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

**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**

Table of Contents

[1.Introduction 2](#_Toc521625125)

[1.1.Cities urbanization and waste management problem 2](#_Toc521625126)

[1.2.Smart cities role in waste management 3](#_Toc521625127)

[1.3.Routing problem 4](#_Toc521625128)

[1.4.Project goals 4](#_Toc521625129)

[1.5.Methodology 4](#_Toc521625130)

# 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, 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 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

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). Methods that deal with the 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).

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 of both problems, 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). The ARC problem is more suitable for door-to-door collections since the garbage truck must collect the waste from a street instead of a specific bin, then this representation can fit better to this problem.

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).

Capacitated arc routing problem (CARP) was proposed by Golden and Wong [1], as a respond to the lacked graph theory which focuses on arc or edge solving for optimality. On the other hand, node routing or vehicle routing problem (VRP) received more attention in research when compared to CARP, which is neglected comparatively. [**Capacitated Arc Routing Problem and Its Extensions in Waste Collection**]

The Capacitated Arc Routing Problem (CARP), first proposed by Golden and Wong [21], is a classical routing problem where a subset of required edges have to be serviced by a fleet of homogeneous vehicles. The CARP has a wide range of applications such as security guard routing [44] and railway maintenance [24], and its well-known applications for winter gritting, street sweeping and waste collection [Constructive heuristics for the Mixed Capacity Arc Routing Problem under Time Restrictions with Intermediate Facilities]

Routing and scheduling problems are important elements of many logistic systems. The most studied routing problems, like the *VRP* (*Vehicle Routing Problem*) consist of processing demands located on the nodes of a network. When the demands are placed on the arcs, the equivalent problem is a *Capacitated Arc Routing Problem* (*CARP*) [Evolutionary Algorithms for Capacitated Arc Routing problems with Time Windows]

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

[introduzir rapidamente o que existe VRP e CARP, e dizer que CARP é utilizado para door-to-door]

[discutir brevemente algumas soluções existentes (genetic algorithm e outras heuristicas)]

[falar porque as heuristicas sao importantes aqui]

[apresentar genetic algorithm como forma de resolver esse problema]

## 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 and 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 issue 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 engage citizens in sustainable practices. This subsection explains the importance of citizenship participation on cities sustainable development and present the issue of engagement and measurement of the citizens’ efforts.

Later on the subchapter *1.4* the objectives of this project are defined. On this subchapter, 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 have a framework in the base of a gamification technique that can be used to engage citizen participation on sustainable practices over the municipality.

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 framework proposed. First the concept of sustainable development will be addressed to have a better understand of what truly is sustainable development, and how to granulate this concept to the specific target of this project that is environmental sustainability. Then indicators will be discussed, describing its importance and how to classify them, this will enable to build an indicator based on the theory that will be studied. On the last section, this chapter will address gamification techniques, since this is a relatively new concept, some useful information will be given on how they are defined, and which elements compose this concept.

[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]

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

Arakaki, R. K., & Usberti, F. L. (2018). Hybrid genetic algorithm for the open capacitated arc routing problem. *Computers and Operations Research*. https://doi.org/10.1016/j.cor.2017.09.020

Bătăgan, L. (2011). Smart Cities and Sustainability Models. *Revista de Informatică Economică*, *15*(3), 80–87. Retrieved from http://revistaie.ase.ro/content/59/07 - Batagan.pdf

Beliën, J., De Boeck, L., & Van Ackere, J. (2011). Municipal Solid Waste Collection and Management Problems: A Literature Review. *Transportation Science*. https://doi.org/10.1287/trsc.1120.0448

Buenrostro-Delgado, O., Ortega-Rodriguez, J. M., Clemitshaw, K. C., González-Razo, C., & Hernández-Paniagua, I. Y. (2015). Use of genetic algorithms to improve the solid waste collection service in an urban area. *Waste Management (New York, N.Y.)*. https://doi.org/10.1016/j.wasman.2015.03.026

Caragliu, A., del Bo, C., & Nijkamp, P. (2011). Smart cities in Europe. *Journal of Urban Technology*, *18*(2), 65–82. https://doi.org/10.1080/10630732.2011.601117

Catania, V., & Ventura, D. (2014). An Approach for Monitoring and Smart Planning of Urban Solid Waste Management Using Smart-M3 Platform. *15th Conference of Open Innovations Association FRUCT*. https://doi.org/10.1109/FRUCT.2014.6872422

Chourabi, H., Nam, T., Walker, S., Gil-Garcia, J. R., Mellouli, S., Nahon, K., … Scholl, H. J. (2012). Understanding smart cities: An integrative framework. In *Proceedings of the Annual Hawaii International Conference on System Sciences* (pp. 2289–2297). https://doi.org/10.1109/HICSS.2012.615

de Oliveira Simonetto, E., & Borenstein, D. (2007). A decision support system for the operational planning of solid waste collection. *Waste Management (New York, N.Y.)*. https://doi.org/10.1016/j.wasman.2006.06.012

Fadzli, M., Najwa, N., & Luis, M. (2015). Capacitated arc routing problem and its extensions in waste collection. In *AIP Conference Proceedings*. https://doi.org/10.1063/1.4915634

Fujdiak, R., Masek, P., Mlynek, P., Misurec, J., & Olshannikova, E. (2016). Using genetic algorithm for advanced municipal waste collection in Smart City. In *2016 10th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP)*. https://doi.org/10.1109/CSNDSP.2016.7574016

Giffinger, R. (2007). Smart cities Ranking of European medium-sized cities. *October*, *16*(October), 13–18. https://doi.org/10.1016/S0264-2751(98)00050-X

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global Change and the Ecology of Cities. *Science*, *319*(5864), 756–760. https://doi.org/10.1126/science.1150195

HAN, H., & Cueto, E. P. (2015). Waste Collection Vehicle Routing Problem: A Literature Review. *PROMET - Traffic&Transportation*. https://doi.org/10.7307/ptt.v27i4.1616

Hollands, R. G. (2008). Will the real smart city please stand up? *City*, *12*(3), 303–320. https://doi.org/10.1080/13604810802479126

Hoornweg, D., & Bhada-Tata, P. (2012). *What a waste: a global review of solid waste management*. *World Bank, Washington DC*.

Karadimas, N. V., Papatzelou, K., & Loumos, V. G. (2007). *Genetic algorithms for municipal solid waste collection and routing optimization*. *IFIP International Federation for Information Processing*. https://doi.org/10.1007/978-0-387-74161-1\_24

Mohammed, M. A., Abd Ghani, M. K., Hamed, R. I., Mostafa, S. A., Ahmad, M. S., & Ibrahim, D. A. (2017). Solving vehicle routing problem by using improved genetic algorithm for optimal solution. *Journal of Computational Science*. https://doi.org/10.1016/j.jocs.2017.04.003

Nam, T., & Pardo, T. A. (2011). Conceptualizing smart city with dimensions of technology, people, and institutions. In *Proceedings of the 12th Annual International Digital Government Research Conference on Digital Government Innovation in Challenging Times - dg.o ’11* (p. 282). https://doi.org/10.1145/2037556.2037602

Pereira, F. B., Tavares, J., Machado, P., & Costa, E. (2002). GVR: A New Genetic Representation for the Vehicle Routing Problem. *Artificial Intelligence and Cognitive Science: 13th Irish International Conference, AICS 2002, Limerick, Ireland, September 12-13, 2002 - Proceedings*. https://doi.org/10.1007/3-540-45750-X\_12

Ramdane-Cherif, W. (2006). Evolutionary algorithms for capacitated arc routing problems with time windows. In *IFAC Proceedings Volumes (IFAC-PapersOnline)*.

Science for Environment Policy. (2015). Indicators for sustainable cities. *European Commission*, (12), 1–189. https://doi.org/10.2779/61700

United Nations. (2014). *World Urbanization Prospects 2014*. *Demographic Research*. https://doi.org/(ST/ESA/SER.A/366)