Master’s thesis Nova IMS

Genetic algorithm

Arc routing problem

Waste management

Smart cities

Complexity NP-Hard

Sustainability

Future:

1. Size of the streets that don’t allow big trucks to pass
2. Predict better the amount of waste in each street

**Title**

Genetic algorithm for Waste Collection in Smart City, case of Campolide.

**Abstract**

The Arc Routing Problem is a routing problem that is within the NP-hard problems set.

**Keywords**

**Index**

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# Introduction

## Cities urbanization and waste management problem

Human activity has been pushing environmental changes. Global warming, air pollution and biodiversity decrease are some of the examples of these changes that can be observed (Bătăgan, 2011). Urban areas are the principal responsible that drive these changes at multiple scale. Being centers of production, consumption and waste disposal, the impacts on the environment can be repeatedly observed among the cities, especially those located in the developed world (Grimm et al., 2008).

The issues generated by the urbanization are even more worrying given that from 1950s to 2014 the urban population went from 30 per cent to more than half of the world’s population with 54 per cent. Furthermore, in the coming decades, the change on the size and distribution of the urban area will be more expressive, projected to have 66 per cent of the entire world’s population living in the cities by 2050 (United Nations, 2014). Megacities, the ones that by convention have more than 10 million inhabitants are emerging mostly in the developing world, and economic growth will follow the urban growth, demanding more services and resources (Grimm et al., 2008). Although the urbanization process brings opportunities for development, at the same time challenges arise, namely on social equity, environmental sustainability and government (United Nations, 2014).

One of the major environmental and socio-economic challenges that comes with urbanization is waste management (Fujdiak, Masek, Mlynek, Misurec, & Olshannikova, 2016; Karadimas, Papatzelou, & Loumos, 2007). The amount of waste is increasing over time in the urban society. Data from the 2012 World Bank’s report shows that the cities were generating about 1.3 billion tons of solid waste per year, costing $205.4 billion. By 2025 it is expected to increase this generation by 2.2 billion tons with the management cost of $375.5 billion, mainly in lower income countries (Hoornweg & Bhada-Tata, 2012).

Waste management is particularly impactful in the short-term to the citizens and the environment, while compared with other problems that massive urbanization may cause (Hoornweg & Bhada-Tata, 2012). The idea of waste management involves many cycles, these can be listed as collection, transport, processing, recycling and monitoring. More steps can be presented depending on the cities’ waste management scenario, although the waste management aim a common goal in every place it is applied, different cities have their own particularities and need to be addressed in own specific ways. The most important of these cycles naturally is collection as it direct impact people living on those urban areas. Collection is also the step that have more costs involved in referring economic terms, because it requires intensive labor work and massive use of trucks to be able to deliver the service to the entire city (Beliën, De Boeck, & Van Ackere, 2011).

Uncollected waste can be harmful to the environment and consequently bring a variety of health issues to the population. Also, poorly waste management have economic impact to the city, because the costs can be higher than it would be to properly address the problem. Manage the waste collection of the households is a hard problem that are faced by cities’ government across the globe (Hoornweg & Bhada-Tata, 2012).

Ongoing urbanization stress the importance of efficiency waste collection, cities must find ways to maximize the acceptance of collection solution (Beliën et al., 2011). Waste collection is the collection of solid waste from residences, commerce, industry and any other agent that produces solid waste, and deliver it at the disposal deposit. The collection can be done house-to-house (or door-to-door), via community bins, self-delivered, among others (Hoornweg & Bhada-Tata, 2012). Waste collection is a hard problem that must be aware of many factors that influence the collection, making this step efficient is difficult since this kind of problems don’t have an exact solution in a feasible time.

## Smart cities role in waste management

Cities’ main challenge have become be able to manage the ecosystem services dependence, which exhaust the biodiversity and natural resources although prioritizing public health and quality of life (Science for Environment Policy, 2015). With such changes and challenges arising, keeping livable conditions within this context demands a deeper understand of a smart city, and how it can help cities among the world to deal with these emerging problems (Chourabi et al., 2012).

The smart city concept heavily base itself on the environmental aspect of the cities and the engagement of people and government on environmental activities (Giffinger, 2007). There is a special motivation on the preservation of natural resources and related infrastructure (Chourabi et al., 2012), and as discussed before, waste management is one of the most important problems with socio-economic impact in the city. Indeed, smart cities itself came to face the challenges that urban areas are facing today and probably the ones that they will face in a near future (Nam & Pardo, 2011).

As others fresh and controversial concepts, the smart city one is not different in the fact that there is no standard definition or template of framing (Nam & Pardo, 2011). In the policy arena in the past years, this concept has been greatly quoted. It seems that the focus approached on this area is about the role of the ICT, an acronym for Information and Communication Technology. The ICT-driven development is believed to be the path to follow for many countries in the EU for example (Caragliu, del Bo, & Nijkamp, 2011).

Obviously, ICT have transformed for better many urban areas economics, social and environment. But laying only in the technology and communication would not benefit the whole city, in some cases, these smart cities needs to deal with a problem brought by this form of approaching the concept, like social polarization that create bigger social divisions over the population. The educated and technology included society, mostly middle class, that are attracted by this kind of policy can produce highly gentrified neighborhoods while excluding traditional and poorer residents of the city (Hollands, 2008).

The problem of waste management within the smart city, either using new techniques, data, ICT components, or even a combination between those concepts, has become more intelligent (Fujdiak et al., 2016). Multiple solution proposed make heavy use of ICT as sensors in recycle bins ACHAR O CASO DE CASCAIS, this approach can bring huge benefits (Catania & Ventura, 2014; Fujdiak et al., 2016). But this approach works well when the garbage is disposed in fixed bins along the streets, where the truck can collect at any time. Door-to-door waste collection have more issues on adopting ICT to improve the collection phrase, for example, a building with some apartments in most cases share the same bins that are collected by a truck in specific days. However, the door-to-door type of collection can be addressed in a different way by the smart cities, where the focus is not about using IOT with sensors and technological chips but using the data DEVO FALAR MAIS DE DADOS COLETADOS?? that was generated by the collections routes in the past and trying to optimize the routes using new techniques, aiming to reduce the economic and environmental impact caused by the collection step of the waste management.

## Routing problem

[falar sobre o problema das rotas de caminhoes de lixo]

Intelligent collection management is vital to ensure cost reduction, improve coverage and efficiency of the waste collection process (Buenrostro-Delgado, Ortega-Rodriguez, Clemitshaw, González-Razo, & Hernández-Paniagua, 2015). While focusing on ICT components, one can use many techniques to ensure that the collection is done efficiently, but as stated before, apply this approach when dealing with door-to-door waste collection can be harder than having chips placed on static bins over the streets. The collection of household waste collection at each door, using ICT is not being considered. The optimization that this project aims to this kind of routing problem is related with the routing of the collection trucks in order to provide a better route for each truck available, while respecting the known limitations.

The most common algorithms used in order to deal with the routing problem are the Vehicle Routing Problem (VRP) (Mohammed et al., 2017) and the Arc Routing Problem (ARP) (Arakaki & Usberti, 2018) and their variations. Both problems are considered hard combinatorial optimization problems (Arakaki & Usberti, 2018; Fadzli, Najwa, & Luis, 2015; HAN & Cueto, 2015). These algorithms run upon graphs, that in the waste collection case represents the streets and collection spots. The difference between the algorithms is that the VRP, the most studied routing problem between these algorithms VRP (Fadzli et al., 2015; Ramdane-Cherif, 2006), consist in process the demands of the nodes in a graph, while the ARP focus on serving the edges instead of the nodes (Ramdane-Cherif, 2006). Relating the two algorithms with the waste management problem, can be stated that the VRP can be applied to deal with community bins, where each bin is a node in the graph and the edges represent the streets between them. In the ARP, the edges can still be the streets and the nodes are intersections between the streets. The ARP approach is more suitable for door-to-door collections, since the garbage truck must collect the waste from a street instead of a specific bin. Indeed it is one of the applications that this algorithm try to solve (Willemse & Joubert, 2016), because serving the edges instead of the nodes fits better in this problem.

Methods that deal with these kind of collection problem, like vehicle allocation and route designation, can be applied using traditional mathematical methods like linear methods, but these can rapidly suppress the computational resources even with medium sized instances (de Oliveira Simonetto & Borenstein, 2007). This set of problems are known as NP-hard (non-deterministic polynomial-time) problems and until nowadays is only viable to use exact methods for very small instances because of their complexity (Pereira, Tavares, Machado, & Costa, 2002). Therefore, heuristics and meta-heuristics are used to approximate solutions. Although these methods don’t guarantee optimal solutions to the problems, they generally provide good solutions that can be used in real life applications (HAN & Cueto, 2015).

Meta-heuristics has been the orientation of many researches in the past years, and its result are appearing to be more promising (HAN & Cueto, 2015). Genetic algorithm has been broadly studied over the literature and seems to allow a more thorough search over the solution space. This approach can lose track of good solutions when jumps to spaces far from optimal solutions, but it also allows moving away local and not global optimum solutions with some techniques including recombination and random mutations. Some authors are applying genetic algorithms to solve the VRP and ARP with success.

## Project goals

## Methodology

The design science research methodology will be used to accomplish the final goal of this project. By applying this research methodology, the motivation, problem and objectives of the project must be clearly defined in this paper. Then with those steps accomplished, the development of the project will be described, based on the theory previously analyzed. With the project complete, a test case will take place, in the case of this project, an effort will be made using Campolide waste collection data, in Lisbon municipality, Portugal, as a test case of the framework. In the next paragraphs the steps of the methodology applied will be presented with more detail, relating where each piece of the process can be found in this written research.

Following this methodology, in the first chapter are presented the motivation and problem of the study, specifically the subchapters 1.1, 1.2. These subsections give a broadly contextualization in the inherent nature of the population growth problem in the urban areas. Relating it with the sustainability concern in these cities and the waste management problem. The emerging concept of smarts cities to deal with the overpopulation and overgeneration of waste issues are presented, and the collection step of the waste management is approached.

Also, in the chapter one, in the subsection 1.3, the problem statement is presented, on how to optimize waste collection routes on door-to-door collection. This subsection explains the importance and challenges of the routing problem of the waste collection is then described. In the end, genetic algorithms are presented as a possible solution to these kinds of problem.

On the subchapter 1.4 the objectives of this project are defined. On this section, a wide vision of the aim and each step that will lead to the objective is defined, trying to follow a train of thought on how each step connects to each other to accomplish the final aim of having a genetic algorithm to deal with the routing of garbage trucks in a city, using Campolide, at the Lisbon municipality as a model to validate the results.

The problem definition and motivation, besides having some theory to based, was explained in a broader aspect because was not the main proposal of this project. In the chapter 2, the theory used to accomplish the research project will be deeper analyzed having a wider approach of the topics and with more details. This chapter will carry the base theory for the construction of the proposed project. First, on the section 2.1, the concept of waste management will be addressed to have a better understand of what truly waste management is, and how to granulate this concept to the specific target of this project that is the routing of the garbage trucks in the waste collection. In the subchapter 2.2 a literature review will take place on the routing problem using meta-heuristics, focusing on genetic algorithms. A variety of works about the use of genetic algorithms to accomplish the VRP or ARP will be presented. Then, in the subchapter 2.3, genetic algorithm is described, with explanations of its core concepts like generating offspring with the current population and the mutation of existing chromosomes.

[MUST BE BETTER DEFINED, DEPENDS ON THE DEVELOPMENT PROCESS] The chapters *3* to *7* demonstrate the steps of the framework construction, each chapter will approach a specific part of the process. The chapter 3 will discuss about the indicators used in the constructed index.

[TEST CASES MUST BE PLACED HERE]

Waste management

Routing problem with meta-heuristics literature review

Genetic algorithms

Open data (falar um pouco e agradecer a camara de lisboa)

1. **Project Goals**
   1. **S**
      1. **A**
2. **Methodology**
3. **Concepts**
4. **Project Construction**
5. **Results**
6. **Future works**
7. **Conclusion**
8. **References**

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