Journal of Environmental Management 220 (2018) 77–86

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Impact assessment of pollutants from waste-related operations as a feature of holistic logistic tool

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ARTICLE INFO

Keywords:
Impact of pollutants
Waste transportation
Local environment assessment
Network edge characterisation

ABSTRACT

Waste management has still been a developing and progressing field, which demands continual improvements in waste transportation as well as proper selection of locations and technical operation of new treatment facilities. Most of research papers on waste management planning have been dealing with optimisation of network flows, thus minimising the cost and improving economic criteria. The shortest paths to treatment facilities are considered together with detailed analysis of their operation including heat and electricity demands in their vicinity. The tasks sometimes include social and global environmental criterions, however, the direct local consequences also play an important role and should be examined. A decision-making strategy in waste management updated with the local emission impact on the population is proposed in this paper. The paper focuses on the first move in analysing the production, dispersion, and impact of pollutants, originating in transport, with regards to the population living close to routes. The calculation of emission produced during the transport of waste takes into consideration the altitude profiles of routes, container loads, and specific types of vehicles. The consecutive estimated impact on the population reckons with the distances between routes and municipalities as well as their sizes in terms of the numbers of inhabitants, where the transportation routes are divided into smaller segments and dispersion is limited with threshold value. The proposed approach describing the emission effect has been tested using real-life operating data corresponding to the specific, 81 km long route along which approximately 25 t of waste is transported 800 times a year. The impact of pollutants on the population was evaluated and discussed. Results of the analysis were quantified for this route to create an edge characterisation needed for further calculations. This approach applied to the whole network then yields input data needed for future research of novel strategies in facility location problems. Other possible extensions of the presented approach include more accurate dispersion function or detailed calculation of the impact of pollutants with respect to specific locations of residential houses.

1. Introduction

The impact of human activity on the environment becomes an increasingly important issue. The paper by Olsthoorn et al. (2001) reviews the existing literature on environmental performance indicators. One of the frequently discussed issues within environmental management is global warming (GW). Danny Harvey (1993) has proposed a guide to global warming potentials (GWP) which summarizes the comparison of different gases and their effects. As stated by Wirl (2012), the future decisions should be strategic regarding prices and quantities. One of the area with the important impact to GW is also waste management. In (Zhang and Huang, 2014), the facility expansion and waste flow allocation planning with consideration of greenhouse gases (GHG) emission trading are analysed. Irrespective of whether the CO_2 equivalent is adopted as criteria to measure the impact, see (Čuček et al., 2012) for GHG footprint analysis, all these indicators are considered globally.

On the other hand, many places around the world are facing the problem of increasing air pollution, especially in the densely populated areas such as large cities. This is primarily due to the centralisation of industry in urban areas and major traffic loads; see (Cai et al., 2018) for a comparison of carbon emissions from different sectors between urban and non-urban areas. These are local issues, which have a direct impact on the quality of lives (haze, frequent respiration problems) and, in the long-term, increased rate of civilisation diseases. Transportation plays an important role in the cities. The evaluation of different vehicle

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https://doi.org/10.1016/j.jenvman.2018.05.003
Received 28 January 2018; Received in revised form 3 April 2018; Accepted 1 May 2018
Available online 12 May 2018

system technologies is proposed in (MacLean and Lave, 2003).

Waste management has still been a developing and progressing field, which demands continual improvements in waste transportation as well as proper selection of locations and efficient operation of new treatment facilities. A comparative analysis of different assessments of municipal waste management systems is reviewed in (Cleary, 2009) or for food waste management systems in (Bernstad and Jansen, 2012). In case of a new system design, the majority of research papers have been dealing with optimisation of network flow to minimise the cost and improve economic criteria, see e.g. (Goulart Coelho et al., 2017). Regarding mixed municipal waste (MMW), which is favoured for thermal treatment, the shortest paths to facilities need to be considered together with detailed analysis of operation including local demands for heat and electricity. The tasks sometimes include social and global environmental criterions (GHG production), however, in case of emissions it is not only their quantity which should be considered, but also their local impact on a particular area with regard to the respective population density. Thus, it is necessary to adapt decision-making which interferes with local city environment towards the possible future consequences.

This paper follows two objectives. First, the initial idea of building advanced reverse logistic model is introduced. Potential locations of waste treatment facilities are given and their optimal capacities with regard to the treatment cost, transportation cost and production of waste in the vicinity are optimised as in (Šomplák et al., 2014), however, the local emission impact assessment is included as well. The approach aims at optimum waste treatment capacities allocation, while future potential risk arising from transport through populated areas is addressed.

An integral part of any reverse logistics problem is a model of infrastructure, which is a graph evaluated using multiple coefficients. Its key elements are edges, each of which is assigned a value corresponding to the locally based emissions. A model without the proper evaluation would not bring any results. Thus, the second objective of this paper is to propose a methodology for edge-related analysis, which provides a deep insight into the problem. It can be considered as a pre-processing phase carried out prior to the main calculation. An analogy to this with capacity-dependent transport price as the function is mentioned in (Gregor et al., 2017). The assessment of production and impact of CO_2, CO, NO_x, and PM was carried out for a particular, 81 km long edge with a specific (constant) amount of transported waste.

The paper is structured as follows: Section 2 starts with the state-of-the-art analysis and then it summarizes idea of an advanced tool in the field. An example of how the advanced tool can be used is described in section 2.2. Together with overview of input data needed to solve real case studies. An approach of handling point and line sources of emissions and their dispersion is proposed in section 2.4. The approach is evaluated using a small case study involving a single route in section 3.

2. Local assessment approach

2.1. Summary of the state-of-the-art and research challenges in the field

Many articles devoted to reducing emissions had considered other environmental aspects as well, see (Cheng et al., 2017). These tasks often combine economic and environmental criteria as done in (Yilmaz et al., 2017). In this context, also Kanzian et al. (2013) introduced a supply chain for processing of forest biomass. The task was designed as a multi-criteria optimisation problem, where profit was maximised while CO_2 emissions were minimised. Further work focusing on second-generation biodiesel supply chains was published in (Hombach et al., 2016). The approach was, again, based on mixed integer programming and the tool was presented on a case study from Germany. The results contributed to the proposed emission reduction plan. The paper by Havukainen et al. (2017) employed the environmental impact assessment using an LCA program to determine whether refuse-derived fuel production and incineration can have a more positive impact on the environment than co-incineration of MMW with coal. An analysis concerning carbon emissions was presented by He et al. (2016). The work focused on a dual-channel supply chain which included traditional and online retailers. It evaluated the impact on pollution reduction as a result of changes in sales channels and the transport of goods. Zohal and Soleimani (2016) presented a multi-criteria decision-making problem, which minimises costs while reducing emissions. The paper seeks to address how a multi-objective logistics model in the gold industry can be created and solved through an efficient meta-heuristic algorithm.

The previously mentioned articles mostly combine economic and environmental problems from the global point of view (objective function is minimised). More complex multi-objective location-routing model for transportation of hazardous waste was developed and tested in Turkey, see (Samanlioglu, 2013). Three criteria were minimised:

i. Total cost (transportation cost of hazardous materials and waste residues and fixed cost of establishing treatment, disposal, and recycling centres).
ii. Total transportation risk related to the population exposure along transportation routes of hazardous materials and waste residues.
iii. The total risk for the population around treatment and disposal centres.

The second and third items addressed the impact on the population and Samanlioglu (2013) considered a certain number of people living in a specific area or within a certain threshold distance from the routes. The way to calculate the impact differs from task to task according to the type of waste and its properties – hazardous waste becomes an issue when the vehicle is involved in an accident. However, in case of MSW, a detailed analysis should be carried out. It is important to consider the distance from the emission source (vehicle, treatment facility), the prevailing direction of wind, as well as the related pollution dispersion. To the authors' knowledge, these aspects have not been addressed in reverse logistics problems yet. The emission models and approaches proposed in section 2 serve as a preparation phase (input data for the calculation) for a comprehensive assessment of supply chains using the facility location model with regard to the ideas presented by Bing et al. (2016). Such a model should consider waste transportation (distance, route profile, load capacity of a lorry) and allocation of treatment plants (Waste-to-Energy (WtE), landfill sites, mechanical-biological treatment producing alternative fuel for co-incineration, transfer stations) in the decision-making process in a holistic approach where local impacts are addressed in defining global solutions where high-level details are required.

2.2. An illustrative example of where an advanced tool is needed

Let us first present an actual case related to the Czech Republic, where there are four WtE plants in operation. The largest one is situated in the capital city of Prague. With its processing capacity of 310 kt/y, it processes residual waste produced in the agglomeration with a population of 1.3M inhabitants. Considering the overall residual waste production of 400 kt of MMW in 2016, additional WtE capacities are needed. As for the heat utilisation, the outmost location of the potential WtE plant is 35 km away, which corresponds to the city of Mělník (96,000 inhabitants). As an alternative, enlargement of the existing Prague facility is also possible. The decision whether it is worth to build a facility outside the populated area can only be made after additional criteria except cost are considered. It is obvious that the impact of additional emissions in Prague caused by the WtE plant would be higher than in case of Mělník, but it is not the only constraint.

Fig. 1 illustrates five situations (V1–V5) that may occur in the real waste management system. It simulates fictional situations, but similar as in the Prague-Mělník case with few additional possibilities. There are