Computers & Operations Research 44 (2014) 22–32

Contents lists available at ScienceDirect

Computers & Operations Research

journal homepage: www.elsevier.com/locate/caor

Review

Operations research in solid waste management: A survey of strategic and tactical issues

G. Ghiani [a], D. Laganà [b], E. Manni [a], R. Musmanno [b], D. Vigo [c,*]

[a] Dipartimento di Ingegneria dell'Innovazione, Università del Salento, 73100 Lecce, Italy
[b] Dipartimento di Ingegneria Meccanica, Energetica e Gestionale, Università della Calabria, 87036 Rende (CS), Italy
[c] Dipartimento di Elettronica, Informatica e Sistemistica, Università di Bologna, 40136 Bologna, Italy

ARTICLE INFO

Available online 27 October 2013

Keywords:
Solid waste management
Optimization
Strategic decisions
Tactical decisions

ABSTRACT

Solid waste management (SWM) is an increasingly complex task, absorbing a huge amount of resources and having a major environmental impact. Computerized systems based on operations research techniques can help decision makers to achieve remarkable cost savings as well as to improve waste recovery. Nevertheless, the literature is quite scattered and disorganized. The objective of this paper is to present an updated survey of the most relevant operations research literature on SWM, mainly focusing on strategic and tactical issues. In addition to providing an extensive bibliographic coverage, we describe the relationships between the various problems, and outline future research.

Contents

1. Introduction

The large and increasing amount of solid waste generated each year in both industrialized and developing countries, along with the public concern for environmental preservation, is making solid waste management one of modern society's most relevant issues. The Municipal Solid Waste (MSW) is defined by the United States Environmental Protection Agency (U.S. EPA) to include waste from residential, multifamily, commercial, and institutional (e.g., schools, government offices) sources [1]. This definition excludes many materials that are frequently disposed with MSW in landfills, including combustion ash, water and wastewater treatment residuals, construction and demolition waste, and nonhazardous industrial process waste. Each year in the European Union about 3 billion tonnes of waste are generated, and some 90 million

* Corresponding author. Tel.: +39 0512093435.
E-mail addresses: gianpaolo.ghiani@unisalento.it (G. Ghiani), demetrio.lagana@unical.it (D. Laganà), emanuele.manni@unisalento.it (E. Manni), musmanno@unical.it (R. Musmanno), daniele.vigo@unibo.it (D. Vigo).

0305-0548/$ - see front matter
http://dx.doi.org/10.1016/j.cor.2013.10.006

tonnes of it are hazardous [2]. Moreover, the amount of waste generated is rapidly increasing, with values close to 20% over a period of 11 years (1995–2006) in North America and the EU [3]. The last U.S. EPA document on MSW generation in the U.S.A. reports a production of about 250 million tonnes of waste in 2009, and about 85 million tonnes of recycled and composted material, leading to approximately 34% of recycling rate [1].

In this context, an integrated Solid Waste Management (SWM) represents a real request and a big challenge at the same time. A recent description of modern and integrated waste management systems can be found in Tchobanoglous [4], whereas decision support models and their practical impact on the Integrated Urban Waste Management Framework are reviewed in the recent book of Vigo et al. [5]. Studying a SWM system from an operations research point of view implies modeling it through a multi-echelon supply chain in which the following processes take place: waste generation in regional districts; waste collection in transfer stations; waste separation performed at the sources or in separation plants; waste treatment through incinerators, waste-to-energy plants, reclamation plants, or composite plants; waste disposal by land filling or land spreading.

SWM involves a number of strategic, tactical and operational decisions, such as the selection of SW treatment technologies, the location of treatment sites and landfills, the future capacity expansion strategies of the sites, waste flow allocation to processing facilities and landfills, service territory partitioning into districts, collection days' selection for each district and for each waste type, fleet composition determination, and routing and scheduling of collection vehicles. Given that dealing with each of these aspects leads to solving several combinatorial optimization problems, computerized systems based on Operations Research (OR) techniques can help decision makers to achieve remarkable cost savings. Several successful applications of OR methods have been described in the last 40 years. Most of the models presented in the literature aim at guiding the decision maker toward the choice of the best strategy, selected among a set of options. Such methods evaluate all the suitable alternatives at every stage of the decision process. In some cases, the goal of the model is simple (e.g., optimize waste collection routes for vehicles), while in others it is more complex (e.g., evaluate alternative waste management strategies). However, because SWM involves also institutional, social, financial, economic, technical, and environmental factors, no model described in the literature is able to capture all different aspects to be considered. On the other hand, general models have so many variables and constraints that solving them through general-purpose solvers can be very hard and time consuming. In general, the literature is still scattered and disorganized. Given that a survey of all OR models in this area would require a very long article, the focus of this paper is to concentrate on some of the most important methodological contributions and the most meaningful applications originating from the application of OR techniques to strategic and tactical problems arising in SWM, as well as to indicate future research directions.

The remainder of the paper is organized as follows. Section 2 describes strategic planning issues (mostly arising at a regional level), whereas Section 3 is devoted to tactical decisions. Finally, Section 4 concludes the paper and outlines future research directions.

2. Strategic issues

For planning purposes, a SWM system can be decoupled into two major subsystems: a regional management system, and a collection system. Each town is in charge of its own curbside garbage collection, using either its own workforce from a municipal or regional agency, or a contracted service. On the other hand, the regional administration is responsible for the treatment and disposal of the collected waste. The primary reason for this is the existence of relevant economies of scale in waste transportation and disposal (see [6]). In the current literature, these two subsystems are usually considered as separate, although remarkable cost savings might result from an integrated approach. Given a set of potential processing facilities and landfills (each characterized by a location and a number of additional technological and economic features), the most relevant regional planning decision amounts to determining which facilities should be built or used, and how waste should be routed, processed and disposed so as to minimize the total waste disposal cost, net of any revenue for reclaimed material and generated energy. Building a new treatment or disposal facility may take 1–4 years, while the operating life of a facility is estimated to be around 15–30 years (similar considerations hold for landfills). After this period, certain replacements are required. Consequently, designing or re-designing a regional SWM system is a strategic decision having long-lasting effects. The main features to take into account are:

- *Time*: Decisions related to building a new facility or closing an existing one affect a long-term planning horizon.
- *Network structure*: A multi-echelon logistic network is needed to model all the strategic decisions.
- *Commodities*: The cost of transporting and disposing waste depends heavily on the type of waste (municipal refuse, industrial waste, farm refuse, demolition and construction debris, etc.). Moreover, each waste type can be processed in a limited number of ways (e.g., inert refuse cannot be composted).
- *Facility cumulative capacity*: Landfills have an overall cumulative capacity for waste disposal, which progressively reduces as long as refuse are stored (see, e.g., [7]).
- *Economies of scale*: The operating cost of a facility is a concave function of its activity level because of economies of scale that may be achieved.
- *Transshipment with waste transformation*: Once a waste type is processed in a facility, its own characteristics change (e.g., its volume reduces). This peculiar feature can be modeled through a network flow with gains (see, e.g., [8]).
- *Objectives*: Decision makers often pursue conflicting goals, such as to locate facilities as close as possible to sources (to minimize transportation costs), and to locate facilities as far as possible from urban centers. In addition, SWM often gives rise to *sociopolitical issues* that are difficult to model (see, e.g., [9,10]).

We now present a Mixed Integer Programming (MIP) model that is a generalization of models from the literature [11] and puts together all the previous aspects, and then categorize the literature with respect to it.

2.1. A MIP model for the strategic planning of a SWM system

The possible configurations of a SWM system to be designed at the strategic level can be represented by a directed graph $G=(V,A)$ in which the vertex set V may be partitioned into four subsets: V_O representing sources, V_S modeling potential transfer stations, V_P describing processing facilities (incinerators, waste-to-energy plants, etc.), and V_L representing landfills, disposal facilities and markets for recycled products and energy. Arcs in set A correspond to feasible shipments between sites (Fig. 1).

Decisions have to be made over a long-term horizon defined over a set T of periods. Each period $t \in T$ may represent, for instance, one year or several years. Moreover, in order to take into account the possibility to manage different types of waste, we