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Assessing the financial and environmental performance of underground automated vacuum waste collection systems

D. Nakou *, A. Benardos, D. Kaliampakos

School of Mining and Metallurgical Engineering, National Technical University of Athens, 9 Iroon Polytechneiou str., 157 80, Zografou, Athens, Greece

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A B S T R A C T

The development of underground infrastructures for the efficient management and collection of urban waste streams offers great advantages and solutions in tackling problems relating to these activities. Nevertheless, in order for such alternatives to gain acceptance and be further utilized, besides their advantages in effectiveness and in environmental friendliness, they must prove their efficiency in terms of financial performance. The paper analyses modern techniques available as the underground automated vacuum waste collection system (AVAC) and presents the financial and environmental assessment of a proposed system in replacement of an existing conventional waste collection scheme in Athens. The comparative financial assessment is undertaken using the equivalent annual cost methodology (EAC) where the capital expenditures and annual operational and maintenance costs for both alternatives are calculated. The findings show that these two systems have roughly the same cost performance using the equivalent annual cost analysis. Yet, they have noticeably differentiations in the operational and capital costs with the AVAC system having almost 40% lower operational cost requirements. Finally the environmental comparison of the alternatives focusing on the city' air quality is further highlighting the superiority of the AVAC scheme. Thus, the selection of such a fixed underground infrastructure over a conventional one can be pursued as it offers equivalent financial performance and yet enhanced operational and environmental characteristics.

1. Introduction

The utilization of subsurface space is nowadays a key issue towards attaining an environmental friendly and sustainable development, especially in urban areas. Thus, activities or infrastructures that are difficult, impossible, environmentally undesirable or even less profitable to be installed above ground, can be relocated underground releasing valuable surface space for other uses and enhancing urban living conditions (Kaliampakos and Benardos, 2008). Underground space development has brought forth a whole new spectrum of possibilities for facilitating the needs of the modern urban societies (ITA, 2012). Parriaux et al. (2006) provides an extended study describing the potential principal resources of underground use (space, water, geothermal energy and geomaterials) that can be utilized for a sustainable future urban form. Bobylev (2009), noted that the sustainable development of urban areas becomes an issue of global importance, explaining that the approach of first-come-first-served – will not be beneficial for the sustainability of the plan but instead a three dimensional design, a definition of the priority of services and the functional correlation among the infrastructures should be considered very carefully. Sterling et al. (2012) further support that In order to maximize the efficiency of underground infrastructures a careful strategic planning is required which will consider life-cycle cost-benefits and the selection of projects that offer the highest contribution to urban sustainability rather than a short-term fix to an individual need.

In the above framework, underground infrastructures facilitating waste management activities can be classified amongst the top priorities for development, allowing for the efficient and cost-effective tackling of one of the most pressing needs of modern society. In response to that, underground projects for the proper management of wastes have been implemented throughout the world, especially focusing on extreme cases and dealing with waste of special character. They are mainly associated with interim or final storage of hazardous and radioactive waste, which represent a small but highly important fraction of the whole waste production.

Until recently, the management of municipal waste was relied on traditional collection and disposal activities, mainly associated with door-to-door collection, recycling and land-filling disposal. This system is highly flexible; however it has several drawbacks giving rise to important environmental impacts and nuisances. One of its weak spots is found in the collection process of the waste

* Corresponding author. Tel.: +30 2108001740, mobile: +30 6979213977; fax: +30 210 7722156.
E-mail address: diananakou@hotmail.com (D. Nakou).

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streams following a conventional door-to-door collection using a combination of trucks and waste bins. Hygiene issues, efficiency shortfalls in the waste collection, traffic disturbances and environmental burdens in urban areas relating to the increased noise and air-emissions are some of its major disadvantages.

The introduction of underground and semi-underground collection systems presents strong potential in the efficient collection/management of the waste in an environmental friendly manner (Jackson, 2004; Kogler, 2007). Nevertheless, the major benefits offered from the adoption of such systems can be overwhelmed by its increased capital cost requirements, especially for the case of stationery systems (automated vacuum collection systems – AVAC), inconveniences to inhabitants and businesses during the execution of construction works and possibility of blockages occurring in tubes and inlet points.

Kogler (2007) presented a cost comparison regarding the operational and investment costs between the two alternatives (conventional door-to-door and AVAC) for the development of the new housing project of Hammarby Sjöstad in the Stockholm region. Also, his research included a hygiene comparison among several waste collection methods and the traffic load. Waste Improvement Network (WIN) organization (2011) conducted a cost analysis for the case of the new Wembley city development project over a 30 year period. Teerioja et al. (2012) conducted a cost and environmental analysis between the two systems for a chosen area in Helsinki, Finland. The latter is one of the very few scientific researches focusing on the development of AVAC systems in already built space with dense population and established city functions. Thus, to further enrich the research on the applicability and performance of AVAC systems in existing residential and business areas this paper attempts the direct comparative analysis of the available alternatives. The area under investigation is part of a densely populated suburb of Athens, Greece, where on the same time a considerable business market exists and is a popular meeting point.

The paper presents the current municipal waste collection process (conventional vehicle-operated method) and furthermore it introduces the design of the automated waste collection system (AVAC) required in order to properly facilitate users needs. It analyses the characteristics the systems and focuses on the comparison of the two alternatives available emphasizing on both their financial and environmental characteristics. Thus, the assessment of the most promising scheme could be brought forward allowing stakeholders to decide whether they should pursue the transition of the waste collection system to the underground fixed infrastructure.

2. Urban/municipal waste

Waste management is one of the major issues of urban engineering. Today, the total amount of waste generated annually worldwide (municipal, industrial, hazardous) is more than 4 billion tons (Veolia, 2009). Almost 45% of these are considered as municipal solid waste, while the rest is industrial waste, including hazardous one. The EU-27 Member States plus Croatia, Norway and Turkey generated in total some 2.6 billion tons of waste in 2008, or roughly 5.4 tons per person (EEA, 2012). The annual generation of municipal waste, mainly from households but also including similar wastes from such sources as commerce, offices and public institutions in the EU-27 has reached 502 kg per capita in 2010. In the 2000–2010 period the waste generation per capita shows a stabilized trend in the majority of European countries, although there are cases where a small decrease (e.g. Ireland, Spain, UK, Estonia, etc.) or increase (e.g. Iceland, Portugal, Norway, Bosnia, Croatia, etc.) of quantities has been noted (Fig. 1).

In general, the production of municipal solid waste is affected from the level of a country's development. The daily waste production per capita ranges from 0.6 kg to 1.4 kg on average basis, with people in highly developed countries producing more waste (Cointreau, 2007). In the years to come a global rise in waste volumes is expected due to both the increase of global population and the growth or GDP per capita in developing countries. Only for the case of urban food waste it has been estimated that between 2005 and 2025 its production is expected to increase by around 45% (Mavropoulos, 2010). This in turn could impose additional requirements and challenges to the waste management process as well as to increased hygienic and environmental considerations.

The main functional element of municipal waste management is the collection process and its choice is a critical parameter as this particular function comprises about 50–75% of the total waste management cost (Sonesson, 2000; Myllymaa et al., 2008; Umweltbundesamt, 2009). Hence, the management of urban waste and more particularly the waste collection process through an underground developed infrastructure can be considered as an important evolution, which could allow for a more environmental friendly and cost-effective operation of the whole system.

3. Underground waste collection systems

The underground waste collection systems can be separated in two main categories; the stand-alone collection points (underground, semi-underground collection bins) and the automated vacuum collection systems (AVAC or automated waste collection systems – AWCS) or pneumatic stationery collection system.

Regarding the first category, underground containers are placed in shaft-like excavations, having only their inlets in the surface environment. Thus, this particular system replaces above ground collection points offering increased storage capacity, compaction of waste and superior hygienic performance especially in summer time. Furthermore, using this scheme visual pollution issues are reduced, while on the same time, the waste collection points can be more easily integrated in the urban environment. Nevertheless, such underground systems are still relying on the typical collection process using specially adapted trucks.

In order to provide a more efficient and vertically integrated service, systems that encompass both the collection and the transport of the waste have been introduced specially focusing on municipal waste streams. Such systems consist of a fully enclosed vacuum pipe network (Fig. 2), where the collection cycle starts when the waste is disposed through inlets to special underground containers, which have a capacity up to 500 l.

These containers are emptied on a regular basis, either automatically or at specified intervals. When emptied, the refuse bags drop to the main pipe network and their automated transport is taking place by vacuum suction through an underground pipe infrastructure, towards a central station. In there, the waste are separated, compacted and stored according to their type (waste stream). The air is conveyed to a filtering circuit and purified before it is released back to the atmosphere. The waste are then carried away using conventional methods (trucks) for further treatment, recycling, incineration or landfilling.

The method could be defined as a pneumatic sewer system, in which the refuse is collected and transported automatically (Castelltort, 2009). This means that there is no need for the manual collection from the underground containers using trucks and workforce. Instead, trucks are only used from the central facility onward.

Major benefit from the usage of AVAC system is the minimized operating cost for the waste handling. Of course, greater initial investments are required (Teerioja et al., 2012) but the more