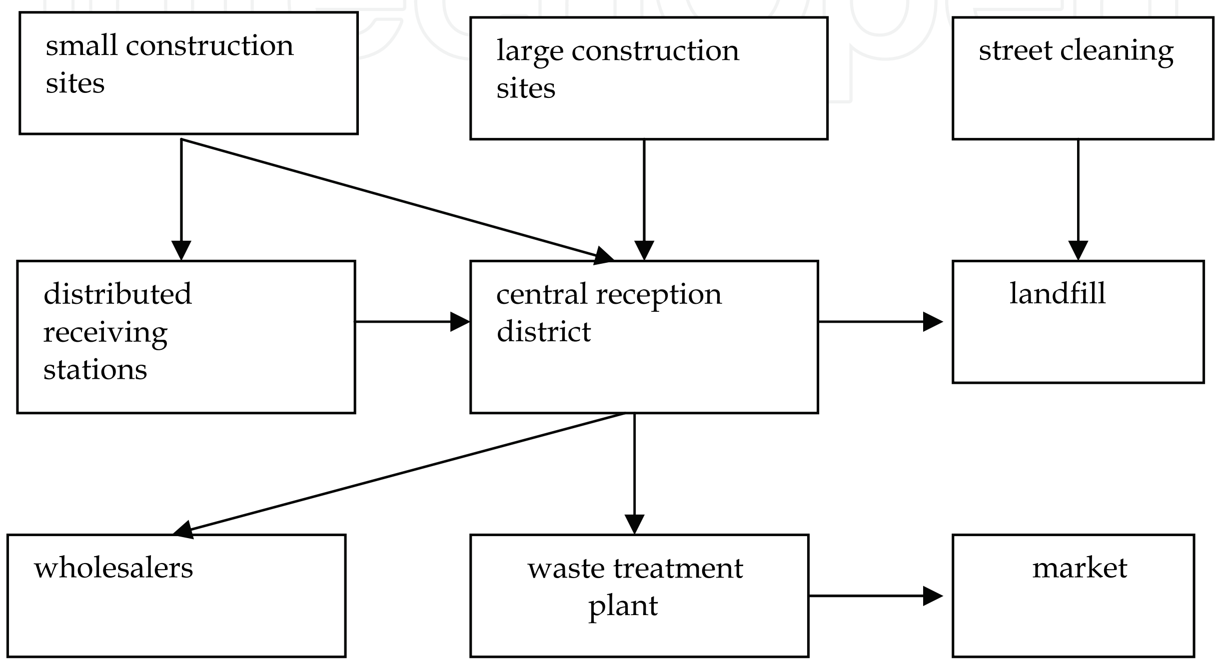

Fig. 2. Material flow of CDD in proposed model

This is a new model, which to the author's knowledge has not yet been experimented with in Brazil. The corresponding bylaw will have to be proactive in the sense that it needs to require constant updating of the management model as experience accumulates. The important fact is that the taxpayer has been relieved from the necessity to support construction and demolition waste handling in town, which is considered part of the sustainability indicator. The starting target of the sustainability indicator measurement will be the complete landfill diversion of type A and B material through privately operated facilities.

4. Conclusions

Urban sustainability has been envisaged as a process, not as a situation.
Landfill diversion of household waste and construction and demolition debris has also been treated as a process that moves towards a target.
The diversion requires a management effort, which in turn also is a process with a final target in mind.
The management talent of the municipal administration has been incorporated into the sustainability indicator.

With a final target in mind and the timeframe to reach it, fractional approaches to sustainability may be reported.
The proposed models induce the city administration to set precise targets on the road to meeting the targets relating to urban sustainability.
The standard management procedure for construction waste suggested by the National Environmental Council has been analyzed and found unfit for sustainable waste management. Its shortcoming is the unrestricted financial burden it places on the municipal taxpayer.
Thresholds have been determined for landfill diversion of household waste as 67% and for construction and demolition debris as 90% of quantities produced. Any target below the threshold can be met by strictly private initiatives if properly stimulated, thus liberating the city administration from financial and physical commitments.
To the author's knowledge, this is the first time such a model is being considered for implementation in a Brazilian municipality.
Urban waste management has been promoted to the position of sustainability indicator for a city.
The threshold targeting method has been shown to be a realistic management tool that can drastically reduce the need for landfill space.
Sample spreadsheets have been provided to show how the management effort may be diluted over time.
Threshold values for landfill diversion are experimental. They are derived from waste composition and source separation tests.
The new concept of sorted waste composition has been introduced and used to identify the diversion threshold.
Sorted waste composition does not reproduce the results expected from raw waste composition.

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Solid Waste Management is one of the essential obligatory functions of the Urban Local Bodies/Municipal Corporation. This service is falling too short of the desired level of efficiency and satisfaction resulting in problems of health, sanitation and environmental degradation. Due to lack of serious efforts by town/city authorities, garbage and its management has become a tenacious problem. Moreover, unsafe disposal of garbage and wastewater, coupled with poor hygiene, is creating opportunities for transmission of diseases. Solutions to problems of waste management are available. However, a general lack of awareness of the impact of unattended waste on people's health and lives, and the widespread perception that the solutions are not affordable have made communities and local authorities apathetic towards the problems. The aim of this Book is to bring together experiences reported from different geographical regions and local contexts. It consolidates the experiences of the experts from different geographical locations viz., Japan, Portugal, Columbia, Greece, India, Brazil, Chile, Australia and others.