Integrating sensors data in optimization methods for sustainable urban logistic

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In the world of urban mobility and logistics, new technologies are spreading and are deeply changing the way in which this business is conducted. These technologies are based on three factors.

The first one is the growth of city population i.e. the increasing number of customers in the same area that decreases the delivery costs. Nowadays, UN [?] calculates that the 54 % of the world's population lives in cities and this percentage is expected to grow to 66 % by 2050.

The second factor is the development and diffusion of technologies that enable industries as well as customers to directly interact without the need of resellers i.e. smart-phones. A new business model based on this opportunity is social engagement, it consists of the request by the companies to the people to perform part of their job in exchange for a reward. Another example is e-grocer which is changing the way the grocery business is conducted. It allows people to purchase groceries online and to receive them at home or in given centers. The flow of operations of this business channel is the following: customers order groceries using websites or mobile applications, the orders are executed by the company (basically, for each order, the company has to collect in a single container all the groceries ordered by the customers), then the containers with the goods are delivered to the customers, either directly to their user house or to a collection point.

The third factor is Internet of Things (IoT), a new paradigm that enriches instruments with the capabilities of collecting data and to communicate with other devices. This technology is already spreading in several applications. In Figure 1, we represent the growth and the expected growth of the number of the connected devices.

The main advantage of this technology is to gather in real time local data of a wide area. Nevertheless, the main problem with this technology is that it requires a large infrastructure in order to give to all the sensors the connectivity or as an alternative to use manpower to visit all the sensors.

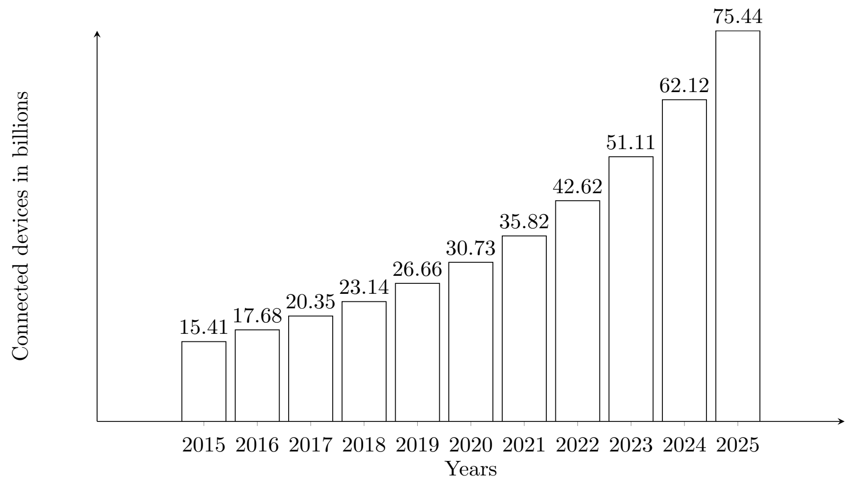

Figure 1: The figure shows the number of connected devices in billions and a future forecast. The data are taken from https://www.statista.com/statistics/471264/iot-number-of-connected-devices-worldwide/

The main objective of this thesis is to develop new optimization methods and algorithms that use new opportunities and solves new problems generated by these factors. In particular, we focus on the exploitation of the sensor data in optimization method for sustainable urban logistics by considering two case studies: the optimization of waste management and social engagement for e-grocery and IoT data collection. In both of them, the use of new technologies modify the way by which information is gathered and communicated, hence it changes how the studied problems can be formulated and solved.

The first case study has been chosen because of the lack of information usually associated with the sector waste collection operations. To our knowledge, the project Optimization for Networked Data in Environmental Urban Waste Collection (ONDE-UWC) [1] is the first one that exploits IoT data for smart-city applications. In this project, the data related to the evolution of the quantity of waste are collected by the vehicles used for the collection. By using these data, it is possible to develop an optimization model, able to consider the evolution of the waste and to plan in an optimal way the routing and scheduling of the waste collection. This is a very important example of how IoT data change the nature of the optimization problem and the associated business model.

Furthermore, we choose this case study because optimization of waste collection is of central importance for public health, it has an important economic component, and the efficiency of the services produces economic benefit. Moreover, waste management has political importance because it involves local ad-

[1] `www.onde.city`

ministrations and it also has a social impact, if we consider emissions and pollution that can compromise the health of citizens and visual pollution.

This problem is even more important due to the expansion of urban areas and the growth of consumption increase waste production. [?] estimates that in the European Union each year more than 2.3 billion tons are produced. The 10% of this quantity is the municipal waste that is characterized by many critical factors due to the urban environment in which it is performed. [?] enlighten the political importance, because of its composition, distribution among many waste generators, and link to consumption patterns. For all these reasons, in this thesis we face the problem of optimizing the number of time shifts and the corresponding routing of the waste collection operations of a company operating near the city of Torino. The results obtained in this application are good enough to convince the companies involved to build a commercial solver based on the solution.

The model developed in this context can be used to describe every problem characterized by a network of nodes where each one of them is producing, with a different rate, a quantity that must be picked up and delivered to a given node, before too much quantity is produced. Examples of this kind of quantities are the number of people waiting for the bus at the bus stations, the quantity of waste in a dumpster or the number of mechanical parts produced by several machines that need to be transported to another machine. Since in those contexts it can be difficult to have real-time information, it is possible to calibrate a statistical model by using the data collected by IoT devices. The study is innovative because it does not enforce the periodicity of the routes. Nevertheless, due to this additional degree of freedom, the mathematical model rises in complexity and it is not solvable with commercial solvers. For this purpose, we develop a math-heuristic able to compute a solution of the problem in a time compatible with the operations of the company. This solution method allows the heuristic to be used in the real field and, with the IoT architecture implemented in the project represent a breakthrough for the sector of municipal waste collection.

We choose to consider social engagement for e-grocery and IoT data collection because collecting data from the sensors and delivering packages are actions that do not require any specialization and that can be performed by every person. Furthermore, while the standard workforce has to travel on purpose to go to the location of the task, it is possible that some person passes in that area for doing other stuff. Then, it is possible to ask common people to perform tasks that otherwise would have required the standard workforce. This principle generates two positive effects: the first one is that the company can use its workforce for doing tasks that require more skilled people, the second is that the tasks are done by using travels that would have occurred in any case (this decreases the total number of travels, hence it decreases traffic and pollution).

We choose to consider both e-grocery and IoT data collection because of their similarities: both problems have an important time constraint. The information of the sensors must be gathered as soon as possible otherwise they are old and they do not describe the real scenario, while for an e-grocery retailer delivering as soon as possible increases the quality of the product and of the service (if the groceries are not delivered for a long time they go bad).

The principle of social sharing can be applied in several situations, for example of the Coiote project by TIM. This project has the goal to invite people sharing their internet connection with dumpsters in order to let each dumpster to communicate its quantity of waste to a central unit. In this way, the central unit can organize the waste collection operations in an optimal way by voiding the dumpsters only when they are nearly full. Logically, in exchange to the internet connection, TIM gives people a reward.

The underline optimization problem is to minimize the amount of rewards and to give connection to all the dumpsters. The importance of this project relies on the fact that it applies the users engagement paradigm to activities of importance to the community.

This problem has never been tacked in the literature despite the fact a huge amount of applications can be described by such a model. For example, the same model of the Coiote project is suitable to every situation where it is possible to ask people to do some tasks by sharing their resources in exchange for a reward. Furthermore, this business model can be related not only to social engagement but also to the workforce of the company distributed in the urban context. The only difference is the costs of the reward for the execution of the task: users are cheaper than workers because they do not need to be hired. The main limitation of this model is the need for a reliable model of the flow of people. Once again, it is important to remark that the technology spread is ready to support these business models [2].

To our knowledge, this is the first time that the optimization problem derived from crowd-sourcing is considered. We formulate the deterministic and the stochastic mathematical model of the problem and we propose heuristic methods able to find a good solution in a reasonable amount of time for both types of problems. Furthermore, we define a model for the urban flow of people and we calibrate it with some real data. The innovation provided by these methods is two-fold: they are the first studies exploiting crowd-resources for performing tasks and they also develop efficient solution methods able to compute a good solution in a time interval compatible with the needs of a real field application.

We consider the problem in a network whose nodes, in the real field, can be thought as mobile phone cells. This assumption makes the problem more realistic because we can have data regarding the number of people in each cell thanks to their mobile phones. We assume that in each cell there is demands or offers i.e. tasks to do or people available to do them (see Fig. 2).

The reason for this assumption is due to the fact that the people in a cell can do all the operations in that particular cell with a little cost. This problem depends on two factors: the variability of the number of people in a cell and the possibility that some people could accept to do the task but then they omit to do

[2] Data available from [?] say that the 64% of the European population has a mobile internet connection (more than 80% in Italy).

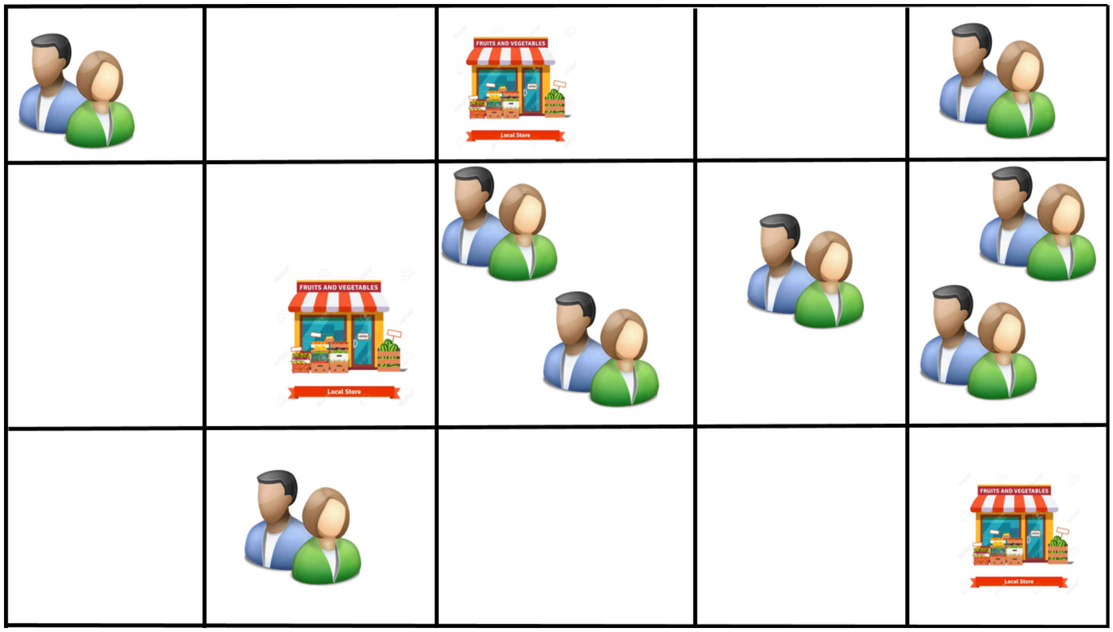

Figure 2: Example of network: in each node there are customers available to transport freight or there is a shop.

it. The problem has been formulated as an integer program in the deterministic setting.

Since the deterministic framework does not take into account the variability in the number of available customers, the problem has been formulated as a multiperiod two-stage integer stochastic programs in the stochastic setting. The stochastic version is approximated by discrete probability distributions that generate the scenario trees. The resulting approximated problem becomes a deterministic integer problem of big dimension, beyond the reach of exact methods. Hence, heuristics and meta-heuristics are required. In this context, we develop useful meta-heuristics for both the deterministic and stochastic versions of the problem. It is important to remark that, since this problem has not been found in the literature, our results define the present best performance. In order to make a complete analysis of the proposed solution methods, to assess the efficiency of the meta-heuristics and to evaluate the robustness of the solutions we ran several numerical experiments by mean of a generator of instances of different sizes. These experiments conclude the analysis of the optimization of social engagement.