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# Supporting mobile WEEE collection on demand: A method for multi-criteria vehicle routing, loading and cost optimisation

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ABSTRACT

The task of increasing collection rates of waste electrical and electronic equipment (WEEE) is an important challenge in the global economy, and especially in the European Union where stiffer collection targets set out in a new WEEE directive are to be effective by 2019. As the circular economy approach replaces the linear model, resource recycling activities become a priority in waste management policy. As new techniques and possibilities of waste collection systems emerge, opportunities are created for improving efficiency for collection companies and affording benefits for the environment.

A model proposed for mobile WEEE collection in this study considers a multi-criteria approach in developing a cost efficient method for pick up on demand from residents or electrical and electronic equipment (EEE) stores. The algorithm used in this model optimises vehicle routes and helps in selecting a number of vehicles from a heterogeneous fleet, incorporating the WEEE loading problem. Using genetic algorithm and fuzzy logic, this model optimises costs and resources required to complete the WEEE collection assuring timely pick up of the waste equipment. The numerical model is verified in a case study in Opole, a city in the south of Poland. The results show that the proposed model can handle the multiple parameter optimisation problem including operational costs, efficient use of vehicles from a fleet, efficient waste loading in vehicles and residents' satisfaction with timely pick up of the waste equipment from a household. Such system can be successfully applied even for large cities. The algorithm provides an opportunity for writing software or mobile apps design to be used by WEEE collection companies.



## 1. Introduction

In recent times, policy makers in developed and developing countries have introduced the notion of a circular economy. In this approach, all resources should be kept in a closed loop with particular focus on recovering and recycling raw materials used in the manufacturing of products. At the same time, special attention is given to energy efficient systems with low emissions and minimal environmental impact through the entire life cycle of the products (Andersen, 2007; Ning, 2001).

An important issue in the effective circulation of resources in the economy is waste management. One type of waste stream is waste electrical and electronic equipment (WEEE). The total amount of WEEE generated in the world is estimated to be up to 50 million tons annually with a yearly growth rate of 3–5% (Cucchiella et al., 2015). This group of products is valuable due to high recycling potential (Buekens and Yang, 2014; Oguchi et al., 2011) of the raw materials acquired after disassembling, bringing benefits for the environment and revenues for recycling companies.

While in large appliances such as washing machines, dishwashers or ovens disassembly is focused on recovery of ferrous metals, aluminium or copper. Other equipment especially used in information technologies (IT) and telecommunications equipment includes precious and rare earth metals (Charles et al., 2017; Cucchiella et al., 2016; Ueberschaar et al., 2017). The potential of WEEE in circular economy including evaluation of reuse and recycling is discussed by Parajuly and Wenzel (Parajuly and Wenzel, 2017).

In the European Union (EU) a framework of the WEEE management system was introduced in 2003 (European Union, 2003), with subsequent improvements introduced in 2012 (European Commission, 2012). The goal of the directives is to involve

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producers, waste collection companies, disassembling plants and the residents disposing of the waste equipment in an efficiently operating system to recover the raw materials used in these products. There are some proposals to improve this law, to include waste batteries (European Parliament, 2016). Similar systems were introduced in other countries such as Switzerland, Norway, China, and India (Hischier et al., 2005; Ongondo et al., 2010; Widmer et al., 2005).

However, many problems are encountered in collecting WEEE. Detailed data published by Eurostat reveals that on average the ratio of the WEEE collected to new electrical and electronic equipment (EEE) placed on the market is only 37% in the EU (Eurostat, 2016). The new directive target for EU members is to collect 65% of EEE placed on market, to be achieved by 2019. This is a reason the governments and collection companies are intensifying work to improve WEEE collection effectiveness.

The collection of WEEE involves more options compared to municipal waste. A task for collection companies and the local administration is to prepare convenient methods of waste collection that are acceptable by residents who want to dispose of WEEE. At the same time, the transportation of the collected waste items should be efficient as it is the main contributor to collection cost. If the collection method requires an extended route length for the vehicles, it causes extensive emissions and environmental pollution (Apaydin and Gonullu, 2008; Larsen et al., 2009).

The methods of disposal and collection of WEEE in comparison to municipal waste are presented in Fig. 1. They include possible replacement of old equipment in EEE stores or superstores by the residents, delivery of the waste equipment to municipal or local waste collection centres or disposal in a special bin or container placed in the residential neighbourhoods.

Mobile collection can be provided through a local collection schedule. This method can be provided as curbside collection. It is mainly applicable in the residential areas outside town or city centres. An alternative method is collection on demand when a resident or EEE store calls a WEEE collection company for waste pick up (Król et al., 2016). This request could be made through various communication channels, like websites or mobile apps. It is important to assure efficiency of the collection system by engaging residents and proposing an efficient and reliable system of waste equipment pick up. Residents' behaviour in disposing of WEEE may be influenced by many factors, such as attitude towards environmental issues, willingness to pay or convenience of disposal of the waste items (Saphores et al., 2012; Song et al., 2012).

When an EEE item becomes obsolete, a resident would like to dispose of it in a convenient way as soon as possible. If the equipment is large or heavy, a resident will need help with carrying it out from a flat or house. In WEEE collection, the unknown factor is the number of requests and the type of waste items being disposed of. It is a random number, which depends on either a WEEE item becoming obsolete or a resident decides to dispose of such waste. The unknown factor is also the location of the households. Other issues in WEEE removal include commitment to use legal disposal methods, alternative storage in the household or illegal discarding (Kahhat et al., 2008; Ku et al., 2009; Saphores et al., 2006).

Solving the problem of the low collection rates of WEEE must involve both the collection companies and the residents. It is essential to provide reliable and convenient methods for residents to dispose of WEEE at any time after the end of its life. The collection companies should offer high quality collection methods for residents, but at the same time prepare efficient routing to minimize collection costs.

Such a mobile collection system on demand should utilise modern communication channels, mobile apps, and use of geographic information systems (GIS) (Faccio et al., 2011; Tavares et al., 2009). An interface should be easy to navigate by users of different ages. While the design of such an interface with a database is not a difficult task, calculation and optimisation of the routes depending on the sequence of waste collection from households is complex. Collection companies are interested in minimizing operational costs. They select vehicles that are most appropriate to be able to load all waste from residents' calls. The loading sequence of waste equipment has an impact on the efficiency of use of the cargo compartment. When small or medium items are loaded first there may be a problem to load large appliances. The sequence of visiting collection points – residences or EEE stores where waste equipment is temporary stored – has the main impact on route length and collection time.

This research proposes a multi-criteria optimisation model, taking into consideration satisfaction of residents on timely collection of the waste equipment from the household according to their request. The residents' satisfaction model uses fuzzy logic. The optimisation of routes and preparation of the sequence of places to be visited to collect WEEE uses genetic algorithms. The

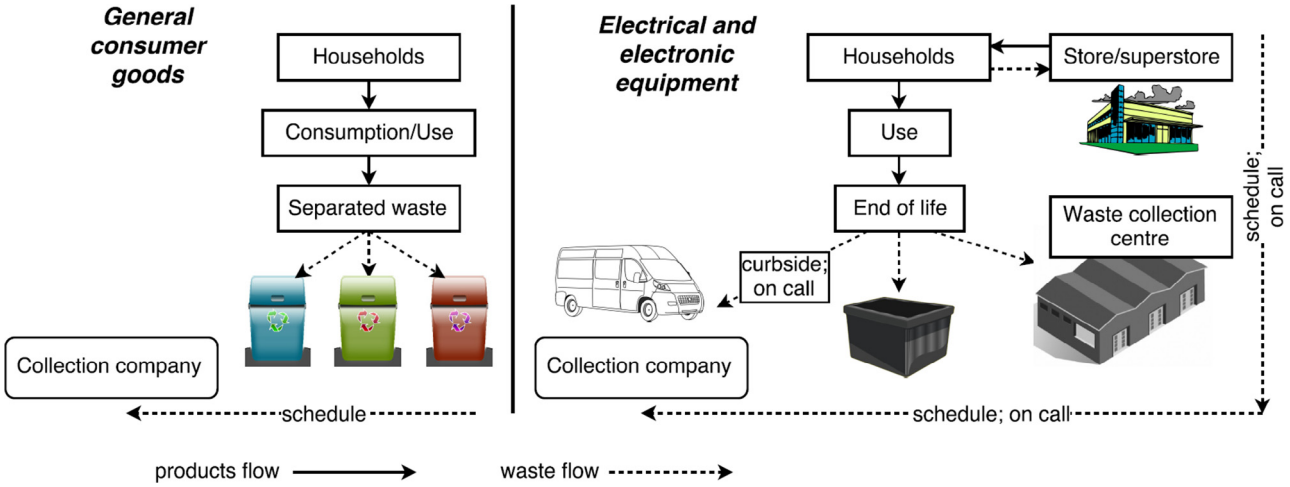


**Fig. 1.** Methods of waste disposal and collection from households.

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