Maria **WALERY** • Izabela A. **TAŁAŁAJ** • Yaroslava B. **MOSIICHUK**

THE VALUE OF THE COST-EFFECTIVENESS INDEX IN TERMS OF CHANGING OF THE INCINERATORS CAPACITY

Maria **Walery,** PhD – *Bialystok University of Technology*
Izabela A. **Tałałaj,** PhD – *Bialystok University of Technology*
Yaroslava B. **Mosiichuk,** MA – *Institute of Water Problems and Land Reclamation NAAN, Ukraine*

Correspondence address:
Faculty of Civil and Environmental Engineering
Wiejska street 45E, 15-351 Bialystok, Poland
e-mail: m.walery@pb.edu.pl

ABSTRACT: The main subject of this paper is the optimization of a model of disposal and treatment of municipal waste, as well as computer software MRGO + (Model for Regional Waste Management), through which the model was implemented. It has been verified by the author and adapted to the needs of the proposed model to optimize the disposal and treatment of medical waste in the example of the Podlaskie Province.
This paper describes the optimization study aimed to analysis of the impact of reducing the capacity incinerators of medical waste on the value of the cost-effectiveness index (E). The study was conducted on the example of the analysis of medical waste management system in north-eastern Poland, in the Podlaskie Province.

KEY WORDS: medical waste management system, system functioning costs, cost-effectiveness index, capacity of incinerators, spatial structure of the system

 JEL: A12, C60, Q50, R40

Introduction

Medical waste generated in healthcare facilities is a significant epidemiological, toxicological and sanitary hazard. Medical waste management system requires a structured logistics system of collection, transportation and disposal of waste due to their potential infectious properties (Bazrafshan et al., 2010; Chaerul et al., 2008). Therefore, it seems necessary to carry out the analysis of medical waste management system as well as the optimization of unit processes and consideration of the mutual relations of all system components, processes and correlation. Many decision problems arising in medical waste management system can be represented by an appropriate decision-making model and consequently, solved through operational research (Chaerul et al., 2008; Eriksson et al., 2011; Gaska, 2007; Kollikkathara et al., 2010). The final decision does not necessarily coincide with the decision resulting from modellingwhich is only to help in the decision making process. According to analysts dealing with this subject the solution of the decision problem using operations research is a procedure consisting of the following steps (Apaydin et al., 2007; Biedugnis et al, 2003; Daellenbach, 2001; Dubrovsky, 2004; Seadon, 2010):

- identification of the decision situation and the resulting decision problem;
- construction of a decision-making model;
- decision-making model solution;
- assessment of the correctness and the feasibility of derived solutions and possible verification of the decision-making model;
- providing solutions to the decision maker and the final preparation of the decision.

The review of literature related to the optimization methods common in designing waste management systems indicates that the study conducted and developed by D. H. Marks and J. C. Liebman was of the fundamental significance. The study related to modelling of the waste management system and was verified on the example of the agglomeration Baltimore, Maryland, based on linear programming methods adopted in whole numbers in system optimization. Issues analysis of regional waste management systems also dealt with N. Morse and E. Roth. The optimization models were characterised by a great number of simplifications that may have a significant effect on the generated results and did not quite reflect the reality in which the systems operated. Subsequent optimization models by E. Berman, H. Jakir, J. Kuhner, and J.J. Harrington were updated with the aforementioned elements and dealt with both municipal solid waste and sewage sludge.

In Poland the works on the issues of modelling and optimization systems and waste exports were led by S. Biedugnis, J. Cholewinski Warsaw University of Technology (Biedugnis et al., 1992). This work gave rise to the establishment of rules and criteria for the application of a mathematical model of municipal solid waste and sludge disposal system.

This paper uses optimization model of the export and disposal of municipal waste as well as a computer program MRGO (Model of Regional Waste Management), which is its implementation. It has been verified by the author and adapted to the needs of the proposed model to optimize the removal and disposal of medical waste.

Medical waste due to the very diverse morphological composition and their potential infectious and toxic properties require a specific action depending on the degree of risk to humans and the environment. Medical waste management system is very different from municipal waste management system in the principles of collection of medical waste at source, storage, means and conditions of transport with regard to the provisions of the European Agreement ADR or processing systems and waste disposal. With this in mind The author has reviewed the structure of the mathematical model MRGO+ with a four-element system, and between themselves correlation to the system three-piece, in which the following system objects: source objects (hospitals), intermediate objects (medical waste incinerators) and final facilities located in the area of medical waste incinerator, i.e. the place for the temporary detention of post-process waste from waste incineration process. Such a solution in functioning of medical waste management enabled the achievement of the overall optimization of the system, relating to the effects and costs of servicing the region, not only in terms of local optimization, e.g. in a single *gmina* (PL administrative district). Therefore, it is extremely important to raise funds for the development of a cost-efficient and modern waste management system, in terms of technical and technological solutions as well as environmental protection requirements. Just one district is not capable of coping with these tasks in terms of financial challenges, especially because disposal of waste is the most serious, most difficult and most capital-intensive element of the system.

The structure of functioning of medical waste management system adopted by the authors, was further verified in terms of the system functional division of transport operational tasks. The infectious medical waste management system does not include waste dumping mode, which normally is capable of a 2-3-fold compaction of waste in lorries of large capacity, minimum several m3. As stated in the Act on Waste Management, infectious waste is not subject to segregation and composting due to its infectious properties, hence the medical waste management system is not composed of two-stage transportation and redistribution stations (waste processing and distribution to various sites of treatment). For this reason, the authors verified multistage transport to the advantage of a single-stage, direct system and in this perspective the elements of the system (stages of activity) are as follows (Eriksson, 2011; Gaska, 2007):

- source forming regions (collection) of medical waste,
- route export of waste from the source areas of collection to an indirect facility in which there are waste treatment processes, independent or combined into a pre-technological and secondary process line,
- route export of waste from the source areas of collection to an indirect facility in which there are waste treatment processes, independent or combined into a pre-technological and secondary process line,
- routes for post-processing waste disposal from the intermediate object to the end-object, where waste undergoes final treatment processes.

In addition, waste landfill storage – one of the methods of waste disposal commonly used in Poland is not applied in the infectious medical waste management system. Only post-process waste may be disposed of I n landfills, and only marked as hazardous type. Therefore, the authors introduced the concept of a "post-process thermal treatment waste temporary storage", i.e. adequately protected and separated area by the medical incineration plant, where post-treatment waste is temporarily stored for up to 3 years in accordance with Polish laws, and then exported to a hazardous waste landfill . Therefore, the costs of transport and storage of waste will be incurred once every three years, which was included in this stage of implementation of transport activities proposed by the author of the cost optimization model.

The aim of the study was to analyse the impact of the parameter describing the degree of reduction in the amount of medical waste in the combustion process (wwp) and the unit cost of transport of medical waste (K_{ij}) on the value of the cost-effectiveness index (E). Optimization studies were carried out on the example of the analysis of medical waste management system in north-eastern Poland in the Podlaskie Province.

With the assumed technical and economical parameters of the system the operating range of tests, performed as part of the optimization study was divided into two stages. In the first stage, the lowest cost of operation of the system was calculated, while the second stage resulted in describing the impact of input parameters of the system, i.e. the degree of reduction in the amount of medical waste in the incineration of waste and the unit cost of transport of waste on the cost-effectiveness index and spatial structure of the system (set of system facilities and related transportation network).

Methodology of operational research

Eighteen sources of waste generation and accumulation (hospitals) within the studied area of the Podlaskie Province were selected for the analysis after taking into account the above mentioned assumptions and environmental conditions. The study also included: four intermediate objects (medical waste incinerators), respectively: IF1 (Suwalki), IF2 (Lomza), IF3 (Bialystok) and IF4 (Hajnowka), where pyrolytic decomposition process of waste will take place, and four end objects (respectively FF1, FF2, FF3, FF4) – areas for temporary storage of post-process waste from the incineration process located in the area of waste incineration facility. The model did not include restrictions on the capacity of intermediate and end objects.

The scope of operational research carried out in the framework of the optimization study was divided into successive stages in order to present options of the proposed model:

Stage I – includes optimization calculations, assuming fixed technical and economic parameters. Sequence 1, made in this stage, was also a comparative course – a benchmark for other solutions and obtained results to compare.

Stage II – included a number of additional runs aimed at determining the impact of the model input parameters of the system on the indicator of expenses of the cost-effectiveness index (E) and the spatial structure of the system (system location of objects and their associated waste disposal routes).

The following input data were taken into account:

- economic parameters describing the system (waste transport unitary costs, inflation and discount rate),
- economic parameters describing the objects of the system (capital and operating costs),
- the size reduction of medical waste in the system of indirect objects expressed in the form of the output factor of the process – wwp [%],
- the planned time horizon [t], (duration of model process).

The data relating to the costs of transport, investments and operation of the system objects, necessary for optimisation calculations, derived from existing plants, located in the model region. The calculation was performed by the unit cost of the work presented in Biedugnis and Cholewinski (Biedugnis et al., 1992) taking into account the current prices and fees. The cost of medical waste removal from the source unit to the disposal site, with the adopted technical and operational conditions is K_{ij} = PLN 9.57, and when expressed in unit cost of 1 ton of transport per 1 minute (k) = PLN 1.33/t/min.

The economic efficiency calculations of the method were presented in the work by Biedugnis and Cholewinski (Biedugnis et al., 1992) whose dynamic model related to inflation and discounting of the annual capital and operating costs in each model period. Transport costs are also dicounted and adjusted for inflation.

Description and interpretation of the results of optimization studies

Calculations were carried out in the following runs:

Stage I – run 1 – the run like in the solution with the following parameters: duration of model period, respectively t1 = 5 and t2 = 15 years, the unitary cost of transportation of medical waste in the first and second model period, respectively, 1.33 and 0.44 PLN/t/min, the level of reduction of medical waste in the intermediate facilities expressed as a coefficient of the process output, wwp=10%.

Stage II – run 2 – the assumed duration of model the period I and II respectively t1 = 5 years and t2 = 15 years, the influence of bandwidth limitations of four incineration facilities to obtain the optimal solution, that means, to obtain the lowest cost-effectiveness index. Capacity constraints were introduced in Bialystok at level of 190 t/year in Lomza – 182 t/year, in Suwalki – 250 t/year and Hajnowka of 330 t/year.

As a result of optimization calculations for the course 1 (Stage 1) of the pre-established model system of the 26 facilities (18 – the source of the medical waste, 4 – incineration, 4 – storage of hazardous waste, 55 – possible routes for waste transport), the was a number of facilities selected in model periods I and II: 3/3 incinerators, 3/3 of the landfills and 21/21 waste transport routes, in consequence minimizing the cost of the system.

Process levels in intermediate and final facilities in each model period for Stage 1 are presented in table 1.

For the stage 2 (table 2) – the introduction of this type of incineration capacity constraints resulted in a significant changes in the spatial structure of the system along with the change of the amount of waste transported in model periods I and II in relation to the first run. Also the change in the quantity of waste transported along specified routes, what further resulted in a modification in the processing activity levels of individual intermediate and final objects during model periods I and II. As a result of calculations optimization solution was obtained, which was proposed incineration facility of medical waste in Hajnowka, the throughput computing in the first and second periods model was defined at the level of 293.100/330.000 t/year, with an overall bandwidth of 88.80/ 100%.

Table 1. The level of processing activities of intermediate and final objects for the 1st run [ton/year]

System facilities	Process	Processing activity level [t/year]	Duration of model studies I=5 years, II=15 years
IF1	incineration	140.400	I
IF1	incineration	148.800	II
IF2	incineration	210.400	I
IF2	incineration	222.400	II
IF3	incineration	434.400	I
IF3	incineration	450.900	II
FF1	storage	14.040	I
FF1	storage	14.880	II
FF2	storage	21.040	I
FF2	storage	22.240	II
FF3	storage	43.440	I
FF3	storage	45.090	II

Source: author's own work.

Table 2. The level of processing activities of intermediate and final objects for the 2nd run [ton/year] within the model area

System facilities	Process	Processing activity level [t/year]	Duration of model studies I=5 years, II=15 years
IF1	incineration	120,099	I
IF1	incineration	120,099	II
IF2	incineration	182,000	I
IF2	incineration	182,000	II
IF3	incineration	190,000	I
IF3	incineration	190,000	II
IF4	incineration	293,100	I
IF4	incineration	330,000	II
FF1	storage	12,010	I
FF1	storage	12,010	II
FF2	storage	18,200	I

System facilities	Process	Processing activity level [t/year]	Duration of model studies I=5 years, II=15 years
FF2	storage	18,200	II
FF3	storage	19,000	I
FF3	storage	19,000	II
FF4	storage	29,310	I
FF4	storage	33,000	II

Source: author's own work.

The introduction of these capacity limitations intermediate objects resulted in a significant increase in the cost of the system, and thus a significant increase in the cost-effectiveness index E of approx. 17% (from 1597.60 PLN/t to 1,864.90 PLN/t).

Conclusions

The medical waste management system is a dynamic system, characterized by its parameters changing with time. Taking into account the time factor in the suggested model allows analyzing the system as an investment enterprise, i.e. assuming its realization from the very beginning, a modernization enterprise or a retrofit enterprise including both retrofitting of existing facilities as well as realization of new system solutions thus providing a solution of the lowest total cost of the entire system.

The structure of the medical waste management system is determined mainly by the process output index – wwp. The increase of this index is correlated with the increase of the amount of post-process waste directed to a storage landfield. A further consequence is the increase in the system functioning cost, expressed by the cost-effectiveness index E. At assumed terrain limitations for final facilities, there is the need to achieve a lowest process output index, by way of selection of a proper technology of the thermal neutralization of medical waste, whilst taking into account technical and organizational aspects, and whilst maintaining environment protection standards.

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Literature

Apaydin O., Gonullu M.T. (2007), *Route optimization for solid waste collection: Trabzon (Turkey) case study,* "Global Nest Journal" Vol. 9, No 1, p. 6-11

Bazrafshan E., Mastafapoor F. K. (2010), *Survey of Medical Waste Characterization and Management in Iran: A Case Study of Sistan and Baluchestan Province*, "Waste Management & Research" No. 29(4), p. 442-450

Biedugnis S., Cholewiński J. (1992), *Optymalizacja gospodarki odpadami,* Warszawa, pp. 340

Biedugnis S., Podwójci P., Smolarkiewicz M. (2003), *Optymalizacja gospodarką odpadami komunalnymi w skali mikro i makroregionalnej,* Warszawa, pp. 96

Björklund A. (2000), *Environmental systems analysis of waste management – Experiences from applications of the ORWARE model*, Stockholm

Chaerul M., Tanaka M., Shekdar A.V. (2008), *A system dynamics approach for hospital waste management,* "Waste Management" Vol. 28, p. 442-449

Daellenbach H.G. (2001), *Systems Thinking and Decision Making: A Management Science Approach*, Christchurch

Dubrovsky V. (2004), *Toward system principles: general system theory and the alternative approach,* "Systems Research and Behavioral Science" No. 21(2), p. 109-122

Eriksson N.O., Bisaillon M. (2011), *Multiple system modeling of waste management,* "Waste Management" Vol. 31, p. 2620-2630

Gaska K. (2007), *Object-oriented modelling, analysis and testing methods of integrated waste management systems,* "Monograph" Vol. 35, AGH Krakow, p. 343-382

Kollikkathara N., Feng H., Yu D. (2010), *A system dynamic modeling approach for evaluating municipal solid waste generation, landfill capacity and related cost management issues,* "Waste Management" Vol. 30, p. 2194-2203

Seadon J.K. (2010), *Sustainable waste management systems*, "Journal of Cleaner Production" Vol. 18, p. 1639-1651