Internet of Things in urban waste collection

Welcome

Dear Colleagues and Friends,

Welcome to Barcelona and to the joint MIC'2017/MAEB conferences. It is our great pleasure to have you here and would like to wish you a pleasant stay in this beautiful city and a fruitful conference.

MIC is now in its 12th edition. Since the first unforgettable meeting in Colorado, it has crossed almost all Continents and, in each new edition, has successfully attracted several new researches with extremely interesting research topics. For MIC'2017, we believe that tradition will not change – we will receive again many old friends that have been present in most of this conference's editions, and younger researchers that will continue to explore this topic in the future and show its potential, both from a theoretical and a practical point of view.

MAEB 2017 represents the 12th edition of a Spanish conference devoted to be a forum for the exchange, discussion and knowledge transference of researchers in the area of Metaheuristics and Evolutionary Algorithms. Since the first meeting in 2002, it has crossed almost all Autonomous Communities in Spain, being the witness of the evolution of the research area. MAEB 2017 covers a wide variety of topics, including methodological contributions and applications for problem solving

In MIC 2017/MAEB there will be presentations covering a wide range of subjects – over 200 high quality presentations, enriched by the presence of four keynote speakers: Paola Festa, Rafel Martí, Manuel Laguna, José Andrés Moreno Pérez and a Discussion Panel in Industrial Applications with the collaboration of Mauricio Resende (Amazon), Nuria Oliver (Vodafone), Ricardo Baeza (NTENT), Henning Wagner (Rhenus), Kristof Roomp (Microsof) and Enrique Alfonseca (Google). We are also very grateful to all authors for contributing to the success of the conferences. We hope that this selection will provide each of you with opportunities to exchange research ideas with other colleagues and to start new collaborations.

Barcelona is a multicultural and cosmopolitan city in the south of Europe. If you enjoy culture, sports, good weather, shopping, gastronomy, etc… Barcelona is the city to visit!

At this moment, we would also like to publicly acknowledge the Program Committee Members and Clusters organizer - the high quality of the programs is also due to their strong engagement in the reviewing process. We are also grateful to all sponsors, for the financial support provided, all members of the organization committee and employees of UPF that without their help will be not possible to organize it, and all colleagues that accept to participate, which greatly enhances the quality of both conferences.

We wish you all a very productive conference and a pleasant and fruitful stay in Barcelona.

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MIC 2017

The 12th edition of the Metaheuristics International Conference (MIC 2017) and the XII Metaheurísticas, Algoritmos Evolutivos y Bioinspirados (MAEB 2017) will be held in Barcelona, Spain, from the 4th to 7th July 2017.

The MIC conference series was established in 1995 and this is its 12th edition. MIC is the main event focusing on the progress of the area of Metaheuristics and their applications. As in previous editions, MIC 2017 will provide an opportunity to the international research community in Metaheuristics to discuss recent research results, to develop new ideas and collaborations, and to meet old and make new friends in a friendly and relaxed atmosphere.

Presentations covering all aspects of Metaheuristic research such as new algorithmic developments, industrial applications, new research challenges, theoretical developments, implementation issues, in-depth experimental studies, hybrid metaheuristics, etc. are welcome.

The MIC 2017 will be organized jointly with the MAEB (Metaheurísticas, Algoritmos Evolutivos y Bioinspirados), the most well-known conference in the area of Metaheuristics, Evolutionary and Bio-Inspired Algorithms.

Topics of Interest

Topics of interest include, but are not limited to:

— **Techniques** such as tabu search, simulated annealing, iterated local search, variable neighborhood search, bio-inspired algorithms, memory-based optimization, evolutionary algorithms, memetic algorithms, ant colony optimization, particle swarm optimization, scatter search, path relinking, hybrid metaheuristics, simheuristics, matheuristics, etc. Including techniques that enhance the usability and increase the potential of metaheuristic algorithms such as parallelization of algorithms, reactive search mechanisms for self-tuning, offline metaheuristic algorithm configuration techniques, algorithm portfolios, etc.

— **Empirical and Theoretical Research** in metaheuristics including large-scale experimental analyses, algorithm comparisons, new experimental methodologies, engineering methodologies for stochastic local search algorithms, search space analysis, theoretical insights into properties of metaheuristic algorithms. Including applications of well-known and classical problems as Traveling Salesman Problem, Vehicle Routing Problems, Scheduling Problems, Location Problems, etc.

— **Industrial Applications** of metaheuristics in fields such as transportation, health care, bioinformatics, data mining, planning and scheduling, production and operations management, economics, marketing, telecommunications, logistics and supply chains, etc. Particularly, it is welcomed are innovative applications of metaheuristics with high impact in real business and organization.

— Contributions on the **Interface of Metaheuristics** with other disciplines, such as agent-based models, integer programming, constraint programming, machine learning, deep learning, etc.

— **Challenging New Problems** such as big data and large-scale optimization problems, multi-objective, stochastic, dynamic problems and new challenge problems.

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MAEB 2017

XII Congreso Español de Metaheurísticas, Algoritmos Evolutivos y Bioinspirados (MAEB 2017)

El congreso nacional sobre Metaheurísticas, Algoritmos Evolutivos y Bioinspirados (MAEB) pretende ser un foro de encuentro, discusión y transferencia de conocimiento entre investigadores en el campo de las metaheurísticas y los algoritmos bioinspirados, con el fin de presentar e intercambiar experiencias y resultados. La XII edición, MAEB'2017, se celebrará en Barcelona, junto con XII Metaheuristic International Conferrence (MIC 2017).

Temas

Son trabajos de interés en este congreso los que aborden alguna de las siguientes metodologías de resolución de problemas de optimización (las siglas corresponden a su denominación original en inglés) o sus aplicaciones a la resolución de problemas:

ACO: Algoritmos basados en colonias de hormigas
CE: Entropía cruzada
CLA: Algoritmos de clasificación y aprendizaje
CP: Programación por restricciones
CH: Heurísticas cooperativas
DE: Evolución diferencial
ECO: Computación evolutiva
EDA: Algoritmos basados en estimación de distribuciones
EE: Estrategias evolutivas
EP: Programación evolutiva
FMH: Metaheurísticas basados en lógica difusa
GA: Algoritmos genéticos
GLS: Búsqueda local guiada
GP: Programación genética
GRASP: Procedimientos voraces aleatorizados
HA: Algoritmos híbridos
HH: Hyperheurísticas
ILS: Búsqueda local iterada
IS: Algoritmos basados en el sistema inmunitario
MA: Algoritmos meméticos
MOMH: Metaheurísticas multiobjetivo
MTH: Mateheurísticas
NC: Computación natural
NN: Redes Neuronales
PA: Algoritmos paralelos y distribuidos
PR: Re-encadenamiento de trayectorias
PSO: Algoritmos basados en nubes de partículas
SA: Enfriamiento simulado
SI: Algoritmos basados en sociedades/enjambres
SS: Búsqueda dispersa
TS: Búsqueda tabú
VNS: Búsqueda de entornos variable

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Metaheuristics: Proceeding of the MIC and MAEB 2017 Conferences

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Contents

Internet of Things in urban waste collection

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Abstract

Nowadays, the waste collection management has an important role in urban areas. This paper faces this issue and proposes the application of a metaheuristic for the optimization of a weekly schedule and routing of the waste collection activities in an urban area. Differently to several contributions in literature, fixed periodic routes are not imposed. The results significantly improve the performance of the company involved, both in terms of resources used and costs saving.

1 Introduction and research challenge

As urbanization and demographic growth increase, according to the expected results provided by a World Bank report [6], global solid waste generation will increase by nearly 50% over the next decade. In this context, the adoption of innovative technologies and the optimization of waste collection management generate gains for local administrations and the whole community. This paper addresses this issue by proposing the solution developed under the Optimization Networked Data in Environmental Urban Waste Collection (ONDE-UWC) project, funded by the Regional Council of Piedmont (Italy). The project involved the Department of Control and Computer Engineering of the Politecnico of Torino, CIDIU S.p.A., a company that manages the waste collection in the urban area near the city of Turin (Italy), and other technological partners. The main goal of the project was to minimize the operational costs i.e. the total costs of all the time shifts used. The company divides the day in three time shifts, the first two are basically equal, while the third one is more expensive. The main characteristic of this project is the application of the Internet of Things (IoT) paradigm to the waste collection. In fact, sensors installed on dumpsters and vehicles share data concerning the number of users' accesses, the waste weight and volume, which are then used as input of a heuristic for the scheduling and routing of weekly waste collection activities. Differently from several approaches in the literature, as [2, 3, 5], our approach does not impose fixed periodic routes. This innovative solution has the aim of increasing the efficiency of the whole process, with the consequent reduction of the total operating and environmental costs.

2 The Metaheuristic

As above introduced, data gathered from the sensor network and on-vehicle weight system are processed by a metaheuristic optimization algorithm, which dynamically provides an efficient schedule. The optimization problem is described by means of a mixed integer linear program (MILP). For a more detailed discussion about the model, the reader can refer to [4]. Due to the high number of variables, on the order of $\mathcal{O}(2^{IJ^2T})$, where I, J and T are respectively the number of vehicles, dumpsters and time steps to plan, the model becomes computationally hard to solve, even for small size instances. This complexity led us to choose a metaheuristic composed by four phases: Clusterization, Exact Optimization, Improvement, and finally Post-Optimization. In the first phase, the *Clusterization*, single dumpsters of each city are grouped into clusters (i.e. we obtain 10 big clusters that are statically created and are considered fixed during the algorithm execution). This choice is inspired by the strategy of CIDIU S.p.A to collect waste from all dumpsters located in the same city. Moreover, this aggregation allows us to reduce the size of the problem, defining a set of clusters $\mathcal{C}$ (with cardinality C). Thus, we define $d_{c_1c_2}$ the distance between cluster c_1 and cluster c_2, whose value is equal to the length of the shortest edge that connects a dumpster in c_1 and a dumpster in c_2. For example, if $d_{j_1 j_2}$ is the distance between dumpster j_1 and dumpster j_2, the distance between clusters will be $d_{c_1 c_2} = \min_{j_1 \in c_1 j_2 \in c_2} d_{j_1 j_2}$. Furthermore, we define Θ_{ct} as the volume of waste that arrives to the cluster in time period t. Since the model in [4] requires this quantity to be expressed as a percentage of the total volume of the cluster, we set Θ_{ct} equal to the maximum growth rate of the dumpsters in the cluster. If we call Θ_{jt} the volume of waste that arrives to dumpster j in time period t, then $\Theta_{ct} = \max_{j \in c} \Theta_{jt}$. Moreover, we have to define the maximum capacity of the cluster V_c as equal to the sum of the capacities of all the dumpsters $V_c = \sum_{j \in c} V_j$. Finally, we denote $\hat{a}$ the time spent to empty a cluster. It is equal to the sum of the emptying times of all the dumpsters, plus the time of a tour between all the dumpsters in the cluster. Once we have defined the clusters, in the *Optimization* phase we solve the MILP problem by considering clusters instead of dumpsters. Due to the transition from single dumpsters to clusters, we have to remove the constraints which impose that only one vehicle can void a dumpster in each time shift.

Taking into account the solution obtained by the Optimization, during the phase *Improvement*, a feasible solution of the problem with the single dumpsters is obtained. The procedure, for each vehicle used in the solution of the cluster problem, creates $list0$ (the list with all the non empty dumpsters in each cluster visited by the vehicle). Then, it sorts $list0$ in decreasing order of quantity of waste and after that, it creates $lists1$: the list of all the dumpsters that the vehicle will void. Next, it adds all the dumpsters of $list0$, one by one, into $list1$ until the vehicle is full or until the limit of the time shift is reached. Finally, it sets to zero the percentage of volume occupied by the waste in each dumpster in $list1$. This procedure is repeated for all vehicles. By using this algorithm we ensure that the vehicles do not visit the same dumpsters more times nor they visit nearly empty dumpsters.

Then, the algorithm applies a Tabu search by considering as starting solution the one obtained and it completes the computation by the *Post-Optimization* phase. In this phase, the feasible solution of the original problem is refined solving a TSP problem, according to [1].

3 Results

In order to evaluate the solution, computational tests and simulations are conducted using real data provided by CIDIU S.p.A. The problem considers 525 dumpsters, 8 vehicles, and a week of company activity (i.e., 3 time shifts for 6 days). In particular, we conduct a comparative analysis, between a real month of CIDIU S.p.A activity before the introduction of the heuristic and a simulated month (by using statistical model of the production computed from historical data) with the use of our heuristic, calculating the following three key performance indicators (KPIs):

- the average number of third shifts during a week of activity (nTS);
- the average number of vehicles used daily (nV), calculated as the number of vehicles used during one month of activity, divided by the number of shifts;
- the average percentage of waste volume that a dumpster contains at the moment of collection (WV%). When a vehicle voids a dumpster, an on-board probe records the volume occupied by the waste. If we divide this value by the volume of the dumpster, then we compute a percentage that indicates how much the dumpster is full. We obtain this KPI by taking the average over all the collections and all the dumpsters.

Due to the originality of the problem, we did not find any benchmark algorithm in the literature to compare with our algorithm.

The main finding is an improvement regarding all the KPIs, as illustrated in the Table 1. In particular, although the initial difficult planning based on aperiodic time shifts rather than the periodic ones, the inefficiency of the overestimated waste production forecasts led the CIDIU S.p.A management to consider a change of the operative strategy in order to adopt the proposed solution, justified by the good performance of the algorithm. In fact, CIDIU S.p.A no longer had recourse to a third shift, and the percentage of vehicles used decreased by 33% in the time window considered. On the one hand, this has a positive

Table 1: KPIs before and after the optimization

KPIs	CIDIU S.p.A solution	Simulated solution
nTS	1.44	0
nV	3	2
WV%	0.28	0.70

impact on the work conditions of the technical staff, particularly of the drivers. Indeed, they will not have to work during night and will also gain a more balanced work load. On the other hand, CIDIU S.p.A obtains a reduction of the operational costs and free resources to invest in offering new services to the citizens, relevant for its competitiveness. Moreover, another important result of the metaheuristic is its lower computational time, providing a good solution in less than one hour. For this reason, the algorithm can be run several times during the day, allowing the plan to be adjusted, and it is possible to account for missed operations (e.g., when the vehicle cannot collect the waste, due to the presence of a parked car that blocks the operation). These important results are leading the partners to continue in the same direction by focusing their research efforts on the ”Project on Innovative Environmental Health for the recovery of solid waste based on optimization methods of waste collection cycles and accurate pricing” (PAIRUMA) project. Starting from the previous initiative ONDE-UWC, this new project has the aim of refining the mechanism of optimization of waste collection activities, in order to extend it as a best practice, also in similar territorial contexts. Moreover, PAIRUMA addresses the integration of the operational perspective of the topic, with the implementation of a new paradigm for the accurate pricing. In particular, the data obtained from sensors on dumpsters will provide the indication of parameters useful to define the right tariff and rewarding mechanism for the final users.

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