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Theory of Sampling (TOS) applied to characterisation of Municipal Solid Waste (MSW)—a case study from France[a]

Philippe Wavrer
CASPEO, 3, avenue Claude Guillemin, 45060 Orléans Cedex, France. E-mail: p.wavrer@caspeo.net

Knowing the composition of household waste is a prerequisite for effective implementation of municipal solid waste (MSW) management facilities. To meet increasing regulations, facilities in terms of collection, sorting and treatment are becoming more sophisticated and expensive: performance reliability partly depends on a valid, representative knowledge of waste composition. In France, the current method of characterisation of household waste is MODECOM™, a guide to organise and manage analysis campaigns with the primary objective of evaluating the recyclable or the packaging material content of waste, or to determine the variations and characteristics related to the nature of housing, for example. Implementation of this methodology leads to primary MSW samples, which are successively screened and sorted into a set of standard categories. Although it is possible to determine the composition of household waste in this fashion, at the end of these operations looms the question of its accuracy. Even if the mass of fully sorted MSW samples (usually around 500 kg) may seem high, this is actually extremely small compared to the total lot from which it was sampled (several hundreds of tons, sometimes much more). The Theory of Sampling of particulate materials (TOS), as initially developed by Pierre Gy in the context of the mineral industry, is quite applicable also to household waste. In particular, it allows an estimate of the Fundamental Sampling Error (FSE) to be calculated for each of the sorted categories. From real-world examples of French MSW characterisations, this contribution shows which data are needed and how the FSE formulas are implemented, illustrating how it is possible to ascribe individual total error estimates for each category. This general overview will help local implementation efforts.

Introduction

Knowing the composition of Municipal Solid Waste (MSW) is a key element of waste management policy for local authorities. This knowledge is essential to anticipate change and to set up the treatment necessary (procedures, equipment) for optimised extraction of the valuable parts of the waste.

However, the composition of household waste may vary in **space**, e.g. from one administrative district to another, and may depend on the geographical region, the type of habitat etc. And it may also vary in **time** according to the season or the evolution of consumption practices.

Characterisation of waste necessarily requires a sampling phase prior to analysis. After this step, decisions that often will have significant consequences will be taken in terms of risk assessment, protective measures, fees, selection and magnitude of treatment processes. Depending on the specific nature of the waste and on the diligence of its characterisation, the risk of providing an incorrect advice may be greater or smaller, especially as analysis is usually only performed on sub-samples of severely reduced size. The evergreen question for practically all commodities and materials, waste no exception, is then: are the samples analysed *representative* of the whole waste lot targeted? And how can this important question be answered? The Theory of Sampling to the fore…

Characterisation of municipal solid waste

European countries have developed several municipal solid waste (MSW) characterisation methods.[1] For example:

- ARGUS (in Germany),
- IBGE (in Belgium),
- EPA (in Ireland),
- MODECOM[b] (in France).

Although each of these addresses its own specific national requirements, they all conform to a common approach: after a first sampling step, the different types of waste contained in the sample are sorted into fractions and categories.

The French approach

In the early 1990s, there was a notable lack of knowledge about the composition of household waste at the national level and a lack of a reference method for comparing data between municipalities or regions managed by different local authorities. In order to address these shortcomings, a programme for characterisation of household waste at the national level was carried out in 1993 by ADEME, the French Environment and Energy Management Agency. Since no method nor reference data about waste existed at that time, it was necessary first to develop a methodology based on feedback from French and foreign sources. This became the MODECOM, acronym for "MéthOde DE Caractérisation des Ordures Ménagères" or Method for Characterisation of Domestic Waste.[2] It has been transcribed as standards by AFNOR, the French Association for Standardization.[3,4]

Representing the real starting point for estimating the composition of household waste at the national level, the MODECOM methodology made it possible to better understand household residual waste streams on French territory.

This methodological tool is still used today, although in a substantially modified version. It was implemented in 1993 during the first national campaign for characterisation of domestic waste, in order to achieve an inventory of the "average composition of the waste bin of a French inhabitant". Fifteen years later, in 2007–2008, a second national characterisation campaign was carried out, still based on

[a]This paper unfortunately did not make it to be presented at WCSB8 due to cancellations. *TOS Forum* is delighted to be of service.

[b]MODECOM is a registered trademark of ADEME.

MODECOM, to estimate "variations of the composition of typical household wastes" and to adapt the waste management systems accordingly. A third national campaign is currently underway; the results are expected in 2019.

Implementation and results of the MODECOM methodology

As it was designed, the MODECOM methodology consists of five major operations, or phases.

1) Preliminary inquiry, designed to collect all data required to *organise* the analytical survey. It may be of interest to subdivide, to stratify, a given area into different sectors, for example according to geographic zones, population districts, type of habitat, economic activity zones amongst others.
2) As MODECOM is based on characterisation of MSW from collection vehicles, the second step consists in selection of which collection vehicles to be sampled (primary sampling). For each stratum defined in the first step, collection vehicles are randomly selected (stratified random selection of collection vehicles assuming equi-probability within strata) based on random numbers, e.g. relating to the order of arrival of the vehicles to the treatment plant. Each vehicle should not contain less than 2 tons of waste. As vehicles are randomly selected within each stratum, every ton of collected waste has the same probability of being drawn; this assured compliance with TOS' Fundamental Sampling Principle.
3) Formation of approximately 500 kg *composite samples* by random selection of 10 increments (of approximately 50 kg each) from the contents of each selected collection vehicle. Increment selection is also here based on random numbers, this time relating to the spatial ordering of potential increments of 50 kg collectively making up entire load contents of the selected vehicle.
4) Concerning sorting, several possibilities are offered according to the specific objectives of the intended characterisation. The one that is taken into account here is the standardised dry sorting method[5] (Figure 1).
   4.1) Opening of all household, and other types of *garbage bags*, in the 500 kg samples (Figure 2), following which all *heteroclite objects* are removed; these will be sorted separately from the remainder of the sample. A heteroclite object is defined as a "single fragment that contributes significantly to heterogeneity by its mass, its volume or its exceptional nature".
   4.2) Quartering of the rest of the sample (Figure 3).

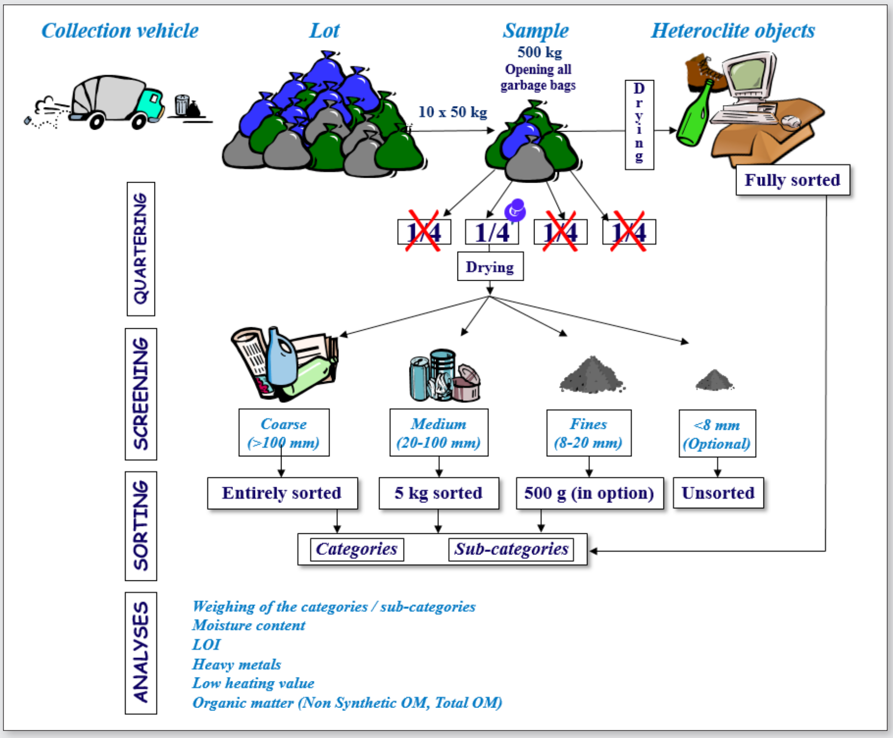

Figure 1. MODECOM sampling and sorting operations.

Figure 2. The lot of MSW before any sampling and characterisation operations.

4.3) Drying of both the extracted heteroclite fraction and the remaining subsample after quartering at 70 °C for 5 days.
4.4) Screening using sieves (or *trommel*) with 100 mm, 20 mm and 8 mm apertures.
4.5) Sorting of coarse elements (>100 mm) and partial sorting of medium-size elements (20–100 mm). Optionally, 8–20 mm fine elements may be also partially sorted.
The contents of the screened and dried samples are hereafter sorted into at least the 12 basic categories of MODECOM (Table 1 and Figure 4). Depending on the objectives of the characterisation survey, some categories may be further sorted into sub-categories amongst others.

5) Laboratory analyses in order to determine standard parameters, e.g. moisture content, lost on ignition (LOI), heavy metals content,[6] low heating value, organic matter content (in particular non-synthetic organic matter content).

The objective of MODECOM was originally to determine the characteristics of MSW produced at the level of an administrative area managed by *local authorities*. Nevertheless, it is also used to determine the composition of MSW at the lower level corresponding to a single waste treatment plant to establish material balances, for example. In this case, only steps 3–5 are involved, i.e. formation of composite sample, sorting and the laboratory analyses. Each of these steps is carried out following the dedicated standard.[7,4,5]

Characterisation results can be presented in several ways, depending on which categories, sub-categories and particle sizes are considered. Classically, the composition of MSW is presented using only the 12 basic categories (Figure 5).

From a rigorous point of view, this compositional assessment is strictly only valid for the single 500-kg composite sample which has been sorted. However, the results from this will be *extrapolated* to the whole waste lot from which this primary sample was taken. This is a critical issue regarding MODECOM—is this canonical sample size adequate for all purposes?

Application of the Theory of Sampling (TOS) to MSW

MSW is a solid material with a very obvious *heterogeneous* composition. However

Table 1. Nomenclature of standard categories and sub-categories in MODECOM.[c]

Categories	Sub-categories
Putrescible waste	Food waste
	Unconsumed food products
	Garden waste
	Other putrescible waste
Papers	Packaging
	Newspapers, magazines, brochures
	Printed advertising matter
	Office papers
	Other papers
Cardboards	Flat packaging cardboard
	Corrugated packaging cardboard
	Other cardboard
Composites	Cardboard composites packaging
	Small appliances
	Other composites packaging
Textiles	Textiles
Health care textiles	Health care textiles, hygienic fraction
	Health care textiles, soiled papers fraction
Plastics	Polyolefine films (PE / PP)
	PET jars and bottles
	Polyolefin jars and bottles
	Other plastics packaging
	Other plastics
Unclassified combustibles	Wood packaging
	Other combustibles
Glass	Colourless glass packaging
	Colour glass packaging
	Other glass
Metals	Ferrous metal packaging
	Aluminium packaging
	Other ferrous metal waste
	Other metal waste
Unclassified incombustibles	Unclassified incombustibles packaging
	Other unclassified incombustibles
Dangerous waste	Chemical products
	Fluorescent tubes and energy saving lamps
	Batteries and accumulators
	Other dangerous waste
Fine elements (–20 mm)	Fine elements with a size ranging from 8 mm to 20 mm
	Fine elements smaller than 8 mm (round mesh)

[c]This nomenclature is the one used for the 2007 national campaign. The list and definition of the sub-categories have later been substantially modified for the current national characterisation campaign to take into account the evolution of the MSW and the changing objectives of the campaign.

extreme this maybe, it is fully possible to apply Pierre Gy's Theory of Sampling, TOS,[8] without any problem. For the moment disregarding the effects that reflect geographical or seasonal variations (which are fairly easy to compensate for by focused application of MODECOM), the following calculations focus on the *constitution heterogeneity* of MSW (Compositional Heterogeneity, CH) which is always high. The constitution heterogeneity (CH) is a result of the varying proportions and physico–chemical properties of the constituent *elements* (units) of the MSW, which generates the Fundamental Sampling Error (FSE). TOS allows to estimate the Fundamental Sampling Error (FSE) variance starting from the heterogeneity model (the compositional MSW characterisation expressed as the standard 12 categories), with respect to the different analytical parameter to be measured.

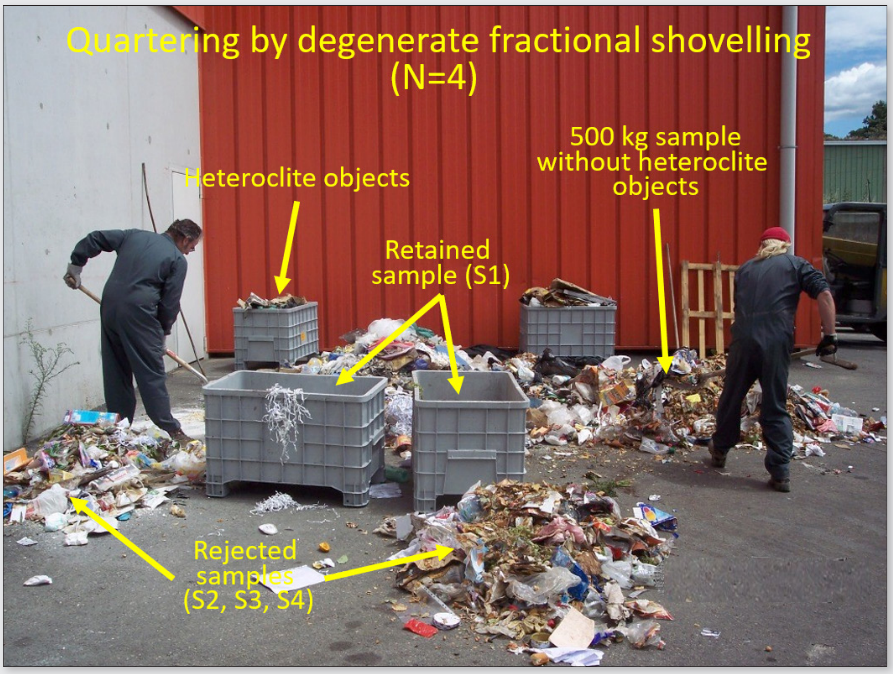

Figure 3. Quartering of the primary sample after removing of the heteroclite objects (step 4.2).

Fundamental Sampling Error (FSE) of the proportions of MSW categories

When sampling MSW, the randomly selected units are *particles* of a very disparate nature. But these particles can be *classified* into families of *similar* particles, mainly regarding their size and composition. This is what is facilitated at the different MODECOM sorting stages: particles are sorted into sizes, categories and sub-categories. For example, particles of paper are considered to be paper with a content of 100% (and 0% of any other constituent)—and similarly for all other categories/sub-categories and constituents.

It is now *assumed* that, after sorting, the sizes, masses and compositions of the

Figure 4. Example of coarse elements (>100 mm) after sorting.

sampled particles display sufficiently narrow ranges so as meaningfully to constitute quasi-homogeneous *families* (a standard assumption in TOS). The measured parameter is the *family proportion* itself. This parameter is not distributed in all the material, but confined to one and the same family. In this case, the particles are called *simple particles.*

The relative variance $\sigma^2(FSE)$ of the Fundamental Sampling Error for the constituent composition of the lot is given by Pierre Gy's formula for simple particles (consisting either of 100 % or 0 % of the constituent in question) (Equation 1).

$$\sigma^2(\mathrm{FSE}) = \left(\frac{1}{M_s} - \frac{1}{M}\right)\left[\left(m_c \frac{1-2t_c}{t_c}\right) + \sum_{i=1}^{n} t_i m_i\right] \tag{1}$$

With:

- σ^2(FSE) the relative variance of the Fundamental Sampling Error for the proportion of the family *c*
- M_s the sample mass
- M the mass of the initial batch (lot) to be sampled
- t_c *the mass proportion of family* c *in the sample*. This is the parameter that we attempt to determine through appropriate sampling
- t_i the mass proportion of family *i* in the sample
- m_c the mean unit mass of one particle of family *c*
- m_i the mean unit mass of one particle of family *i*

Experience shows that this sample mass, 500 kg, recommended by the MODECOM procedure, has been observed using this formula as being able to reach a *sufficient level* of representativeness for *most families* with a *reasonable* and *manageable* sample size, see references.

Determination of mean (average) unit masses

The mean (average) unit mass is a key factor which can be difficult to determine.[9,10] In the case of MSW, estimation of the unit masses by calculation, using size, density and shape factor of particles, is inappropriate and can be very inaccurate because of the extreme heterogeneity in MSW. The mean unit mass of each category/sub-category can alternatively be obtained by weighing the entire sorted family and dividing the resulting weight by the number of constituent particles. It is important to weigh a sufficiently large number of particles randomly, selected from *each* sorted family: 200 items is considered to a minimum.

Even if this operation **can** be performed for each waste characterisation, it is very time consuming. Some surveys for the determination of the average unit masses per category/sub-category were carried out at the national level.[11] More local and time-limited determinations have also been carried out in the frame of medium or large scale MSW characterisations. Databases gathering the average unit weights of the different household waste categories / sub-categories could therefore be aggregated and could be used for the determination of the fundamental sampling error following the above approach.

Example: a case study from France

To illustrate the approach, we consider here MSW treated in a biological treatment plant

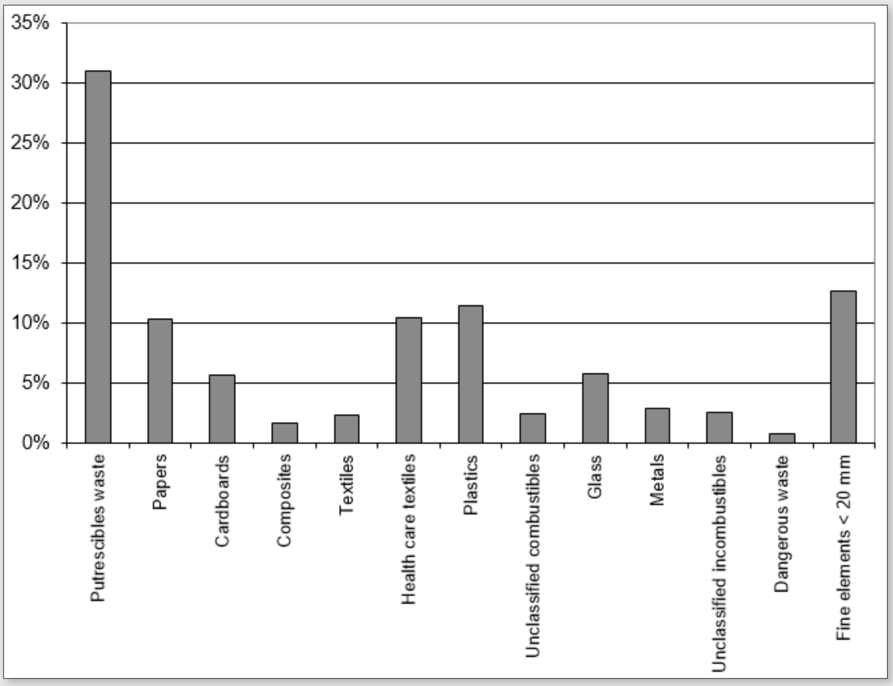

Figure 5. Example of a global MSW composition accounting after MODECOM sorting.

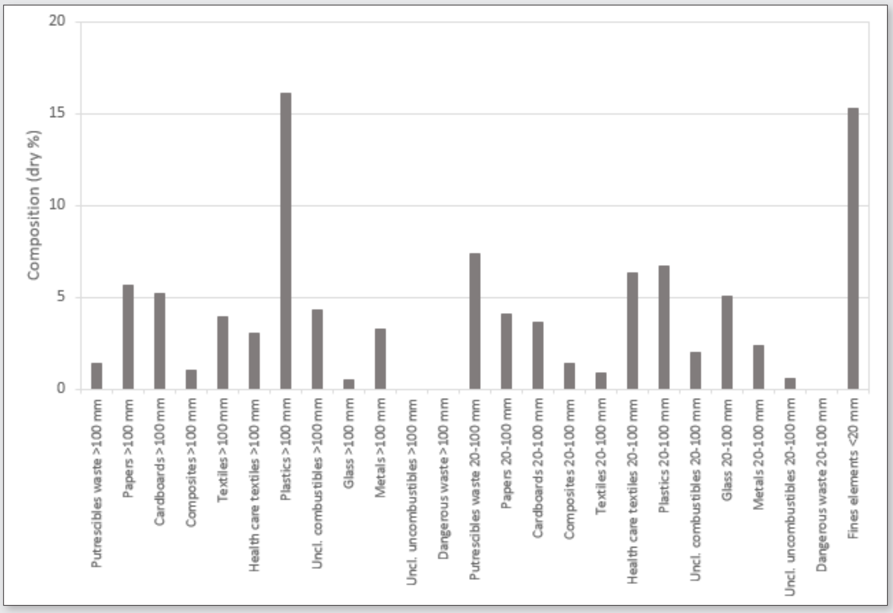

Figure 6. Composition of MSW from the French case study.

Heteroclites.sam

Title Heteroclites

Date 6th July 2017

Comment

Number of families 37

	Family name	Unit mass	Sample mass	Mass proportion	Relative error	S Heteroclites	T Rest
2		g	kg	%	%	%	%
3	Papers heteroclites > 100 mm	120	0.595	0.207	89.7	100	0
4	Cardboards heteroclites > 100 mm	800	7.875	2.74	62.1	100	0
5	Composites heteroclites > 100 mm	250	0.594	0.207	130	100	0
6	Textiles heteroclites > 100 mm	900	8.48	2.95	63.4	100	0
7	Plastic films heteroclites > 100 mm	200	13.37	4.65	23.7	100	0
8	Other plastics heteroclites > 100 mm	300	3.088	1.07	61.8	100	0
9	Uncl. combustibles heteroclites > 100 mm	1200	10.89	3.79	64	100	0
10	Glass heteroclites > 100 mm	250	1.485	0.517	81.7	100	0
11	Metals heteroclites > 100 mm	250	2.09	0.727	68.8	100	0
12	Textiles heteroclites 20-100 mm	200	1.2	0.418	81.4	100	0
13	Glass heteroclites 20-100 mm	100	3.564	1.24	33.4	100	0
14	Metals heteroclites 20-100 mm	150	0.143	0.0498	205	100	0
15	Putrescibles waste >100 mm	80	4.053	1.41	28	0	100
16	Papers >100 mm	45	15.597	5.43	11	0	100
17	Carboards >100 mm	37	7.087	2.47	14.7	0	100
18	Composites >100 mm	26	2.383	0.829	21.2	0	100
19	Textiles >100 mm	70	2.752	0.958	31.9	0	100
20	Health care textiles >100 mm	55	8.681	3.02	16	0	100
21	Plastics >100 mm	42	29.785	10.4	7.95	0	100
22	Unclassified combustibles >100 mm	110	1.446	0.503	55.1	0	100
23	Glass >100 mm	220	0.023	0.008	619	0	100
24	Metals >100 mm	77	7.315	2.55	20.4	0	100
25	Unclassified incombustibles >100 mm	293	0	0	0	0	100
26	Dangerous waste >100 mm	60	0	0	0	0	100
27	Putrescibles waste 20-100 mm	16	21.207	7.38	6.65	0	100
28	Papers 20-100 mm	13	11.69	4.07	7.71	0	100
29	Cardboard 20-100 mm	7	10.426	3.63	6.59	0	100
30	Composites 20-100 mm	7	3.993	1.39	9.31	0	100
31	Textiles 20-100 mm	8	1.309	0.456	16.1	0	100
32	Health care textiles 20-100 mm	9	18.19	6.33	5.98	0	100
33	Plastics 20-100 mm	25	19.166	6.67	7.98	0	100
34	Unclassified combustibles 20-100 mm	23	5.768	2.01	13.1	0	100
35	Glass 20-100 mm	32	11.025	3.84	11.2	0	100
36	Metals 20-100 mm	21	6.632	2.31	11.8	0	100
37	Unclassified incombustibles 20-100 mm	29	1.67	0.581	26.6	0	100
38	Dangerous waste 20-100 mm	42	0	0	0	0	100
39	Fine elements <20 mm	0.14	43.801	15.2	4.31	0	100
40	Total		287.37	100		18.573	81.427
41	Relative error (%)					17.4	3.98
42	Absolute error					3.2376	3.2376
44	Batch mass						
45	infinity						
46	g						

Figure 7. Relative Fundamental Sampling Errors at 95 % confidence per category of heteroclite objects for the 287 kg of sorted dry MSW sample.

in a city in North-West France. The selection of collection vehicles and composite sampling of the MSW from each has been implemented according to the MODECOM methodology described above. As a result, a sample of 512 kg was aggregated. The sorting was performed following the dry method (Figure 1) considering the 12 basic categories (Table 1) for both coarse fraction (>100 mm) and medium-sized fraction (20–100 mm). Fine elements <20 mm have not been sorted but are still considered as a category. After drying, the mass of the sample was 287 kg. The dry composition of the MSW, after sorting, is shown in Figure 6.

The calculation of the Fundamental Sampling Error for each category considering every sampling step of the methodology was conducted using Equation 1 and ECHANT, a software based on TOS dedicated to the calculation of FSE.[12]

Figure 7 shows the results in terms of relative errors at 95 % confidence level, as well as the unit masses used for the FSE calculations for each heteroclite objects category (in red). The relative FSE associated with the proportion of the heteroclite objects and of the rest (representing about 81.4 %) is also calculated (in green). According to the dry method, the part of the sample, without heteroclite objects fraction, was quartered before screening and sorting.

Figure 8 shows the results for each >100 mm fraction category (in red) and the <20 mm fine element category (in blue). The mass of the batch taken into account here for the calculation (designated as secondary batch) is no longer equal to infinity, but is equal to about 234 kg, the mass of the initial sample *without* heteroclite objects. The mass of sorted sample (58.5 kg) corresponds to the mass obtained after quartering of the secondary batch. For each category, the resulting FSE is not the total FSE, but only these one generated by the quartering step.

Here again, the FSE generated by the sample screening is also calculated for both fractions >100 mm and 20–100 mm (in green).

Figure 9 shows the results for each 20–100 mm fraction category (in red). The mass of the batch taken into account for the calculation (designed as the final batch) is equal to about 28 kg, corresponding to the total mass of the 20–100 mm fraction after the previous step. The mass of sample sorted (5 kg) corresponds to the mass recommended by the MODECOM protocol for this fraction.

This step is the last one in the dry sorting approach when the <20 mm fraction is not sorted into categories. For each 20–100 mm category, the resulting FSE is not the total FSE, but only the one generated by the final step.

From the above results, it is now possible to calculate the *total* Fundamental Sampling Error for each of the categories by considering the variance of the FSE generated at each sampling (or quartering) step following appropriate error propagation rules.[9] The resulting FSE for the considered sample is detailed in Table 2 and error bars associated with the proportions in Figure 10.

According to these results, it can be seen that the Fundamental Sampling Error is not the same across all categories, in fact it varies significantly. For example, based on the considered raw sample of 512 kg, corresponding to a dry mass of 287 kg, "Glass >100 mm" represents 0.5 % associated with a relative FSE equal to 1073 %. In this case, the mass of the category "Glass >100 mm" is only 23 g in the sorted sample, while the mean unit mass taken into account for this category is 220 g; this is typically the case of a *nugget effect* and, strictly speaking, Pierre Gy's FSE formula cannot, and should not, be applied in such cases.

On the other hand, "Putrescible waste 20–100 mm" represents 7.4 % associated with a relative FSE equal to only 22 %.

In other words, this case highlights that a sample mass of 500 kg is, in general, not

Fraction sup 100 mm quartée et inf 20.sam

Title: Quartered >100 mm fraction   Number of families: 37

Date: 6th July 2017   Comment

	Family name	Unit mass	Sample mass	Mass proportion	Relative error	Absolute error	S >100 mm fraction	T 20-100 mm fraction	U <20 mm fraction
2		g	kg	%	%	%	%	%	%
3	Papers heteroclites > 100 mm	120	0	0	0	0	0	0	0
4	Cardboards heteroclites > 100 mm	800	0	0	0	0	0	0	0
5	Composites heteroclites > 100 mm	250	0	0	0	0	0	0	0
6	Textiles heteroclites > 100 mm	900	0	0	0	0	0	0	0
7	Plastic films heteroclites > 100 mm	200	0	0	0	0	0	0	0
8	Other plastics heteroclites > 100 mm	300	0	0	0	0	0	0	0
9	Uncl. combustibles heteroclites > 100 mm	1200	0	0	0	0	0	0	0
10	Glass heteroclites > 100 mm	250	0	0	0	0	0	0	0
11	Metals heteroclites > 100 mm	250	0	0	0	0	0	0	0
12	Textiles heteroclites 20-100 mm	200	0	0	0	0	0	0	0
13	Glass heteroclites 20-100 mm	100	0	0	0	0	0	0	0
14	Metals heteroclites 20-100 mm	150	0	0	0	0	0	0	0
15	Putrescibles waste >100 mm	80	1.0133	1.73	48	0.83	100	0	0
16	Papers >100 mm	45	3.8993	6.67	17.7	1.2	100	0	0
17	Carboards >100 mm	37	1.7718	3.03	24.5	0.74	100	0	0
18	Composites >100 mm	26	0.59575	1.02	36	0.37	100	0	0
19	Textiles >100 mm	70	0.688	1.18	54.7	0.64	100	0	0
20	Health care textiles >100 mm	55	2.1703	3.71	26.8	0.99	100	0	0
21	Plastics >100 mm	42	7.4463	12.7	11.8	1.5	100	0	0
22	Unclassified combustibles >100 mm	110	0.3615	0.618	95	0.59	100	0	0
23	Glass >100 mm	220	0.00575	0.00983	1.07E+003	0.11	100	0	0
24	Metals >100 mm	77	1.8288	3.13	34.6	1.1	100	0	0
25	Unclassified incombustibles >100 mm	293	0	0	0	0	100	0	0
26	Dangerous waste >100 mm	60	0	0	0	0	100	0	0
27	Putrescibles waste 20-100 mm	16	5.3018	9.06	9.33	0.85	0	100	0
28	Papers 20-100 mm	13	2.9225	5	11.5	0.58	0	100	0
29	Cardboard 20-100 mm	7	2.6065	4.46	9.29	0.41	0	100	0
30	Composites 20-100 mm	7	0.99825	1.71	14.7	0.25	0	100	0
31	Textiles 20-100 mm	8	0.32725	0.559	27.2	0.15	0	100	0
32	Health care textiles 20-100 mm	9	4.5475	7.77	7.95	0.62	0	100	0
33	Plastics 20-100 mm	25	4.7915	8.19	12	0.98	0	100	0
34	Unclassified combustibles 20-100 mm	23	1.442	2.46	21.6	0.53	0	100	0
35	Glass 20-100 mm	32	2.7563	4.71	18.1	0.85	0	100	0
36	Metals 20-100 mm	21	1.658	2.83	19.3	0.55	0	100	0
37	Unclassified incombustibles 20-100 mm	29	0.4175	0.714	45.5	0.32	0	100	0
38	Dangerous waste 20-100 mm	42	0	0	0	0	0	100	0
39	Fine elements <20 mm	0.14	10.95	18.7	3.64	0.68	0	0	100
40	Total		58.5	100			33.813	47.469	18.718
41	Relative error (%)						6.15	3.73	3.64
42	Absolute error						2.0788	1.7714	0.68064
44	Batch mass								
45	234								
46	kg								

Figure 8. Relative fundamental sampling errors (FSE) at 95 % confidence per category of >100 mm fraction and <20 mm fine elements after the quartering step.

sufficient to have a good accuracy regarding the proportion of "Glass >100 mm". It is important to note that the mass of 500 kg recommended in MODECOM corresponds to a *compromise* between the time required for sorting, the associated cost and the accuracy of categories corresponding to the materials which are potentially *recyclable* when the methodology has been developed (this means mainly plastic-, metals- and cardboard-packaging, as well as papers).

Conclusions

The example presented shows that the Theory of Sampling can fully be applied to household waste. In France, the composition of MSW is determined using the MODECOM protocol from a stipulated 500 kg composite sample sorted into categories/sub-categories. Municipal solid waste is a highly heterogeneous material, so the composition resulting from sorting is associated with a total measurement error, for which the sampling error is the main component.

It is possible to calculate the Fundamental Sampling Error from data available in the literature. However, in the case of MSW, the mean unit mass for each category/sub-category is a critical parameter which can be difficult to determine experimentally, as this is time-consuming and often also expensive.

On a limited time-scale, the constituents of MSW are relatively stable. It is, therefore, possible to use unit masses coming from a database built up from large-scale

Fraction 20 100 mm.sam

Title: 20-100 mm fraction

Date: 6th July 2017

Comment

Number of families: 37

	Family name	Unit mass	Sample mass	Mass proportion	Relative error	Absolute error
2		g	kg	%	%	%
3	Papers heteroclites > 100 mm	120	0	0	0	0
4	Cardboards heteroclites > 100 mm	800	0	0	0	0
5	Composites heteroclites > 100 mm	250	0	0	0	0
6	Textiles heteroclites > 100 mm	900	0	0	0	0
7	Plastic films heteroclites > 100 mm	200	0	0	0	0
8	Other plastics heteroclites > 100 mm	300	0	0	0	0
9	Uncl. combustibles heteroclites > 100 mm	1200	0	0	0	0
10	Glass heteroclites > 100 mm	250	0	0	0	0
11	Metals heteroclites > 100 mm	250	0	0	0	0
12	Textiles heteroclites 20-100 mm	200	0	0	0	0
13	Glass heteroclites 20-100 mm	100	0	0	0	0
14	Metals heteroclites 20-100 mm	150	0	0	0	0
15	Putrescibles waste >100 mm	80	0	0	0	0
16	Papers >100 mm	45	0	0	0	0
17	Carboards >100 mm	37	0	0	0	0
18	Composites >100 mm	26	0	0	0	0
19	Textiles >100 mm	70	0	0	0	0
20	Health care textiles >100 mm	55	0	0	0	0
21	Plastics >100 mm	42	0	0	0	0
22	Unclassified combustibles >100 mm	110	0	0	0	0
23	Glass >100 mm	220	0	0	0	0
24	Metals >100 mm	77	0	0	0	0
25	Unclassified incombustibles >100 mm	293	0	0	0	0
26	Dangerous waste >100 mm	60	0	0	0	0
27	Putrescibles waste 20-100 mm	16	0.95462	19.1	21.3	4.1
28	Papers 20-100 mm	13	0.52622	10.5	27.5	2.9
29	Cardboard 20-100 mm	7	0.46932	9.39	22.6	2.1
30	Composites 20-100 mm	7	0.17974	3.59	36.1	1.3
31	Textiles 20-100 mm	8	0.058924	1.18	66.9	0.79
32	Health care textiles 20-100 mm	9	0.81881	16.4	18.9	3.1
33	Plastics 20-100 mm	25	0.86274	17.3	27.1	4.7
34	Unclassified combustibles 20-100 mm	23	0.25964	5.19	52.2	2.7
35	Glass 20-100 mm	32	0.49628	9.93	42.6	4.2
36	Metals 20-100 mm	21	0.29853	5.97	46.4	2.8
37	Unclassified incombustibles 20-100 mm	29	0.075174	1.5	111	1.7
38	Dangerous waste 20-100 mm	42	0	0	0	0
39	Fine elements <20 mm	0.14	0	0	0	0
40	Total		5	100		
41	Relative error (%)					
42	Absolute error					
44	Batch mass					
45	28					
46	kg					

Figure 9. Relative fundamental sampling errors at 95 % confidence per category of the 20–100 mm fraction for a 5 kg sorted sample.

determination campaigns (national campaigns for example). Nevertheless, to take into account the variations related to local consumption behaviours, or changes in manufacturing processes for example, this database has to be updated regularly.

Considering the partitioning into categories/sub-categories *per size*, it can safely be assumed that the variability of the unit mass may be high within some categories/sub-categories. Thus, determinations of FSE from mean unit masses may easily lead to over- or under-estimations. Furthermore, while FSE gives a reliable estimate of sampling error in the ideal case, in the case of MSW, FSE represents only a part of the total sampling error, mainly because of their high constitution and distributional heterogeneity (CH and DH). But FSE is certainly the largest component.

Thus, the calculation of the Fundamental Sampling Error (FSE) associated with the composition of MSW following the approach presented in this paper, in the author's opinion represents a significant step forward regarding awareness of the significant heterogeneity of this type of material. This article presented a systematic procedure to estimate the specific FSE across the spectrum of standard categories following MODECOM.

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Table 2. Total Fundamental Sampling Error budget (FSE).

Family name	Mass proportion (dry %)	Total FSE variance	Total relative FSE (%)	Total absolute FSE (dry %)
Putrescibles waste >100 mm	1.41	6.04E-02	48.2	0.68
Papers >100 mm	5.64	2.18E-01	91.5	5.16
Carboards >100 mm	5.21	1.16E-01	66.9	3.48
Composites >100 mm	1.04	4.74E-01	135.0	1.40
Textiles >100 mm	3.91	1.83E-01	83.8	3.28
Health care textiles >100 mm	3.02	1.91E-02	27.1	0.82
Plastics >100 mm	16.12	1.18E-01	67.3	10.86
Unclassified combustibles >100 mm	4.29	3.42E-01	114.6	4.92
Glass >100 mm	0.53	3.00E+01	1073.1	5.63
Metals >100 mm	3.28	1.55E-01	77.1	2.53
Unclassified incombustibles >100 mm	0	0	0	0
Dangerous waste >100 mm	0	0	0	0
Putrescibles waste 20-100 mm	7.38	1.26E-02	22.0	1.62
Papers 20-100 mm	4.07	2.05E-02	28.0	1.14
Cardboard 20-100 mm	3.63	1.41E-02	23.2	0.84
Composites 20-100 mm	1.39	3.47E-02	36.5	0.51
Textiles 20-100 mm	0.87	2.90E-01	105.5	0.92
Health care textiles 20-100 mm	6.33	1.01E-02	19.7	1.25
Plastics 20-100 mm	6.67	1.99E-02	27.6	1.84
Unclassified combustibles 20-100 mm	2.01	7.17E-02	52.5	1.05
Glass 20-100 mm	5.08	7.71E-02	54.4	2.76
Metals 20-100 mm	2.36	1.15E+00	210.3	4.96
Unclassified incombustibles 20-100 mm	0.58	3.22E-01	111.1	0.65
Dangerous waste 20-100 mm	0	0	0	0
Fine elements <20 mm	15.20	7.57E-04	5.4	0.82
	100			

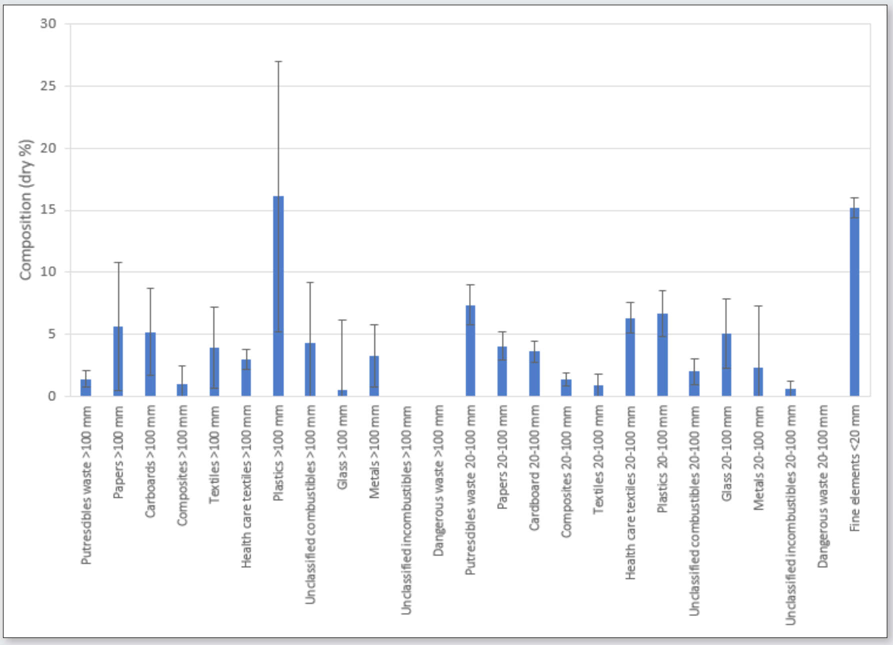

Figure 10. Total composition of the case study MSW and associated FSE (error bars).

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