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Vehicle route planning in e-waste mobile collection on demand supported by artificial intelligence algorithms

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ABSTRACT

Mobile collection of e-waste on demand is one of the methods that can contribute to an increase in the collection rate of waste. In this method, a person requests the waste pick up from a household at a preferred time. To support such a collection method an efficient algorithm and information system for convenient waste disposal for residents has to be applied.

Our study investigates using artificial intelligence algorithms for solving the vehicle routing problem with time windows for a heterogeneous fleet of waste collection vehicles. We present an algorithm and a productive model of the online system enabling comprehensive communication for people that request waste equipment for collection, registering of data and solving the VRPTW. The system includes parametric models of four algorithms (simulated annealing, tabu search, greedy, bee colony optimization). The result of the optimization is the assignment of a minimal number of collection vehicles, a vehicle routing plan, timely collection of waste from a household and collection cost reduction.

The study includes the simulation of e-waste collection requests in Tokyo, Philadelphia and Warsaw to compare algorithms for various urban arrangements of streets and buildings. The results show that the best of the four algorithms, to facilitate e-waste mobile collection on demand, is simulated annealing and the worst is tabu search. The proposed model and algorithm can bring significant improvement in planning the routes of the vehicles in the e-waste collection, including a positive social impact on the new method of waste collection, especially in urban areas.

1. Introduction

E-waste or waste electrical and electronic equipment (WEEE) has become one of the most important groups of waste that contain materials easy to recycle, dangerous for the environment and detrimental to one's health. Waste collection companies apply various collection methods, and for WEEE they can be divided into stationary and mobile (Baxter et al., 2016; Goodship and Stevels, 2012).

Stationary WEEE collection is conducted at the municipal waste collection points, in the offices of collection companies, in containers located in popular places or in the vicinity of places of residence. Stationary collection is also conducted by stores selling new equipment when the residents who buy new equipment give the old back (European Union, 2003). Mobile collection can be

Abbreviations: ACO, ant colony optimization; AI, artificial intelligence; BCO, bee colony optimization; BCOi, improved bee colony algorithm; BPP, bin packing problem; EA, evolutionary algorithm; EU, European Union; GA, genetic algorithm; GrA, greedy algorithm; IT, information technologies; MCSS, mobile collection support system; PSO, particle swarm optimization; SA, simulated annealing; TS, tabu search; TSP, traveling salesman problem; VRP, vehicle routing problem; VRPTW, vehicle routing problem with time windows; WEEE, waste electrical and electronic equipment

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conducted as a kerbside collection or at a resident's or company's request (Król et al., 2016). In such a case, it is important to prepare collection vehicles and collection schedules. A different way is to give the old equipment back at the moment of the delivery of new equipment. Stationary collection carries a great many inconveniences because the residents have to use their own vehicles, personally load the vehicle and bear the costs (Saphores et al., 2006; Schultz, 1999). Therefore, mobile collection gives the possibility of a better organization of waste collection from residents and companies and it complements the stationary method.

The participation and engagement of the residents in a proper way of waste disposal are among the most important elements of the way a collection system works. Many studies prove how great is the importance of a correctly organized and convenient collection while disposing of equipment (e.g. Bhat and Patil, 2014; Borthakur and Govind, 2017; Darby and Obara, 2005; Manomaivibool and Vassanadumrongdee, 2012; Nowakowski, 2016). Collection companies are responsible for preparing such means of collecting WEEE, which is effective. As the Eurostat data show the level of collection in the EU amounts to approx. 38% of the weight of the equipment introduced to the market (Eurostat, 2016). According to the requirements of the amended EU directive, the level of collection should amount to 65% by 2021 for all EU member states (the majority of them have to achieve this level by 2019) (European Commission, 2012). In addition, in different countries, there are many hindrances in the collection of equipment and as a result of its proper processing.

The WEEE mobile collection may be carried out at kerbside. Such collection has a great many disadvantages, which are connected with the lack of possibility of putting the waste equipment on the pavement or in a place where there is not much space. The problem is particularly important in the centres of cities and dense tall development, where there are large clusters of apartments. Recently, new means of collecting equipment have appeared–on demand (Król et al., 2016; Nowakowski et al., 2017). This type consists of a prior notification by a resident or a company of the collection of waste equipment. A collection company after registering a notification establishes a collection date and prepares a collection schedule. Such a solution should be based on a properly prepared IT system, which, on the one hand, will make it possible easily and conveniently to report waste equipment for collection, and on the other, will enable a proper preparation of a collection schedule. Currently, collection companies decide to collect large equipment or material of substantial weight. Studies carried out among several WEEE collection companies' managers in Poland indicate that the IT collection support, regarding routes and their optimization, is very rarely used.

A mobile collection support system affords great possibilities for reducing costs of the collection with a properly prepared sequence of equipment collection. It should connect two features. On the one hand, people requesting WEEE for collection should easily report the type of equipment together with its location–so the interface should be intuitive and to a large extent simplified, and on the other, the system has to facilitate the preparation of a collection plan by collection companies from every place where the waste collection calls come.

Fig. 1 presents components of the system, which should be taken into consideration at the developmental stage (see Table 1).

One of the more important links of the system supporting mobile collection of WEEE is an application integrated with a database system, which after the introduction of computations will make it possible to prepare optimum routes of collection vehicles, taking into consideration the declared time windows convenient for the residents, companies or institutions requesting WEEE collection. The optimization task will be directed towards minimization of waste collection costs, and the profits of the collection company will be dependent on the weight of raw materials that the collected equipment contains.

The problem of an effective collection of WEEE connects a great many aspects. First, it takes into consideration the social aspect through the preparation of a convenient collection of waste—on time—according to an available date provided by the residents or companies, who desire to dispose of waste. Simultaneously, the assumption is that the waste equipment, collected by an authorized company, is to be sent to a disassembly plant, in which the process of disassembly and removal of dangerous substances is carried out in compliance with the environmental standards. WEEE collection on demand connects tightly two aspects: a social aspect that derives from the need of the residents to dispose of the equipment in a convenient way with a punctual collection of the equipment by a collection company. Research that confirms the impact of social factors in waste collection has been presented in a study by

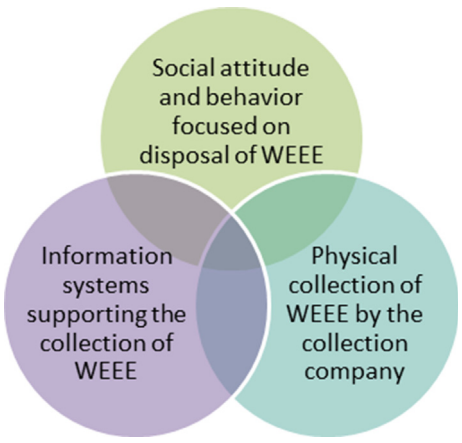

Fig. 1. The components of the system supporting mobile WEEE collection on demand.