On the contribution of risk management plans to municipal solid waste management: Evidence from a major Greek municipality

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Abstract. Municipal Solid Waste (MSW) management is becoming a highly important issue of considerable complexity, considering the plethora of processes, technologies and strategies available, and taking into account the number and diversity of the stakeholders involved. As complexity increases in times of uncertainty, risks increase in the development and operation of waste management systems, requiring consistent management. The aim of this paper is to briefly demonstrate the application and importance of a risk management perspective in the design, implementation and further development of a robust and resilient municipal solid waste policy. We concentrate on a major Greek municipality (Patras) and outline the use of a risk management method, as well as discussing its benefits when applied in the framework of the existing solid waste management system.

1. Introduction

The efficient management of municipal solid waste is an important societal objective, aiming to protect public health and the natural environment by reducing pollution. In addition, it can contribute to the conservation of natural resources by developing an increasingly consistent ecological consciousness [1]. However, the intense urbanization, combined with industrial development and a consumption culture, create many serious issues related to the optimal management of energy resources and environmental protection, which become demanding challenges that society as a whole has to face [2].

Municipal waste management needs to be transformed into sustainable materials management, which, in addition can contribute to the creation of new economic opportunities [3]. Based on the above, it can be argued that for every major municipality, MSW constitutes both a multi-level and complex (disposal) problem, but also a potentially valuable resource [4], whose management is exposed to many risks [5, 6].

Risks in municipal waste management systems have already been considered explicitly in both their design/configuration (e.g. [7, 8]) and operation (e.g. [9]) at different levels of analysis and detail. In this paper, by considering the case of the Municipality of Patras, in Southern Greece, and by adopting a holistic and operational perspective, we consider risks at the level of individual activities, within the framework of an integrated risk management system. The purpose of such risk management system is, on the one hand, to identify and define risks and develop strategies to reduce, or avoid, these
risks, and on the other, to maximize the exploitation of opportunities in waste. In this paper we will only deal with threat, or exposure to risk, management. Other aspects, such as public acceptance of waste management [10], are not considered here.

The paper is organized as follows: Section 2 provides a short quantitative and qualitative overview of MSW in Patras, while section 3 presents the existing management scheme. In section 4 we discuss the contribution of developing a risk management plan, before we conclude in section 5.

2. Quantities and types of MSW in Patras
The Municipality of Patras (MoP) is part of the Regional Unit of Achaia. It was defined by the Kallikrates Regional Authority Program, after merging the municipalities of Patras, Vrachneika, Messatida, Paralia and Rio. The area of the Municipality is 334.85 km² and the permanent population is 213,984 inhabitants according to the 2011 census.

In general, MSW can be classified in the following categories: food residues, wood waste, fabric and paper waste, plastic waste, and rubber waste [11]. In other words, it includes household waste, as well as other forms of waste, which by their nature or composition, are similar to household waste, such as waste from commercial activities, office buildings and public organizations (schools, hospitals and government buildings), as well as waste from council recycling or disposal facilities [12], while it may also include bulky waste (mattresses, furniture, etc.), garden waste (leaves, tree branches, vegetables), and waste from road cleaning.

As Figure 1 shows, in the Municipality of Patras, more than 105.000 tons of MSW were produced in 2014, according to the "Modification of the Regional Waste Management Plan" of the Region of Western Greece [13]. The qualitative composition of waste does not remain constant, but it changes both spatially and temporally. The temporal and spatial variation of the composition is mainly due to different consumption and dietary habits of the inhabitants of different regions, and the evolution in their preferred packaging and their overall daily activities.

A representative picture for the management of the municipal solid waste generated on a yearly base is given by the corresponding Local Waste Management Plan of the municipality [14], according to which, the total amount of waste generated in 2014 and ended up for final disposal (landfill) amounted to 100.308,33 tons. A significant percentage (94,46%), corresponding to 94.751tons, was directly disposed in the municipal landfill which has a carrying capacity of 100.000 tons/year, while it is located 5km east of the city. In addition, in the same year (2014), a total quantity of waste equal to

![Figure 1. Percentage composition of MSW in Patras (2014).](image)
16.234 tons was sent for processing in the Recycling Materials Sorting Centre (capacity 2.5 tn/h), which is located within the landfill site and occupies an area of 1.500 m² of active space. Of the total quantity sent for treatment, the recovered materials amounted to 9.145 tons, or 9.12% of the total load, while the percentage of the corresponding residue that was sent for final disposal in the landfill, amounted to 5.54%, or 5.557tons.

3. The MSW management scheme

With the exception of the separation at source of packaging waste (the stream of blue bins) and recently of printed paper and small paper packaging (the stream of metal bins with the yellow lid) as well as some other streams (e.g. electrical & electronic appliances, batteries, etc.), all municipal solid waste of the Municipality of Patras is sent for landfilling and some to the West Achaia Landfill (Floka). In operational terms, the existing municipal solid waste management system comprises of the following activities:

1. Temporary storage,
2. Collection and transport,
3. Sorting of recyclable materials at the Sorting and Recycling Facility (SRF),
4. Disposal at the landfill sites (Xerolaka and Floka)

On the other hand, the waste collection streams involved in the system include (see Figure 1):

- a mixed waste stream (green plastic bins).
- a mixed recycling stream for paper packaging, plastic packaging and aluminum (blue plastic bins), which is transported to SRF.
- a stream for printed paper and small paper packaging (metal bins with yellow lids).
- a glass stream (‘bell type’ blue bins)
- a stream for garden waste and bulky waste (pruning leftovers, furniture etc.).

The collection/transportation of mixed municipal waste, green and bulky waste is carried out by the Municipality of Patras, while the collection of recyclable materials takes place mainly under the responsibility of the Hellenic Recycling Utilization Company SA, a nationwide scheme and concerns five individual municipal units.
4. Developing a risk assessment plan

In view of creating an additional risk-prone collection stream for biological, waste in the era of the pandemic of Covid-19, the MoP decided to implement a waste risk management system comprising all the streams, beginning with the existing ones, as exemplary/demonstration case to assess the difficulties and benefits of such a system. The starting point for the development of a corresponding risk management system, in general, involves the assessment of the importance of each individual activity which has been depicted in the previous section: temporary storage; collection and transport; processing of recyclable materials at the SRF; final disposal at the two landfill sites (Xerolakas and Floka). More specifically, each activity plays a distinct role in the overall Waste Management System, and for the purpose of risk management, is characterized by a gravity coefficient, which demonstrates its importance for the successful operation of the applied management plan.

| No | Name                                           | Description                                                                                                                                                                                                                                                                                                                                 | Importance |
|----|-----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| C1 | Impact of the activity on Public Health       | The impact that the incomplete or incorrect functioning of activities: the temporary storage of waste or their collection and transport or disposal to the landfill can bring to public health.                                                                                                                                                                                      | 0.265      |
| C2 | Impact on the economic cost activity          | The economic impacts borne by the existing waste management system as a result of the problematic operation of waste collection and transport activity (multiple problems in the mechanical equipment) or reasons for serious functional problems of the Recycling Materials sorting center that their restoration                                                                                                                                       | 0.135      |

Figure 2. Municipality of Patras: existing MSW streams.
requires the disposal of significant financial resources.

C3  Impact of the activity on the environment
Impacts raised by the incomplete or incorrect operation of activities: the temporary storage of waste or collection and transport or processing of recycled materials to MSRC or their disposal in the landfill, on the environment. 0.265

C4  Impact on the municipal solid waste management system
Potential impacts that incomplete or incorrect functioning of activities: the temporary storage of waste or collection and transport or processing of recycling materials to MSRC or their disposal at the landfill can bring to the existing waste management system. 0.152

C5  Impact on local and regional waste management planning
Potential impacts that incomplete or incorrect functioning of activities: the temporary storage of waste or collection and transfer or processing of recycling materials to MSRC or their disposal in the landfill can bring to local and regional design 0.183

In order to organize the weighting coefficients into a hierarchy, the Analytical Hierarchy Process (AHP) method was used. AHP is a structured technique for organizing and analyzing complex decisions, where the corresponding factors are classified in a hierarchical structure [15]. More specifically, it is a method based on relative comparisons between the factors determining the execution of an activity. The individual comparisons are made according to the common basis of Saaty's fundamental scale [15]. AHP include three steps: 1) Labeling and organizing the objectives, criteria, constraints and alternatives in a hierarchy, 2) Assessing comparisons per pairs between relevant data at each level of the hierarchy, 3) Composition of the results using its resolution algorithm for the results of all pairwise comparisons, at all levels. Table 1 provides a synopsis of five criteria which can be used for the assessment of the four individual activities of the existing MSW management scheme, while Table 2 presents the overall assessment of the aforementioned activities for the case of MoP.

Table 2. Patras MSW management scheme: Assessment of individual activities

| Code | Activity                      | Criterion | Importance of criterion | Activity Rating² | Importance of Activity¹ | Significance (%) |
|------|-------------------------------|-----------|-------------------------|------------------|-------------------------|-----------------|
| A1   | Temporary storage             | C1        | 0.265                   | 5                |                         |                 |
|      |                               | C2        | 0.135                   | 2                |                         |                 |
|      |                               | C3        | 0.265                   | 5                | 4.26                    | 0.24            |
|      |                               | C4        | 0.152                   | 4                |                         |                 |
|      |                               | C5        | 0.183                   | 4                |                         |                 |
|      |                               | C1        | 0.265                   | 5                |                         |                 |
|      |                               | C2        | 0.135                   | 4                |                         |                 |
| A2   | Collection & Transportation   | C3        | 0.265                   | 5                | 4.86                    | 0.27            |
|      |                               | C4        | 0.152                   | 5                |                         |                 |
|      |                               | C5        | 0.183                   | 5                |                         |                 |
|      | Sorting of recyclable materials | C1        | 0.265                   | 5                |                         |                 |
|      |                               | C2        | 0.135                   | 3                |                         |                 |
A3  
C3  0.265  4  3.87  0.22  
C4  0.152  4  
C5  0.183  4  
C1  0.265  5  
C2  0.135  4  

A4  
Landfill disposal  
C3  0.265  5  4.71  0.27  
C4  0.152  4  
C5  0.183  5  

Each Activity is rated with respect to each individual criterion on a (1-5) scale.  

Sum of the individual products (Importance of criterion x Activity Rating) which gives the value of the Importance of the related activity.

In general, risk can be defined as the combination of the probability of an event occurring and the consequences of that event. In all activities, there is a possibility for the occurrence of events that will result in consequences that represent upside opportunities or downside threats to the successful outcome of that event. This means that risk management is essential for any activity, whether short or long term. Benefits and opportunities must be considered not only within the context of the activity itself, but also in relation to the different stakeholders that may be affected by the execution of the activity.

In a major project such as the MSW management system under consideration, uncertainty and risks are inherently present. The successful implementation of a risk management system requires careful and effective planning as well as a clear organizational structure. For the case of the waste management system of the MoP, the most important risks for each activity of the MSW management plan considered above, were defined as in Table 3.

More specifically, based on the combination of the probability of a risk occurring and a scale of potential impacts of the threat, a risk matrix was constructed [16]. Risks with values ranging from 0,01 to 0,04 were classified as 'low-risk risks', and accordingly, risks within the range of 0,05 to 0,15 were classified as 'medium risk', while risks between 0,16 to 0,74 were classified as 'high risk'. Following the above classification, the vast majority of the risks identified were classified as 'medium risk'. A risk classified as a "medium risk" is obviously not acceptable to the management team. Usually the opposite is true for risks classified as 'low-risk'. The risk that a threat carries is a dynamic characteristic, which over time exhibits variations that are directly dependent on the way it is managed. A risk classified as a medium risk, if not immediately addressed by those responsible through an appropriate risk management/mitigation program, it is possible to escalate over time into a high risk, resulting in unwanted consequences for the design and implementation of the solid waste management program under consideration, which will be exponentially greater than those originally estimated. On the contrary, identification of risks, combined with a number of necessary actions such as recording risks, maintaining a risk log and monitoring risks within a risk management system, can lead decision-makers to take appropriate decisions to optimally address risks.

Table 3. MSW management in Patras: Identification and assessment of the principal risks.

| No | Risk Description | Probability | Consistency | Risk |
|----|-----------------|-------------|-------------|------|
|    |                 | a           | b           | c = a*b |
| Activity 1: Temporary storage |
| A1.1 | Reduced acceptance of the project by the residents, due to lack of information, reduced awareness and/or lack of environmental consciousness. | 38% | 0.16 | 0.06 |
| A1.2 | Variation within population of municipality. | 29% | 0.14 | 0.04 |
Activity 2: Collection & Transportation

A2.1 Increase in the total cost of managing municipal solid waste 47% 0.26 0.12
A2.2 Seasonal peculiarities (e.g. the fact that in autumn and spring, there is an increase in the production of garden and green waste.) 79% 0.11 0.09

Activity 3: Sorting of recyclable materials

A3.1 Incorrect and/or incomplete recording of data leading to incorrect forecasts/estimates 48% 0.22 0.11
A3.2 Failure to identify potential sources of contamination, resulting in a failure to ensure that it recycle materials contamination-free. 24% 0.35 0.08
A3.3 Market failure (i.e. there is no demand for recycled glass). 28% 0.38 0.11

Activity 4: Landfill disposal

A4.1 Taking decisions which are not in agreement with, or deviate from, the original program. 15% 0.46 0.07
A4.2 Incorrect estimation of the dynamics of production of the quantity of MSW 20% 0.45 0.09
A4.3 The saturation of the landfill is accelerated due to the indiscriminate and uncontrolled final disposal of materials 35% 0.60 0.21

Clearly, such an exercise involves a great deal of subjective judgment provided by different stakeholders, especially when it takes place in the broader context of the design of an Integrated Municipal Waste Management System. The initial assessment of activity risks in AHP will be a participatory process, whose benefits should be also sought in the learning that takes place in debates and exchange of views. Systems tools and problem structuring methodologies, such as Viable System Design, System Dynamics and Soft System Methodology can be employed to facilitate the design of the risk management system and its embedment in the broader Municipal Waste Management System.

5. Conclusions
This paper claims that the adoption of risk assessment is an important tool in the hands of MSW policy makers. In this vein, and focusing on the case of a large municipality in Greece (Patras), we provided an outline of an activity-based risk management approach, in the context of a MSW management plan. Using the AHP method, we quantified the importance of five assessment criteria, which could be used for the assessment of the four activities of the example MSW management system of the Municipality of Patras. Following, a matrix of principal risks may be used to examine the stability and/or viability of a specific waste management system/plan. In general, in addition to providing the operational boundaries of the system, the very participatory development process of a complex municipal waste risk management system, constitutes itself a learning exercise with many long-term benefits concerning the complexities and uncertainties of the system.

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