Procedura selettiva pubblica per titoli ed esami per la copertura di n. 59 posti di cat. D – Posizione economica D1 – famiglia professionale “Specialista della trasformazione digitale” (BURERT n. 252/2019)

Prova Scritta 09 Luglio 2020

Prova n. 3 – Sorteggiata

The Smart Waste-Bin Project.

Waste management is one of the primary problems that the world faces in developed as well as developing countries.

In many parts of the world, the solid waste management system has been perpetuating over the centuries without any innovation. Collection methods are still very inefficient: weekly agendas, trucks travelling long distances, waste often laid out on sidewalks and public roads.

One of the key issues in the waste management is that the garbage bins at public places overflow before the next collection shift. This causes various problems, from unpleasant appearance to rat proliferation, leading sometimes to major health problems.

To avoid those issues and maintain public cleanliness and health, Region Emilia-Romagna wants to enhance the waste recollection and management process.

The idea is to develop a smart garbage alert system for a better garbage management, with the support of an advanced ICT system. The ICT system should encompass the whole process: from garbage level sensing to planning of vehicle trips and monitoring of bin emptying. In case of failure of some components, appropriate remedial or alternate measures have to be put in place.

A review text is attached as a support reference.

Your Task.

You are expected to outline a solution to the problem at hand and make a proposal as to the design and implementation of a digital system to support it. The description should comply with the following item list:

1) Rappresentare sinteticamente il processo attuale e quello che viene proposto, evidenziando il ruolo delle tecnologie
2) Delineare l’architettura del sistema a supporto del nuovo processo, proponendo possibili tecnologie abilitanti, individuando le principali funzionalità applicative, uno schema ad alto livello dei dati coinvolti e i tipi di interfaccia richiesti

3) Definire il macro-piano di lavoro che identifichi le principali fasi e le reciproche relazioni di dipendenza, gli obiettivi di ogni fase, le competenze specialistiche necessarie
4) Individuare le modalità con le quali sia possibile, a partire dai dati inseriti a sistema o acquisiti dal sistema, estrarre informazioni utili al processo decisionale dell’Ente, descrivendo gli strumenti utilizzabili per la fruibilità e l’analisi dei dati per l’Ente e per i cittadini (anche in logica OPEN DATA).

Allegato Prova Scritta n. 3

The future of waste management in smart and sustainable cities: A review and concept paper

(abridged version. Full text available at: https://www.researchgate.net/profile/Behzad_Esmaeilian/publication/328188191_The_future_of_waste_management_in_smart_and_sustainable_cities_A_review_and_concept_paper/links/5bbe0aa9a6fdccf2978fdd2d/The-future-of-waste-management-in-smart-and-sustainable-cities-A-review-and-concept-paper.pdf)

Behzad Esmaeiliana, Ben Wangb, Kemper Lewisc, Fabio Duartee, f, Carlo Rattif, Sara Behdadc, d,

a *Industrial Engineering and Engineering Management, Western New England University, 1215 Wilbraham Road, Springfield, MA 01119, USA*
b *The H. Milton Stewart School of Industrial & Systems Engineering, Georgia Institute of Technology, 755 Ferst Drive, NW, Atlanta, GA 30332, USA*
c *Mechanical and Aerospace Engineering Department, University at Buffalo, SUNY, 318 Jarvis Hall, Buffalo, NY 14260, USA*
d *Industrial and Systems Engineering Department, University at Buffalo, SUNY, 243 Bell Hall, Buffalo, NY 14260, USA*
e *Urban Management, Pontificia Universidade Católica do Paraná, Curitiba, Brazil*
f *The Senseable City Lab, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA*

ABSTRACT

The potential of smart cities in remediating environmental problems in general and waste management, in particular, is an important question that needs to be investigated in academic research. Built on an integrative review of the literature, this study offers insights into the potential of smart cities and connected communities in facilitating waste management efforts. Shortcomings of existing waste management practices are highlighted and a conceptual framework for a centralized waste management system is proposed, where three interconnected elements are discussed: (1) an infrastructure for proper collection of product lifecycle data to facilitate full visibility throughout the entire lifespan of a product, (2) a set of new business models relied on product lifecycle data to prevent waste generation, and (3) an intelligent sensor-based infrastructure for proper upstream waste separation and on-time collection. The proposed framework highlights the value of product lifecycle data in reducing waste and enhancing waste recovery and the need for connecting waste management practices to the whole product life-cycle. An example of the use of tracking and data sharing technologies for investigating the waste management issues has been discussed. Finally, the success factors for implementing the proposed framework and some thoughts on future research directions have been discussed.

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3. The role of data, technology, and people in smart and sustainable cities

To transform the urban environment into smart regions, many infrastructure and management-related factors are involved. In this section, we will discuss the role of three factors of technology, data, and people as highlighted by (Deloitte, 2015) with particular emphasis on the role of data and citizens, as they are among main driving forces of our proposed framework in Section 4. Later on in Section 4, we will discuss that new business models and policies are important too.

Technology or infrastructure is only one element of this transformation, the collection of appropriate data toward defining smart solutions and changes that smart solutions bring into consumer behavior are two other cornerstones of SCs (Deloitte, 2015). The collection of citizen-generated data is becoming more convenient as the number of smartphones and mobile devices users are increasing. The number of mobile devices sold in the global market in 2015 reached an all-time high of 1.4 billion units of which 70% were expected to purchase to replace older devices (Gartner, 2016). *Data* collected through smartphones is one of the main elements of smart communities. Data are often geo-referenced meaning that the data can be linked to a specific geographic location through a pair of coordinates.

In addition, data are often time-specific meaning that data are relevant to a specific moment of time. The geo-referenced data not only are helpful for understanding the behavior of individual citizens but also for extracting trends and ommunity features. Data can be categorized under 1) private social data generated mainly by citizens, and 2) information about the public infrastructure collected by sensing technologies that are deployed for monitoring and management purposes. We are reaching the point when smart dust, the pervasive network of millimeter-size sensing and communication technologies are embedded in devices present in all daily activities (Warneke et al., 2001). In addition to data collection, new advancements in data processing systems such as edge and fog computing enable IoT users to localize their data processing needs and bring data processing close to data collection nodes. This improves the system latency, removes the need for centralized cloud servers, and reduces the computational costs as well as data privacy issues and energy consumption (Shi et al., 2016).

Several sources of data can be used to retrieve smart communities data, ranging from the surveys conducted by the US Census Bureau to datasets collected by various governmental departments and private companies to apps and crowd-sensing where data acquisition is done by integrating readings from various devices and embedded sensors carried by citizens. As an example of datasets available through governmental agencies, SF OpenData publishes the data collected in the city of San Francisco under ten main categories of (1) economy and community, (2) city management and ethics, (3) transportation, (4) public safety, (5) health and social services, (6) geographic locations and boundaries, (7) energy and environment, (8) housing and buildings, (9) city infrastructure and (10) culture and recreation (SF OpenData, 2017). Pan et al. (2013) grouped the main devices for collecting data into four categories: mobile devices, vehicles equipped with GPS devices, smart cards, and floating sensors.

Currently, data are collected essentially everywhere by different organizations, but what is missing is the communication between different sources and the lack of an integrated and connected data cloud that can be shared between different stakeholders (Lohr, 2014; Dasu and Johnson, 2003). Pan et al. (2013) have discussed that the data collected from SCs have been analyzed in the literature for the following purposes: (1) prediction of the patterns and models of citizens behavior, (2) tracing the citizen data at individual levels, (3) tracing the social relation and interactions among individual citizens, (4) connection between region characteristics and residents behavior of each region, (5) visualization of complex data and dynamics of city evolution, and (6) unwanted privacy issues and personal identity.

In addition to data, *citizens* made up another element of SCs as social machines. The sustainable cities may seek ways to use the capabilities of disruptive technologies toward making proper changes in human behavior, disruptive technologies that change consumer behaviour toward pro-environmental behavior. Chourabi et al. (2011) categorized the critical factors of SC initiatives under eight categories of management, governance, policy, technology, people, infrastructure, economy, and natural environment.

The structure and dynamics of socio-technological communities formed in SCs contribute to sustainability results. Cities are made up of both citizens and infrastructures for food, water, energy, transportation, and other service activities. Therefore, they are considered as complex social-technological systems, where citizens as human agents operate various technological systems (Nam and Pardo, 2011a). Sustainability requires critical insights into the way SCs are designed, the ùway citizens use technologies, as well as the ways technologies, are valued and should be altered in more sustainable ways. The technological systems can be divided into two types depending on the type of decision makers: (1) systems that are built through decisions collectively made through public policy, and (2) systems that are built through individual decisions by citizens. The waste generation system is categorized under the second group, where the waste generation rate is influenced by decisions made by individuals. Arguably, most of the decisions made by individuals are mainly based on technical criteria such as cost rather than societal or ecological values (Miller et al., 2008). Therefore, waste management is becoming a complex urban problem. The role of citizen behavior is further discussed in Section 4.2.2. We should note that the relationship between citizens and technology is a two-way connection. While citizen decisions influence waste management system, the waste management infrastructure surrounding individual citizens also influence citizens behaviour (Liboiron, 2014). Cities require innovative, cross-industry solutions to facilitate collection and disposal of solid waste. The solutions should be replicable, adaptable, and scalable (Patil et al. 2017). Ahvenniemi et al. (2017) conducted a study to compare the extent in which the concept of SCs addresses the same concerns as the concept of sustainable cities. They compared the set of performance assessment systems used in both SCs and sustainable cities and concluded that the existing SCs frameworks do not sufficiently target the sustainability-related indicators, particularly environmental indicators such as energy, waste, and water management are underrepresented. Neirotti et al. (2014) reported a different conclusion about the energy domain and concluded that renewable energy and people mobility domains have received the most attention in many SC initiatives. The coverage of waste management domain is still *limited*. Surprisingly, even in the context of sustainability, the set of 29 indicators used by United Nations Cities Reports and adopted by various organizations only include energy and water consumed as main resources and does not include other types of resources such as solid and hazardous waste (Cote et al., 2006).

4. Review of IoT-enabled waste management practices

In this section, first, we briefly provide an overview of waste management practices and then discuss the major trends in waste management in SCs literature.

To the best of our knowledge about waste management literature, the studies on waste management have been focused on three main objectives of (1) waste characterization, (2) waste quantification, and (3) waste management practices.

Waste *characterization* studies mainly focus on sampling waste stream in different geographical regions with the aim of sorting and classifying waste stream into several fractions such as organic, paper, metal and plastic (Gomez et al., 2008; de Vega et al., 2008). Waste *quantification* studies on the other hand were mainly focused on estimating the amount of waste generation in a wide range of industries such as construction (Bossink and Brouwers, 1996), food (Parfitt et al., 2010), e-waste (Bigum et al., 2013), forestry waste (Castro et al., 2017), medical waste (Patwary et al., 2009), and ship scraping waste (Reddy et al., 2003). In addition to waste generated, estimations of waste recycled, incinerated, landfilled, and composted have been of interest in the literature.

The existing *management* practices include three main practices: prevention practices (e.g. product design), end-of-pipe strategies (e.g. recycling, waste separation, incineration, proper landfill), and environmental restoration practices (Dornfeld, 2013). *Prevention* practice studies have been mainly focused on analyzing strategies such as waste minimization (Ajayi et al., 2017), improving residents awareness (Clarke and Maantay, 2006), and waste legislation (Cooper, 2000). *End-of-pipe strategies* on the other hand aimed at recovering the value still embedded in the waste stream through practices such as proper and on-time collection (Wäger et al., 2011), recycling, waste repurposing (Wadhwa et al., 2015), waste separation methods both destination-separated collection and origin-separated collection (Sukholthaman and Sharp, 2016), reuse, recycling, and incineration or waste-to-energy (Syngellakis, 2014). Finally, *environmental restoration strategies*, also known as oops strategies have been focused on restoring the damaged environment after waste streams leak to the environment.

It should be noted that among the above-mentioned three practices, prevention practices offer the highest effectiveness with the lowest cost, while environmental restoration is the most expensive practice with the lowest effectiveness (Dornfeld, 2013). Although a lot of work has been done on the waste management topic, the concept of IoT-enabled waste management is quite new and the number of publications in this field is growing. The studies that have addressed IoT-enabled waste management systems can be classified into the following four categories:

- Development of data acquisition and sensor-based technologies (Glouche and Couderc, 2013; Catania and Ventura, 2014);
- Development of communication technologies and data transmission infrastructure (Medvedev et al., 2015; Chowdhury and Chowdhury, 2007; Longhi et al., 2012);
- Test the capabilities of IoT systems in field experiments (Hong et al., 2014; Gutierrez et al., 2015); and
- Truck routing and scheduling for waste collection operations (Anagnostopoulos et al., 2015; Ustundag and Cevikcan, 2008; Chang et al., 1997).

Several studies have discussed the overall system architecture of IoT enabled waste management systems in which a number of bins are equipped with RFID tags for identification purpose, capacity sensors for waste level detection, actuators to lock the bin lids once they are filled, and wireless antennas to transmit sensor data to the network for waste collection operations (Longhi et al., 2012; Anagnostopoulos et al., 2015; Medvedev et al., 2015). Anagnostopoulos et al., (2015) have used the above-defined architecture integrated with a transportation system consisting of a number of low and high-capacity trucks equipped with GPS spatial technologies to describe the capabilities of IoT in both real-time monitoring of waste levels in trash bins as well as truck navigations for efficient waste collection. Hannan et al. (Zhang et al., 2012) provided a review of ICT technologies in waste management applications and classified the technologies into four groups of spatial technologies (e.g. GIS, GPS), identification technologies (e.g. RFID, barcodes), data acquisition technologies (e.g. sensors, imaging) and data communication technologies (e.g. GSM, Wi-Fi, Bluetooth). The last three groups have received more attention in the waste management literature.

Before we start reviewing data identification, data acquisition, and data communication technologies, we will briefly discuss the way spatial technologies have been used for waste management. Reviewing the literature reveals that spatial technologies have been mainly used for the purpose of landfill site selection, path planning, and routing optimization problems. For example, Ghose et al. (2006) have developed a GIS-based routing model that define the optimal path for solid waste collection based on the population density, the types of road, and road network. Sumathi et al. (2008) have applied GIS-based data in a multi-criteria decision model to identify the optimal site for a landfill construction. Şener et al. (2010) also have used GIS data for landfill site selection. Leao (2001) have conducted a dynamic analysis in the GIS environment to quantify the demand of proper land for solid waste disposal over time.

One stream of literature has been focused on the development and application of identification and data acquisition technologies. The *identification* technologies are mainly RFID-based. To name a few studies, Glouche (2015) developed an RFID-based framework for waste identification in which digital information and

QR codes attached to objects help users with correctly sorting and placing wastes in trash bins. Chowdhury and Chowdhury (Chowdhury and Chowdhury, 2007) showed how municipalities can use an RFID-based automatic waste weighting and identification system to identify stolen bins and communicate waste management information with individual households. Rada et al. (2013) also discussed the way that using an integrated Web-GIS system with RFID allows efficient waste separation in Italy. Al-Jabi and Diab (2017) also pointed out the application of an integrated RFID card, weight sensor, and ultrasonic sensor in monitoring the amount of waste that citizens drop in trash bins, and providing feedback reports to them. Abdoli (2009) however questioned the environmental implications of RFIDs and commented that while RFID tags facilitate the automatic identification of recyclable components in the solid waste stream, if used broadly, it may result in dissolving toxic and valuable materials in the established recycling processes.

The data acquisition technologies for detecting bin levels can be categorized under two groups of camera (or image-based) and sensor- based technologies such as weighing, ultrasonic, and light-emitting diode (LED) sensors (Elia et al., 2015). Reverter et al. (2003) designed a point-level capacitive sensor for improving solid waste col lection. Vicentini et al. (2009) also designed a sensorized container that allows measurement of the actual weight and volume of the waste. They have tested the prototype of their design in the Pudong New Area, Shanghai. Medvedev et al. (2015) have extended the current sensor-based technologies by combining two types of technologies and adding surveillance cameras as an assistive technology that can provide further evidence to authorities in the case of an inefficient waste collection in inaccessible regions. Along similar lines, Hannan et al. (Rada et al., 2013) developed several image-processing algorithms to analyze the information received from a camera for waste bin level detection. Catania and Ventura (2014) discussed the application of the sensor-based smart-M3 platform, an open-source project, for real-time monitoring of waste bins with the aim of helping service providers avoid collecting semi-empty bins and helping consumers to locate closest bins to them and be aware of the fullness status of the nearest bins.

Another stream of literature has been focused on developing and employing *communication and data processing* infrastructure. To name a few studies, Lata and Singh (2016) developed a web interface to help authorities monitor trash bins with the data received through an embedded Linux board from a wireless sensor network. Toma and Popa (Shyam et al., 2017) discussed three types of IoT communication protocols available for machine-to-machine communication including Constrained Application Protocol (CoAP), MQ Telemetry Transport (MQTT), and Representational State Transfer (REST). Mahajan and Chitode have shown the application of ZigBee as a data transmission technology for bin monitoring in waste collection systems (Mahajan and Chitode, 2014).

The third stream of studies has shown the applications of enabling technologies in different domains and tested the capabilities in several pilot and field experiments. To name several studies, Zhang el al. described the use of RFID technology in enhancing construction waste logistics (Zhang et al., 2012). Tao and Xiang (2010) proposed a conceptual information platform model for waste cycle management in Wuhan city, China. Elia et al. (2015) discussed the information flow required to design a Pay-As-You-Throw (PAYT) strategy in solid waste management systems based on the existing bin level detection and data transmission technologies. Hong et al. (2014) designed a food waste management system in which battery-operated RFID-based garbage bins are connected through wireless communication to a server that informs administrators of the status of all bins for timely food pickup schedules in the Gangnam district, Seoul, Republic of Korea. Gutierrez et al. (2015) conducted a simulation experiment to test the efficiency and economic feasibility of such smart systems for waste collection in the city of Copenhagen, Denmark. They have used a GIS simulation environment along with graph optimization algorithms and available Open Data about the city. Shyam et al.

(2017) conducted a simulation using Open Data from the city of Pune, India to estimate the cost to collect and dispose of wastes. On a separate note, Ho and So (2017) discussed the impact of media campaign emerging in smart cities on promoting the environmental friendly life among Guamanians.

Finally, the research has shifted from developing sensor-based technologies and data transmission infrastructure to support the use of such technologies. The main use of IoT-enabled technologies was for the purpose of waste collection and scheduling problems.

To clarify the nature of waste management practices in SCs, we should note that waste collection in SCs requires *dynamic* models rather than *static* planning approaches (Anagnostopoulos et al., 2015). The availability of capacity sensors and wireless communication infrastructure makes it possible for municipalities to monitor trash bins status and adjust collection scheduling and routing prob lems accordingly for each municipality region or even trash bin as a demand node (Lundin et al., 2017). Anagnostopoulos et al. (2015) analyzed several dynamics collection routes models for waste collection in SCs. They have proposed four different models including the dedicated trucks model, where a specific number of trucks are dedicated to waste collection activities from a number of high priority trash bins, the detour models in which trucks can deviate from their original routes to serve high priority region, the minimum distance model and the reassignment model, where the demand nodes will be reallocated when new information is coming to the system. Often, the objective of collection routes problems is to maximize on-time collection and minimize waste depletion cost. McLeod et al. (2014) developed a vehicle routing and scheduling method based on tabu search algorithms to show how remote sensing technology can facilitate more efficient charity collection scheduling in the UK. On a side note, Schafer commented that data privacy and data security concerns may limit the capabilities of IoT-based waste management systems (Schafer, 2014) since it opens the venue for having municipalities access to individual household data.

The review of previous studies shows that studies about waste management in SCs so far have been primarily focused on making waste *monitoring, separation* and *collection* more efficient with the help of sensor-enabled solutions, however an effective waste management practice requires considering the whole product lifecycle from design up to end-of-use stage, where various value-driven strategies can be adopted during the product lifecycle to avoid waste generation rate and maximize waste management practices. We should highlight that dynamic routing and scheduling optimization should not be the only motive for IoT-enabled infrastructure, but the real value of such infrastructure is when the leakage of product value gets minimum during its entire lifespan through the on-time and effective use of information collected from IT-enabled infrastructure. Anagnostopoulos et al. (2017) also provided a review of ICT-based waste management models and emphasized on the need for defining a novel framework for waste management efforts.