Multi-agent gathering Waste System

Álvaro Lozano Murciego[a], Gabriel Villarrubia González [a], Alberto López Barriuso [a], Daniel Hernández de la Iglesia [a] and Jorge Revuelta Herrero[a]

murciego@acm.org, gvg@acm.org, albarriuso@acm.org, ahernandezdelaiglesia@acm.org, jrevuelta@acm.org

[a] ACM Students Members

KEYWORD

CVRP; Smart Cities; WSN; ESP8266; IoT; Route Optimization

ABSTRACT

Along this paper, we present a new multi agent-based system to gather waste on cities and villages. We have developed a low cost wireless sensor prototype to measure the volume level of the containers. Furthermore a route system is developed to optimize the routes of the trucks and a mobile application has been developed to help drivers in their working days. In order to evaluate and validate the proposed system a practical case study in a real city environment is modeled using open data available and with the purpose of identifying limitations of the system.

1. Introduction

At the present time the number of cities that integrate new systems to improve the public services offered is exponentially increasing. More and more cities and towns have a network infrastructure that provides Internet access to citizens and sensors that can be placed throughout the city. This makes possible the implementation of systems providing the cities with intelligent features to turn them into smart cities. There are several descriptions of potential systems which may be included in smart cities (Gutierrez, Jensen, Henius, & Riaz, 2015), such as energy grids, public lighting, water management, public security, transport mobility and logistics, healthcare, etc. This article focuses on the design of a smart waste collection system in all these systems.

Thanks to the emergence of new, cheap and efficient sensors on the market, as the ESP8266 sensor (Mehta, 2015), it is possible to design new devices that can be easily integrated into the Internet of Things (IoT) and can be used to create affordable wireless sensor networks (WNS) (Dargie & Poellabauer, 2010). This allows the development of the infrastructure of low cost intelligent systems and enables its deployment in cities and towns with very low budgets. This article describes how to develop a wireless sensor network based on devices that have a volumetric sensor for detecting the filling level of containers. It also explains how they communicate with the system through a network infrastructure.

Furthermore, one of the fundamental objectives of smart cities is savings in transport and city logistic. Having more information about the city and its state makes possible the development of intelligent systems to optimize transport and routes. This article describes how to include frameworks as Optaplanner ("OptaPlanner - Constraint satisfaction solver (Java^{TM}, Open Source)," n.d.) with algorithms in order to solve the classic Capacitated Vehicle Routing Problem (CVRP) (Lysgaard & Wøhlk, 2014) and optimize routes that followed by the trucks follow when collecting waste.

To complete the system, an application has been developed. This application al-lows truck drivers to follow the daily planned route as well as notify the location of each truck to the system in real time. Additionally, a geographic information system (GIS) has been added to store a history of the routes taken by trucks and all data related to routes such as average speed, etc.

Finally, the city of Málaga has been chosen as a case study for a first approximation of the system. An open dataset (Ayuntamiento de Málaga, n.d.) has been used to perform a simulation of the system on a real environment.

2. Background

2.1. Current Systems

Nowadays there are several studies in the literature (Gutierrez et al., 2015; *Internet of Things, Smart Spaces, and Next Generation Networks and Systems: 15th International Conference, NEW2AN 2015, and 8th Conference, ruSMART 2015, St. Petersburg, Russia, August 26-28, 2015, Proceedings*, 2015) concerning smart systems for collecting waste in cities(Gutierrez et al., 2015). The European Union has already funded projects focused on designing these systems, such as project LIFE E-WAS (Wellness Telecom, 2013).

There are numerous professional solutions on the market like Enevo (ENEVO ®, 2016), which offers a similar system with robust sensors but with a very high cost. This article is intended to design a system that uses new low-cost sensors and open source route optimization frameworks in order to reduce costs and make possible the implementation of the system in cities and towns at a reduced price.

2.2. CVRP Problem

A fundamental part of the system, apart from sensor network in the city or town, is the optimization of the routes that must be followed by the truck when it comes to collect waste.

The main objective is the optimization of the distance travelled by trucks to collect waste. This will reduce fuel costs and increase the useful life of the vehicle fleet. This is a classic optimization problem called Vehicle Routing Problem (VRP) (Optimization, n.d.)

The VRP (Eksioglu, Vural, & Reisman, 2009) is a nonspecific name given to a whole class of problems in which a set of routes for a fleet of vehicles based at one or some depots must be determined for a number of geographically disseminated cities or customers. The objective of the VRP is to deliver a set of customers with known demands on minimum-cost vehicle routes starting and finishing at a depot. In this case, the customers are the city containers and their demand is the filling level. Fig. 1 shows a usual input for a VRP problem and its possible outputs:

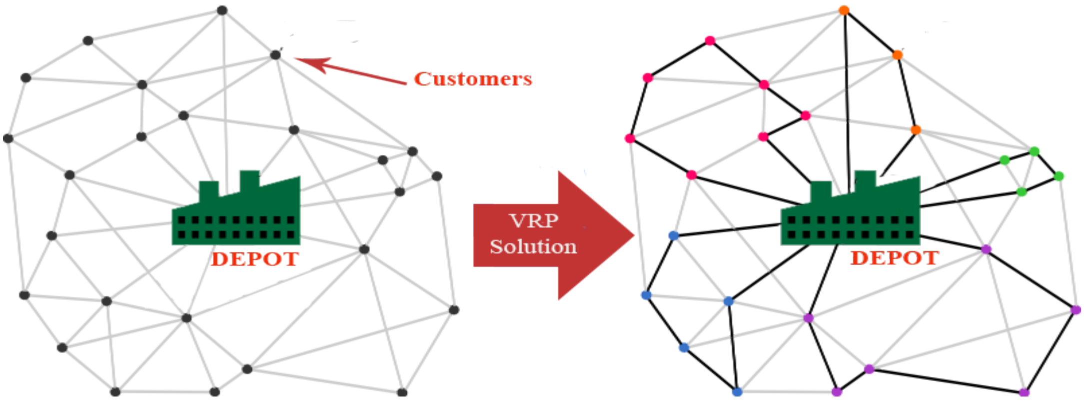

Fig. 1. Classic VRP input.

A variant of this case is a Capacitated Vehicle Routing Problem (CVRP), which is the same problem as VRP, but with the additional constraint that every vehicles must have uniform capacity of a single commodity. In this case, this restriction refers to the maximum load that each one of the trucks in the fleet can store.

There are a lot of VRP variants, as VRP with Pick-Up and Delivering, VRP with Time Windows, etc. For this work we assume the case of study as a CVRP(Huang & Hu, 2012).

There are several solution methods for VRP. Most of them are heuristic and metaheuristic solutions because the exact approaches cannot guarantee optimal solutions in a reasonable time whit a high number of containers, like in this case. Some of these methods are indicated below:

- **Exact Approaches**: This computes every possible solution until one of the best is gotten. Such us Branch and bound (Fisher, 1994) or Branch and cut (Jens Lysgaard, n.d.; Lysgaard & Wøhlk, 2014)
- **Heuristic methods**: This methods perform a limited exploration of the search space and they normally obtain good quality solutions within modest computing times.
- **Metaheuristic methods**: Generic methods of exploration of the search solution space for search and optimization problems. This methods provide a line of design that is adapted in each context, and can generate more efficient algorithms. In general, metaheuristic methods outperform classical heuristic methods, but incur higher runtimes. Some of these methods are:
  - Ant Algorithms (Schelter & Owen, 2012)(Gambardella, Taillard, & Agazzi, 1999)
  - Constraint Programming(Maher & Puget, 1998)(Shaw, 1998)
  - Genetic Algorithms(Goldberg, 1989)
  - Tabu Search (Glover, 1986)(Rochat & Taillard, 1995)(Barbarosoglu & Ozgur, 1999)

3. Multi agent gathering waste system

3.1. Proposed system architecture

The overall architecture proposed (**Fig. 2**) for the system consists of the following parts:

- **Wireless Sensor Network**: based on a Wi-Fi infrastructure. The developed sensors are installed in the containers and they send the filling level of the containers using the MQTT(Hunkeler, Truong, & Stanford-Clark, 2008) communication protocol.
- **Broker MQTT & Web Services API**: the system has a MQTT broker in which each sensor of the WSN publishes its messages and the system stores it. The system also has a Web services API which is used by the mobile app and the administration website.
- **Mobile Application**: This application guides drivers through the planned route for each working day. The application also records information about the route followed by each truck and sends it to the server.
- **Administration web**: Website that shows the route calculated for each day and the location of the trucks in real time during the waste collection.
- **GIS**: Collects information on planned routes for each collection, routes that the trucks have followed, information regarding the location and status of sensors, etc.
- **Route Optimization System**: system in charge of calculating the route planning to be followed each day based on the information from the sensors and the fleet of vehicles available for collection.

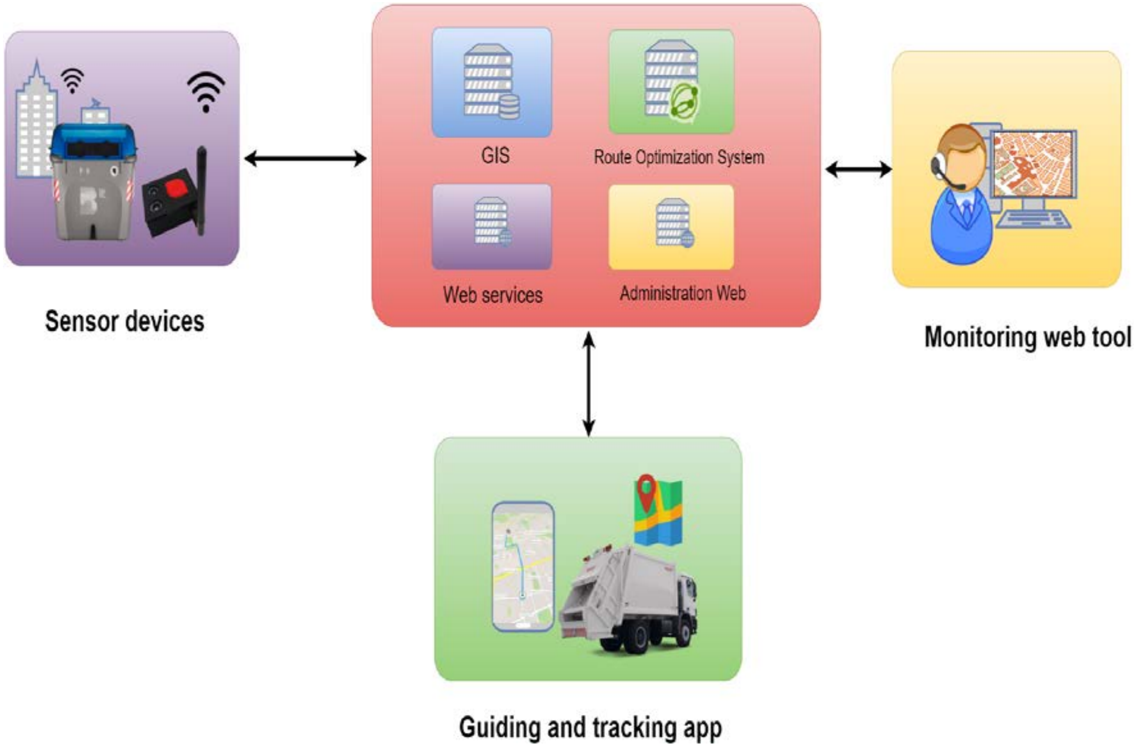

Fig. 2. System diagram

3.2. Developed sensor prototype

A Wi-Fi volumetric sensor prototype has been developed trying to minimize the cost. The **Table 1** shows the components used in the prototype development and their market prices:

Component	Price
LiPo Battery 7.4V (1500 mAh)	8.93€
ESP8266 12E	3.08€
Power Supplies	1.20€
Wifi Antenna 5dB	1.03€
Ultrasonic Sensor HC-SR04	0.79€
Resistors & wires	2.00€
Board	1.00€
3D printed case	1.30€

Total	19.33€

Table 1.

The figures below show some of the components without soldering on the board (**Fig. 3** a)) and the prototype assembled in a printed 3D case (**Fig. 3** b)).

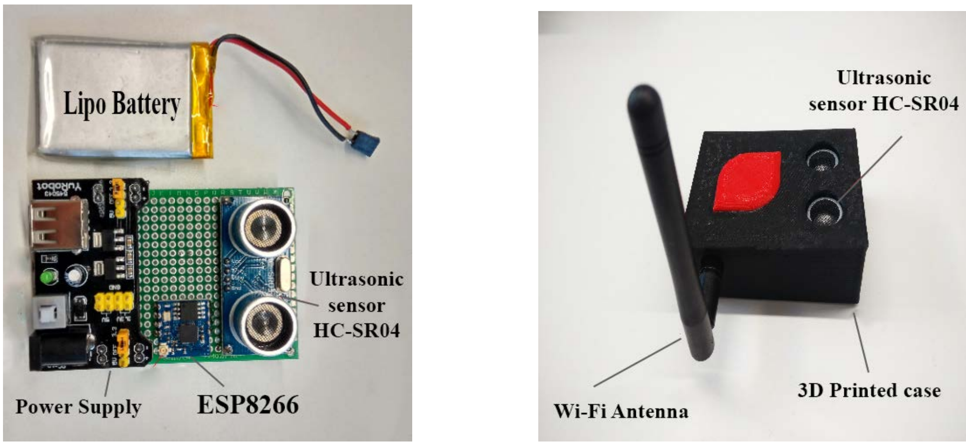

Fig. 3. a) Prototype components b) Final prototype

The prototype is placed on the top part inside the container. This makes possible to obtain the approximate filling volume of the container with the ultrasonic sensor. When the device performs a measurement and sends it over the network its maximum consumption is about 250 mAh. The rest of the time, the ESP8266 device disables the other sensors and parts of the board and enables the Deep Sleep mode (Systems, 2015). The consumption of the whole board in *Deep Sleep* mode is about 128µA. It is important to consider these values to select the battery capacity of the prototype. The device must be operating every day between cleanings. The periods between the containers cleanings are usually marked by the city council and the concessionaire cleaning company.

3.3. Routing Optimization System

The routing optimization system has been built on the open source framework Optaplanner. This is mathematical optimization framework that solves constraint satisfaction problems with construction heuristic and metaheuristic algorithms.

The following figure (**Fig. 4**) shows a diagram of the process of route optimization.

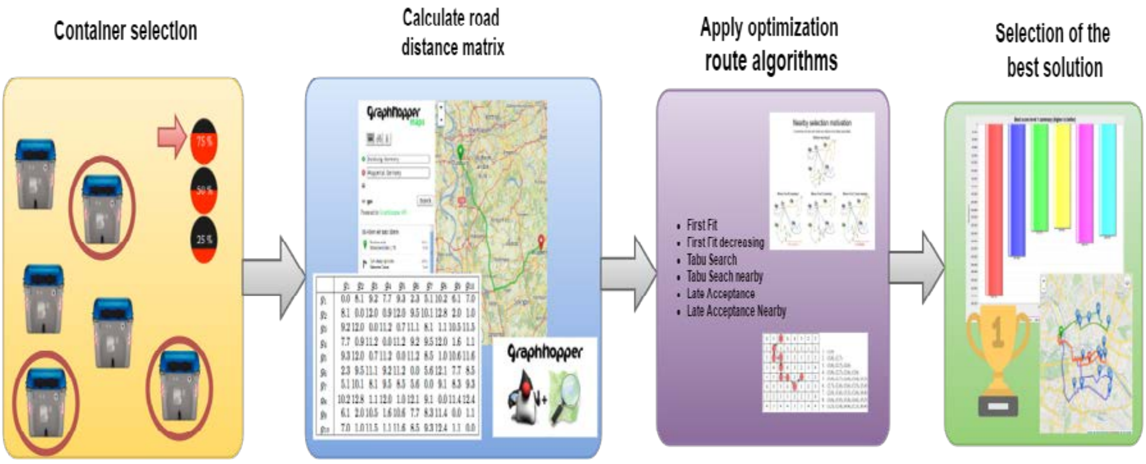

Fig. 4. Diagram of optimization route process

- Firstly, the filled containers previously defined and threshold are selected. The locations and the filling level of selected containers are obtained.
- Secondly, the road distance matrix of all selected containers is obtained. To perform this process the real distances are extracted using the framework GraphHoper. (GraphHopper, 2015; Mora & Squillero, 2015) with stored geographic data. The result of this process will be a N x N distance matrix.
- Subsequently, several algorithms are applied for a fixed time period. At this point, the possible routes to be followed by trucks will be calculated.
- Once the solution is obtained, the best score is selected. This solution is stored as waste collection planning for the next workday.

3.4. Android mobile application

A mobile application has been developed to allow truck drivers use it while performing waste collection. This application consists of two main features:

- **Guiding**: At the time of the collection of waste, the application gets the route that has been assigned by the routimg optimization system for that day (**Fig. 5**). The application provides a guide for the working day.
- **Tracking**: The application records information about the GPS location of the truck and storing data related to the speed and journey. This information is used by the website administrators to monitor trucks and stored for later studies.

Fig. 5. Smart Waste System App

4. Case of study

In order to validate the operation of the system in a real environment, a case study has been performed in Málaga. Málaga City Council has an open data portal in which there are several sets of data regarding waste from the city. We have chosen a data set of paper and paperboard containers including a total of 1473 containers of three different types: bell, underground and lateral load. We have done a simulation of the collection process of side loading containers (640 containers) and we have established a recycling center as a depot. The following figure (**Fig. 6**) shows the system administration page showing lateral load containers and recycling center.

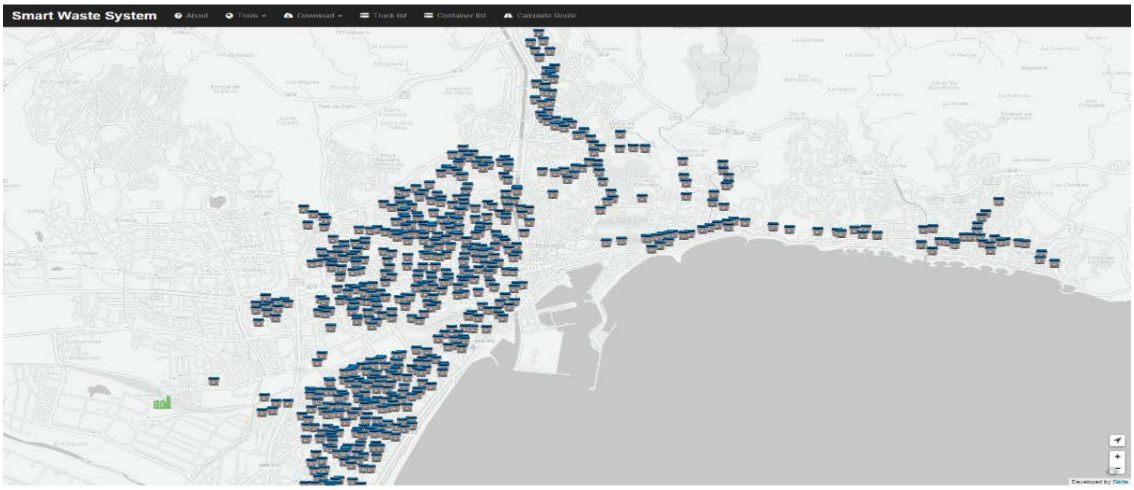

Fig. 6. Locations of lateral load containers

The load levels of containers have been generated randomly to perform the simulation. It has been set a fleet of 10 vehicles that can pick up lateral load containers.

The following figure (**Fig. 7**) shows a simulation of the route calculation performed by the Tabu Search algorithm using a tool provided by Optaplanner. The simulation shows the containers filled levels randomly generated and shows how the algorithm finds solutions during its execution. The tool draw curved lines to emphasize that in this case is road distances. The tool also showed (in the lower right corner) the total distance that involves the obtained solution.

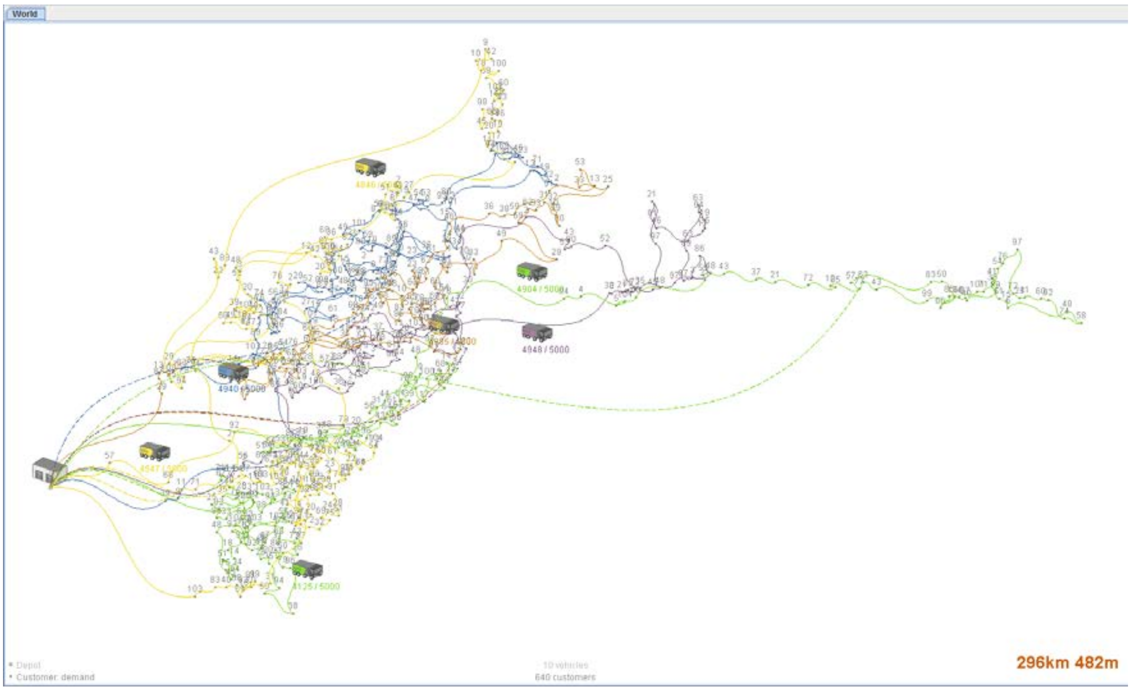

Fig. 7. Optaplanner simulation

The figure below (**Fig. 8**) shows the above solution but already represented in the web management system.

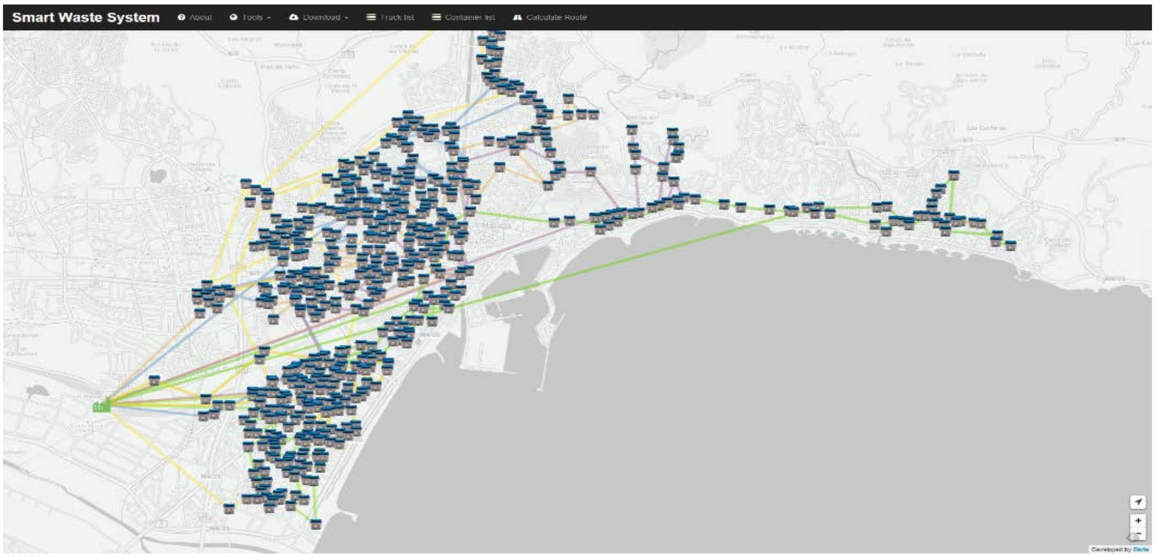

Fig. 8. Simulation on web administration page

5. Conclusions and future works

In the case study has been proven the performance of different algorithms implemented in the framework Optaplanner. It can be seen in the following charts the score obtained by the algorithms after 5 minutes (**Fig. 9**) and 2 hours of execution (**Fig. 10**).

Tabu Search algorithm to find the best solution after 5 minutes of execution, while after 2 hours of execution the best solution is found by Latte Acceptance algorithm.

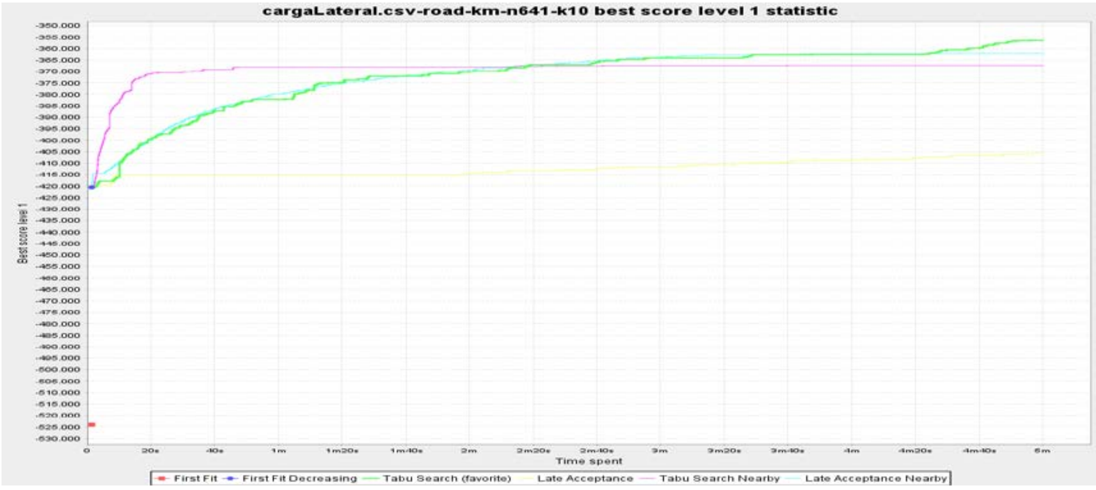

Fig. 9. Algorithms score benchmark results after 5 minutes

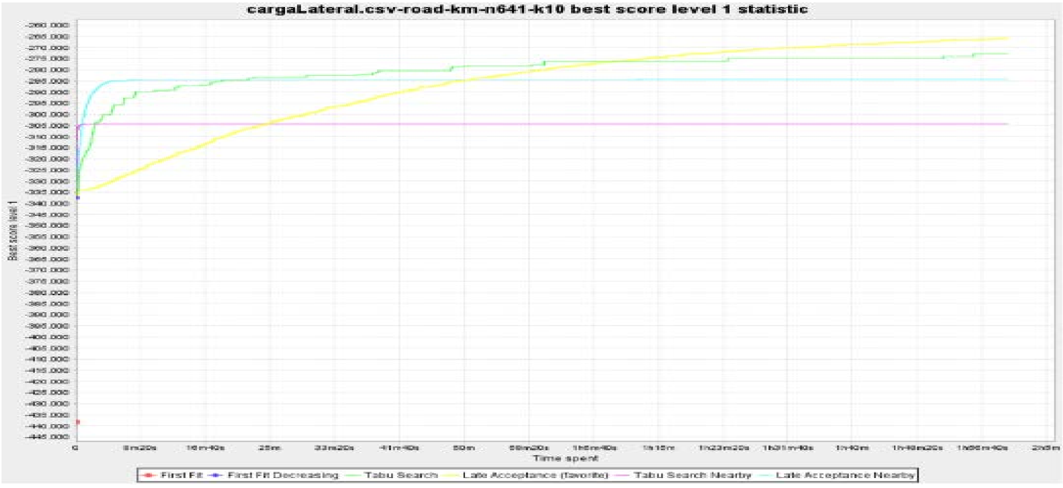

Fig. 10. Algorithms score benchmark results after 2 hours

This aspect should be kept in mind when implanting the final system as the time dedicated to the calculation may offer a better solution. Therefore there must be a balance between time and best score.

After testing in the case study, the proper performing of the optimization routing system in an environment with real data has been evaluated. In this work we have also demonstrated the feasibility of building a low cost prototype able to be a part of a WSN and get data from the containers located in the city.

Subsequent studies should evaluate and identify potential weaknesses of this prototype as well as evaluate potential adverse conditions that the prototype may suffer as well as evaluate potential adverse conditions that the prototype may suffer. Testing should be performed in real working environments.

In conclusion, the system optimizes the waste collection of a city and reduces the consumption of the vehicle fleet, and increases its life. The system and its use subsequently generate data that will be used to perform studies on areas producing more waste which will help to identify the city needs.

Acknowledgements. The research of Alberto L. Barriuso has been co-financed by the European Social Fund (Operational Programme 2014-2020 for Castilla y León, EDU/128/2015 BOCYL).

6. References

Ayuntamiento de Málaga. (n.d.). Contenedores para papel y cartón - Conjuntos de datos - Datos abiertos Ayto. Málaga. Retrieved February 8, 2016, from http://datosabiertos.malaga.eu/dataset/contenedores-para-papel-y-carton

Barbarosoglu, G., & Ozgur, D. (1999). A tabu search algorithm for the vehicle routing problem. *Computers & Operations Research*, *26*(3), 255–270. http://doi.org/10.1016/S0305-0548(98)00047-1

Dargie, W. W., & Poellabauer, C. (2010). *Fundamentals of Wireless Sensor Networks: Theory and Practice* (Vol. 5). John Wiley & Sons. Retrieved from https://books.google.com/books?id=8c6k0EVr6rMC&pgis=1

Eksioglu, B., Vural, A. V., & Reisman, A. (2009). The vehicle routing problem: A taxonomic review. *Computers & Industrial Engineering*, *57*(4), 1472–1483. http://doi.org/10.1016/j.cie.2009.05.009

ENEVO ®. (2016). Enevo – Optimising Waste Collection. Retrieved February 5, 2016, from https://www.enevo.com/

Fisher, M. L. (1994). Optimal Solution of Vehicle Routing Problems Using Minimum K-Trees. *Operations Research*, *42*(4), 626–642. http://doi.org/10.1287/opre.42.4.626

Gambardella, L. M., Taillard, E., & Agazzi, G. (1999). MACS-VRPTW: A Multiple Ant Colony System for Vehicle Routing Problems with Time Windows. Retrieved from http://dl.acm.org/citation.cfm?id=870474

Glover, F. (1986). Future paths for integer programming and links to artificial intelligence. *Computers & Operations Research*, *13*(5), 533–549. http://doi.org/10.1016/0305-0548(86)90048-1

Goldberg, D. E. (1989). Genetic Algorithms in Search, Optimization and Machine Learning. Retrieved from http://dl.acm.org/citation.cfm?id=534133

GraphHopper. (2015). GraphHopper - OpenStreetMap Wiki. Retrieved February 8, 2016, from http://wiki.openstreetmap.org/wiki/GraphHopper

Gutierrez, J. M., Jensen, M., Henius, M., & Riaz, T. (2015). Smart Waste Collection System Based on Location Intelligence. *Procedia Computer Science*, *61*, 120–127. http://doi.org/10.1016/j.procs.2015.09.170

Huang, M., & Hu, X. (2012). Large scale vehicle routing problem: An overview of algorithms and an intelligent procedure. *International Journal of Innovative Computing, Information and Control*, *8*(8), 5809–5819.

Hunkeler, U., Truong, H. L., & Stanford-Clark, A. (2008). MQTT-S — A publish/subscribe protocol for Wireless Sensor Networks. In *2008 3rd International Conference on Communication Systems Software and Middleware and Workshops (COMSWARE '08)* (pp. 791–798). IEEE. http://doi.org/10.1109/COMSWA.2008.4554519

Internet of Things, Smart Spaces, and Next Generation Networks and Systems: 15th International Conference, NEW2AN 2015, and 8th Conference, ruSMART 2015, St. Petersburg, Russia, August 26-28, 2015, Proceedings. (2015). Springer. Retrieved from https://books.google.com/books?id=XBNcCgAAQBAJ&pgis=1

Jens Lysgaard, A. N. L. R. W. E. (n.d.). A New Branch-and-Cut Algorithm for the Capacitated Vehicle Routing Problem. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.7.6581

Lysgaard, J., & Wøhlk, S. (2014). A branch-and-cut-and-price algorithm for the cumulative capacitated vehicle routing problem. *European Journal of Operational Research*, *236*(3), 800–810. http://doi.org/10.1016/j.ejor.2013.08.032

Maher, M., & Puget, J.-F. (Eds.). (1998). *Principles and Practice of Constraint Programming — CP98* (Vol. 1520). Berlin, Heidelberg: Springer Berlin Heidelberg. http://doi.org/10.1007/3-540-49481-2

Mehta, M. (2015). Esp 8266 : a Breakthrough in Wireless Sensor Networks and, *6*(8), 7–11.

Mora, A. M., & Squillero, G. (Eds.). (2015). *Applications of Evolutionary Computation* (Vol. 9028). Cham: Springer International Publishing. http://doi.org/10.1007/978-3-319-16549-3

OptaPlanner - Constraint satisfaction solver (Java™, Open Source). (n.d.). Retrieved February 3, 2016, from http://www.optaplanner.org/

Optimization, N. N. and E. (n.d.). Vehicle Routing Problem | Vehicle Routing Problem. Retrieved February 5, 2016, from http://neo.lcc.uma.es/vrp/vehicle-routing-problem/

Rochat, Y., & Taillard, É. D. (1995). Probabilistic diversification and intensification in local search for vehicle routing. *Journal of Heuristics*, *1*(1), 147–167. http://doi.org/10.1007/BF02430370

Schelter, S., & Owen, S. (2012). Collaborative Filtering with Apache Mahout Categories and Subject Descriptors. *Recommender Systems Challenge at ACM RecSys*, *i*.

Shaw, P. (1998). Using Constraint Programming and Local Search Methods to Solve Vehicle Routing Problems. *Computer*, *1520*(Springer), 417–431. http://doi.org/10.1007/3-540-49481-2

Systems, E. (2015). ESP8266EX Datasheet, 1–31. Retrieved from https://www.adafruit.com/images/product-files/2471/0A-ESP8266__Datasheet__EN_v4.3.pdf

Wellness Telecom. (2013). E-WAS. Retrieved February 5, 2016, from http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4947