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Development of a *Business Intelligence* Conceptual Model for Waste Collection and Transportation Monitoring

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Project Proposal presented for obtaining the Master's degree in Information Management

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DEVELOPMENT OF A BUSINESS INTELLIGENCE CONCEPTUAL MODEL FOR WASTE COLLECTION AND TRANSPORTATION MONITORING

by

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Project Proposal presented as partial requirement for obtaining the Master's degree in Information Management, with a specialization in Knowledge Management and Business Intelligence

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Este trabalho simboliza o fim de uma etapa da minha vida.

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ABSTRACT

The need to answer ever-increasing urban challenges and the integration of new technologies in every aspect of our daily lives prompt the creation of the Smart City concept. These new technologies gather an enormous quantity of data that reveals interesting patterns about cities, enabling opportunities to enhance public decision-making and problem-solving. One critical aspect of urban life is its relationship with the environment. There's a real need to work on a unified global approach on how to tackle issues such as pollution and waste management, but there is not a single framework or guideline to handle these new data gathered.

This work focuses on structuring a framework of analysis for waste collection and transportation purposes. The objective was to develop monitoring dashboards for *Departamento de Higienização Urbana (DMHU),* using proven metrics of efficiency and effectiveness, result of a comprehensive literature review. A BI framework was developed using Power BI to perform efficiency-based analysis of waste collection circuits – the main process of DMHU.

The receptivity of DMHU towards the solution presented seems to indicate that a BI solution is indeed valuable for complex monitoring problems such as solid waste management.

KEYWORDS

Smart City; Smart Environment; Business Intelligence; Solid Waste Management; Waste Collection

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LIST OF ABBREVIATIONS AND ACRONYMS

SC	Smart City
SE	Smart Environment
ICT	Information and Communications Technology
BI	Business Intelligence
CC	Cloud Computing
DSR	Design Science Research
IS	Information Systems
SWM	Solid Waste Management
DMHU	Departamento Municipal de Higienização Urbana
IoT	Internet of Things

1. INTRODUCTION

One of the main drivers of global economic growth is urbanization. Even though more than half of the world's population lives in cities, many urban centers cannot respond to their ever-increasing demands. Therefore, it is critical to delivering the needed infrastructure required to provide economic growth and societal development for a growing global population (Bose & Kielhauser, 2019).

The need to answer these new urban challenges prompt the creation of the Smart City (SC) concept. SC generally refers to the search and identification of intelligent solutions that allow modern cities to enhance the quality of the services provided to citizens (Giffinger et al., 2007). Information and Communications Technology (ICT), logistics, energy production, and so on, cooperate to create benefits for citizens in terms of well-being, inclusion and participation, environmental quality and intelligent development (Dameri, 2013).

The SC concept is usually divided into six main domains (Caragliu et al., 2011): Economy, Environment, Governance, Living, Mobility, and People. For this work, we will focus on the concept of Smart Environment (SE). SE is an important characteristic of smart cities and has received strong attention from researchers. Studies that investigated the SE discussed some of the key themes affecting smart cities such as air pollution, waste management, water quality, and energy efficiency (Ismagilova et al., 2019).

Solid Waste Management (SWM) is considered a critical public service, particularly in developing countries, since uncollected solid waste is usually the leading contributor to flooding and air and water pollution. Solid waste is inextricably linked to urbanization and economic development. As countries urbanize, their economic wealth increases. As standards of living and disposable incomes increase, consumption of goods and services increases, which results in a corresponding increase in the amount of waste generated and the quality of infrastructure needed (Hoornweg & Bhada-Tata, 2012), which is the purpose of this work.

1.1. BACKGROUND

According to the World Bank, waste volumes are increasing rapidly, at a faster rate than urbanization. The global Municipal Solid Waste is estimated to be 1.3 billion tonnes per year and is expected to increase to 2.2 billion tonnes per year by 2025 (Hoornweg & Bhada-Tata, 2012).

Even though there is enough data to estimate global amounts and trends of Municipal Solid Waste, it is generally insufficient to make informative decisions locally, as they are usually inconsistent, incomparable, or inexistent, especially in underdeveloped countries where the data is further compromised by large season variations, incomplete waste collection and disposal (eg. Local burning, thrown into waterways, etc.) or a lack of weight scales at landfill sites to record waste quantities (Hoornweg & Bhada-Tata, 2012). This is an extremely important issue considering the impact of an effective SWM strategy on an environmental, economic, and sociological level.

Nowadays, new Internet of Things (IoT) applications are enabling SC initiatives worldwide. They provide the ability to remotely monitor, manage, and control devices, and to create new insights and actionable information from massive streams of real-time data. (Kim et al., 2017). Several initiatives have been implemented in the SWM area to improve the quality and efficiency of its process. ICT's have become significantly important in dealing with SWM necessities such as automated data acquisition, identification, communication, storage, and analysis in connection with swift and parallel computing. (Hannan et al., 2015).

There are some studies in the SE field that focus on how a Big Data approach can answer the challenges of waste monitoring data (Fazio et al., 2015). However, in this work, we are going to focus on a BI approach. BI is a data-driven process that combines data storage and gathering with knowledge management to provide input into the business decision-making process (Negash & Gray, 2008).

1.2. PROBLEM IDENTIFICATION

The *Departamento Municipal de Higiene Urbana* (DMHU) is Lisbon's Municipal Sanitation Department, responsible for the collection and transportation of waste. There is a need to improve its process control, monitoring, and optimization of the data gathered in its existing Information System related to waste quantities and fleet information. DMHU needs the analysis of this data for two distinct purposes:

1. Daily monitorization of truck circuits, by circuit realization and by comparison with average values;

2. Periodic assessment and evaluation of circuit performance, by different types of circuit (different types of waste collected)

The department has also created some management dashboards where the information is visualized. However, as this project was done merely for analytical purposes, there is not an integrated infrastructure that provides easy and intuitive access to data, as well as flexible analysis. The department often struggles with the dashboards and feels that a more structured and professional approach is required to handle this data properly and to be able to answer new challenges that may surge.

1.3. STUDY OBJECTIVES

This work purposes to provide a business intelligence conceptual model to aid an urban waste collection and transportation monitoring initiative.

Firstly, this work will try to answer the question: "Is BI a correct approach for waste circuits performance monitoring?". A comprehensive breakdown of the concepts of BI and SWM, as well as the potential symbiosis between them, will be carried.

Finally, a BI solution will be developed following the conceptual model created as a proof of concept. Consequently, this work intends to create an infrastructure concept that guarantees the ETL, multidimensional analysis, and visualization of the data gathered.

We will opt to use Microsoft Power BI to handle ETL needs, the creation of reports and monitoring dashboards. These specific milestones need to be achieved:

1. Conceptual Model Creation

a. Defining system requirements;

b. Describing processes;

c. Selection and analysis of Key Performance Indicators.

2. Proof of Concept

a. Development of a data model for DMHU

b. Buildout of monitoring dashboards

3. Evaluation of results

1.4. Study Relevance and Importance

Lisbon's waste management efficiency will be the obvious benefactor of this project. DMHU will not only have greater control, understanding and confidence over its processes through more efficient monitoring but also will benefit from new insights about its service, which may be fundamental to take action.

Some studies (Ismagilova et al., 2019) have purposed that most SE research has relied on theoretical assumptions and simulations, with few studies using real-world live data. Therefore, exists a real need for further studies using real data analysis from different parts of the world.

This is an excellent opportunity for BI projects to be carried in various cities as, through the process of consistent and reliable data gathering and analysis, global benchmarks and guidelines can be created, improving the decision making, in issues related to waste collection monitoring.

Past studies using a BI approach in a similar waste management context, have also proved that the usage of external data, integrated into a BI solution, can be a key asset for organizations creating analytical business values that are descriptive, predictive and prescriptive. (Strand & Syberfeldt, 2020).

Accordingly, as climate change is the biggest and most challenging issue humanity has to face in the 21st century and waste is one of the main causes, an attempt to reduce cities' ecological footprint, by improving the decision making, quality of information of its leaders and society, and efficiency of resources, is of utmost importance. More accurate and meaningful discussions can take place and new topics will emerge.

1.5. Methodology

The methodology that is going to be used for this work will be the *Design Science Research* (DSR) - a research paradigm in which a designer answers questions relevant to human problems via the creation of innovative artifacts, thereby contributing new knowledge to the body of scientific evidence (Hevner & Chatterjee, 2012).

According to the same authors, the DSR paradigm is highly relevant to IS. The conception of Design Science (Simon, 2019) supports a pragmatic research paradigm that calls for the creation of innovative artifacts to solve real-world problems. Therefore, DSR combines a focus on the IT artifact with a high priority on relevance in the application domain (Hevner & Chatterjee, 2012).

Hevner, et al., also provided seven guidelines for conducting DS research in IS:

1. Design as an Artifact: DSR must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.

2. Problem Relevance: The objective of DSR is to develop technology-based solutions to important and relevant business problems.

3. Design Evaluation: The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.

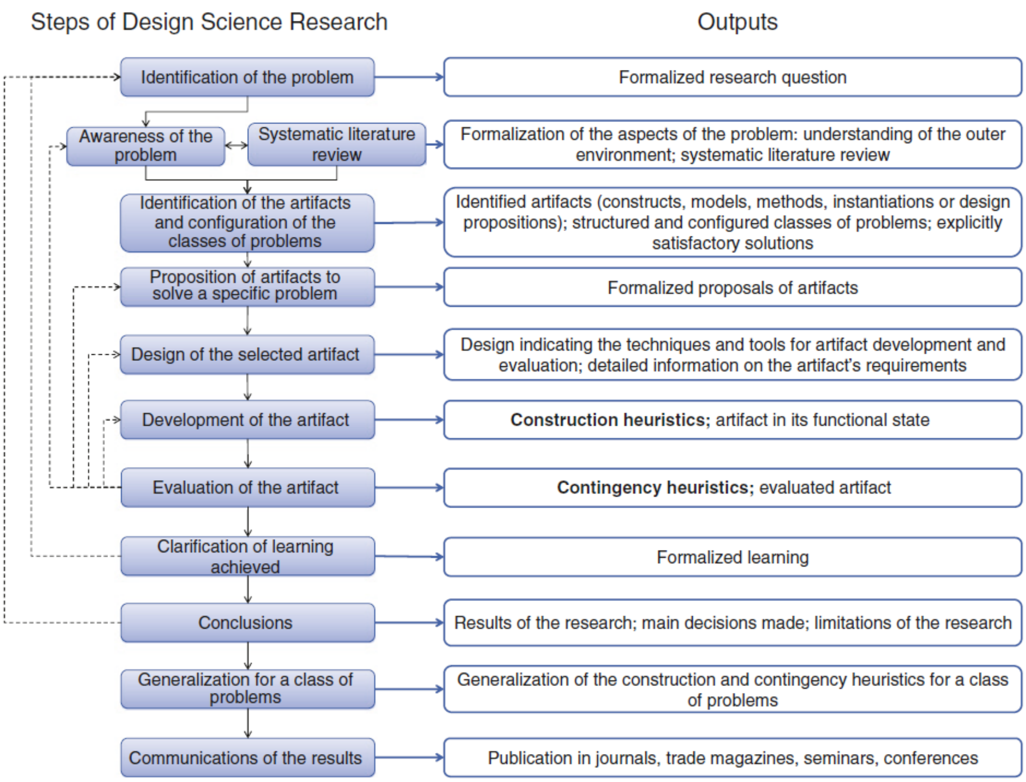
4. Research Contributions: Effective DSR must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.

5. Research Rigor: DSR relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.

6. Design as a Search Process: The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.

7. Communication of Research: DSR must be presented effectively both to technology-oriented as well as management-oriented audiences.

Figure 1 – Design Science Research steps and their outputs - (Dresch et al., 2018)



Based on these guidelines, this work will follow a methodology comprised of 12 steps (Dresch et al., 2018). Each step has an output that serves as a pre-requirement for further steps:

1. Identification of the problem – Highlight and justify the relevance of the problems studied. The expected output of this step is a formalized research question. The research question has already been formulated in previous chapters: "Is BI a correct approach for waste circuits performance monitoring?".

2. Awareness of the problem/ Systematic literature review – Extensive understanding of every aspect of the problem - the context, and its causes. Overview of the functionalities of the artifact, its expected performance, and its operational requirements. The expected output is a systematic literature review.

3. Identification of the artifacts and configuration of the classes of problems – Evidence of potential artifacts and classes of problems that address problems similar to the one being solved.

4. Proposition of artifacts to solve a specific problem – the researcher must propose the artifacts, considering their reality, context of performance, and feasibility.

5. Design of the selected artifact – an artifact must be selected from among a previously proposed set. All the procedures that will be employed should be described – artifact's construction and evaluation.

6. Development of the artifact – Construction heuristics that can be formalized from the artifact's development.

7. Evaluation of the artifact – Observation and measurement of the artifact towards a satisfactory solution of the problem. Contingency heuristics.

8. Clarification of learning achieved – ensure that the research will be useful as reference and support for knowledge generation in both practical and theoretical fields.

9. Conclusions – Results of the research, decisions made during its conduction and limitations of the research.

10. Generalization for a class of problems – The developed artifact must be generalized for a class of problems, even if it has been used for a particular situation.

11. Communications of the results – communication of results through publications in journals, trade magazines, seminars, conferences, etc.

2. LITERATURE REVIEW

2.1. INTRODUCTION

In this chapter, we will approach the second, third, and fourth steps of our DSR methodology. To create a project framework, an extensive concept review on three main topics will be carried:

1. *Smart City:* Research on how ICTs can improve the city's future by addressing their problems.
2. *Solid Waste Management:* Research on the biggest challenges in SWM. Analysis of the ICTs that are improving its efficiency.
3. *Business Intelligence:* Research on business intelligence frameworks. "How can BI be useful in a monitoring context?"

2.2. SMART CITY

Cities are complex entities and play multiple and complex economic and social roles. (Marceau, 2008). Governments are only now coming to grips with issues about how to best deal with the problems while also encouraging the generators of their wealth (Marceau, 2008). Making a city "smart" is emerging as a strategy to mitigate the problems generated by urban population growth and rapid urbanization. (Chourabi et al., 2012). Difficulty in waste management, scarcity of resources, air pollution, human health concerns, traffic congestions, and inadequate and deteriorating infrastructures are among some of these problems (Chourabi et al., 2012).

Since it first appeared with Van Bastelaer (1998), the Smart City concept has had different interpretations regarding its meaning and context (Anthopoulos, 2015). The focus of its definition seems to vary between the role of its components and the interconnectivity between them. (Camero & Alba, 2019). Other approaches also refer to the SC as an abstract concept where the main idea is being holistic and smart in the city (Camero & Alba, 2019). The different meanings address the scale and complexity of the SC domain and describe alternative approaches, schools of thought and researchers who deal with this phenomenon. (Anthopoulos, 2015).

Table 1 - Popular SC definitions - (Camero & Alba, 2019) and (Anthopoulos, 2015)

Author	**Definition**
(Caragliu et al., 2011)	"We believe a city to be smart when investments in human and social capital and traditional (transport) and modern (Information and Communications Technology, ICT) communication infrastructure fuel sustainable economic growth and high quality of life, with a wise management of natural resources, through participatory governance"
(Giffinger et al., 2007)	"A Smart City is a city well performing in a forward-looking way in these six characteristics, built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens"

(Hall et al., 2000)	"A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens."
(Washburn & Sindhu, 2009)	"The use of Smart Computing technologies to make the critical infrastructure components and services of a city—which include city administration, education, healthcare, public safety, real estate, transportation, and utilities—more intelligent, interconnected, and efficient"
(Dameri, 2013)	"A smart city is a well-defined geographical area, in which high technologies such as ICT, logistic, energy production, and so on, cooperate to create benefits for citizens in terms of well-being, inclusion and participation, environmental quality, intelligent development; it is governed by a well-defined pool of subjects, able to state the rules and policy for the city government and development"

From a critical review of literature on smart urban growth from an economist's perspective, a summarization of common SC characteristics identified six features that are present across the literature (Caragliu et al., 2011):

1. Use of networked infrastructure to improve economic and political efficiency and enable social, cultural, and urban development. (Hollands, 2008).
    a. Networked infrastructure refers to business services, housing, leisure, and lifestyle services, and ICTs, such as mobile and fixed phones, computer networks, e-commerce, and Internet services.
    b. Establishment of "wired city" as the main urban development model, and connectivity as the source of growth.
2. Emphasis on business-led urban development. (Hollands, 2008).
    a. Data shows that business-oriented cities are indeed among those with satisfactory socio-economic performance.
3. Focus on achieving the social inclusion of various urban residents in public services.
    a. To what extent do all social classes benefit from a technological integration of their urban fabric.
4. The crucial role of high-tech and creative industries in long-run urban growth.
    a. Importance of the "soft infrastructure", namely knowledge networks, voluntary organizations, crime-free environments, after-dark entertainment economy, etc.
    b. Value of the "creative". Role of the creative and skilled workforce on urban performance.
5. Attention to the significance of social and relational capital in urban development.

a. People need to be able to use technology to benefit from it.

b. Focus on the learning culture, adaptability, and innovative spirit of the urban population.

6. Social and environmental sustainability as a major strategic component of smart cities.

a. The duality between the scarcity of resources and the reliance of cities' development and wealth on tourism and natural resources.

b. Safe and renewable use of natural heritage.

Based on these topics, Caragliu et. al (2011) argue that a definition of SC based on the role of communication infrastructure is not enough. Therefore, their definition is based on a project conducted by the Centre of Regional Science at the Vienna University of Technology, where six main dimensions are identified. These six dimensions are Economy, Environment, Governance, Living, Mobility, People. As they connect with traditional regional and neoclassical theories of urban growth and development, Caragliu et. al (2011) believe that it offers a solid background for a theoretical framework. Nowadays, there is a wide consensus on accepting these six domains as the de-facto SC domains of work. (Camero & Alba, 2019)

Smart Economy refers to e-business, e-commerce, and economic opportunities that are enabled by CS/IT, including manufacturing and service delivery, innovation, and new products, services, or business models. (Camero & Alba, 2019)

Smart Environment encompasses smart energy (energy grids, metering, control and monitoring improved by CS/IT, as well as renewable energy sources), water, green buildings, green urban planning, urban services (waste management, drainage systems, public lightning), and efficiency, reuse, and substitution of resources to improve environmental conditions. (Camero & Alba, 2019)

Smart Governance is concerned with using CS/IT to improve democratic processes and public services (e-government) and to support and facilitate better planning and decision making. Smart Living refers to initiatives that use CS/IT to enable new (and improved) lifestyles, providing a safe and healthy city, which is attractive to the citizens. (Camero & Alba, 2019)

Smart Mobility gathers the group of initiatives that improve transportation and logistics by using CS/IT. (Camero & Alba, 2019)

Smart People is concerned with improving creativity and fostering innovation by using CS/IT to enable working (e.g. work-at-home), human resources, capacity management, and having access to education and training. (Camero & Alba, 2019).

Smart Living refers to initiatives that use CS/IT to enable new (and improved) lifestyles, providing a safe and healthy city, which is attractive to the citizens (Camero & Alba, 2019).

Other interesting SC concepts have also been created, such as the "smartness footprint" of a city, which is measured with indexes, for instance, the education level of its inhabitants, the innovative spirit of its enterprises, etc (Giffinger et al., 2007).

2.2.1. Limitations of the Smart City research

In a literature review of the Smart City topic, Ismagilova et. el (2019) has made several interesting observations regarding the limitations of its research.

From analyzing 104 publications on SC, it was found that it was only recently that SC research has adopted a holistic IS perspective, focusing on aspects such as citizen, quality of life, and sustainability, rather than the technological aspects. It was highlighted the role of integration as an important key in successful Smart City implementations.

Furthermore, it was observed that most of the publications seemed to not rely on case-related empirical data, but on simulations and, in some cases, survey-sourced data. Therefore, there seems to be a need for implementing smart systems in cities of various sizes and stages of the Smart City implementation. This appears to be especially true in the Smart Environment category as Ismagilova et. al (2019) pointed up that many of the studies within SE relied heavily on simulations to develop their findings. Studies also seem to be conducted in countries such as Spain, USA. India, UK, and Italy. This furthers the need for more research in different cities, particularly in developing countries.

2.3. SOLID WASTE MANAGEMENT

Solid Waste Management (SWM) is an essential urban service that requires planning, management, and coordination across all levels of government and stakeholders. It includes waste collection from households and commercial establishments; haulage to a collection point or transfer station; transportation from a collection point or transfer station to a final treatment or disposal site; treatment and disposal of waste; street cleaning and drainage management. (Kaza et al., 2018).

SWM is usually the responsibility of local governments. These oversee taking care of the residues in the most efficient and socially acceptable way. SWM requires massive amounts of investment and coordination, as it is considered one of the most crucial services provided by municipalities, and on which every other service relies upon, such as health, education, etc. Not only do they represent a big portion of the yearly municipal budget, but they are also one of the most important employers.

According to the World Bank (2012), it is an urgent priority for authorities responsible for SWM to improve their services, especially in low- and middle-income countries. The overall target of SWM is to monitor, collect, treat, and dispose of solid wastes generated by the population groups, in a cost-effectively, environmentally, and socially satisfactory manner. (Hannan et al., 2015).

2.3.1. SWM challenges

Cities face a plenitude of societal, economic, and environmental problems regarding their poorly managed waste (Hoornweg & Bhada-Tata, 2012; Kaza et al., 2018) such as the contamination of oceans; the clogging of drains causing flooding; the increase of respiratory problems caused by burning waste; the harming of animals that consume waste unknowingly; the impairment of economic development, etc (Kaza et al., 2018).

High costs and complex waste operations are the main issues that prevent successful SWM system implementation. Local authorities often struggle with limited resources and limited capacity for planning, contract management, and operational monitoring (Kaza et al., 2018).

Another critical challenge that SWM faces is data. SWM data is critical to creating policy and planning the local context. Accurate data enables local governments to select appropriate management methods and plan for the future, as it allows to design systems with a suitable number of vehicles, establish efficient routes, set targets for diversion of waste, track progress, and adapt as waste generation patterns change (Kaza et al., 2018).

2.3.2. Integrated Sustainable Waste Management (ISWM)

The concept of Integrated Sustainable Waste Management is a framework to describe, theorize, and address common problems with waste management assessment and planning in low- and middle-income countries (Anschütz et al., 2004). It is composed of three dimensions: (1) stakeholders; (2) elements of the waste system; (3) sustainability aspects of the local context. For each dimension, Anschütz et al. (2004) also provide a list of topics; methods, and techniques that originate data points; and ideas for the presentation of results.

Firstly, there is a need to identify the key stakeholders and classify their roles and interests in the waste management process. The challenge of ISWM is to get them to agree to co-operate to improve the waste system. (Anschütz et al., 2004)

Secondly, the elements of the movement or flow of materials need to be analyzed. These are generally comprised of five stages: (1) waste generation and separation; (2) waste collection, transfer, and transportation; (3) recycling; (4) waste treatment; (5) waste disposal. A full ISWM assessment means taking a careful look at every element of the system.

Finally, a third dimension consists of six sustainability aspects: (1) political-legal; (2) social-cultural; (3) institutional-organizational; (4) technical performance; (5) environmental health; (6) financial-economic.

Table 2 – Topics, techniques, and presentation approaches for the Waste system elements analysis - (Anschütz et al., 2004)

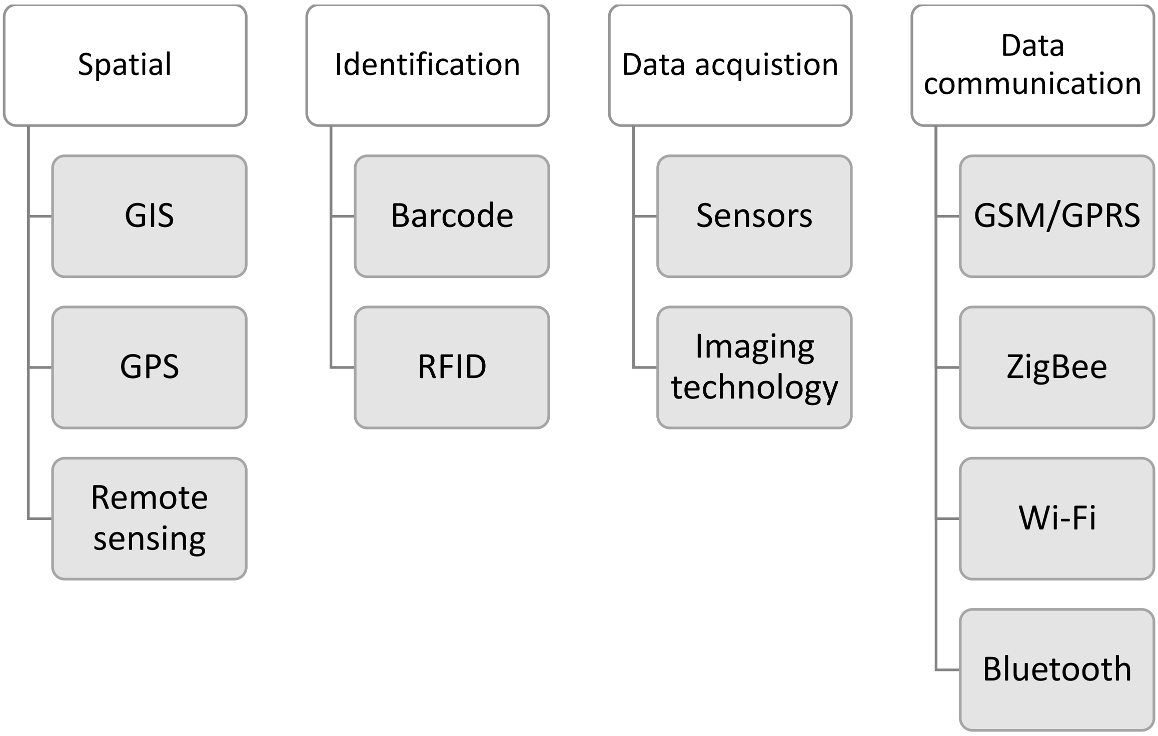
Topics	Methods and techniques	Presentation of results
-Waste quantity -Waste composition -Density -Moisture content -Collection coverage -Uncollected waste -Performance of the system -Equity of system	- Waste generation and characterization studies - Review of reports on discharges to air, ground, and water - Field visits to a range of socio-economic and geographic locations - Visual observation at discharge points - Volume measurement of waste discharges at dumps and transfer point - Mapping and transects of illegal and informal disposal sites - Interviews with collection workers, street sweepers, and waste collection entrepreneurs - Statistical economic data on inputs and outputs to the economy	- Tables, charts, statistical trends - Diagrams - Maps and routing diagrams - Photo and video-documentation
-Recycling, reuse, and recovery	-Interviews with waste pickers, itinerant buyers, dealers, MSEs involved in pre-processing and recycling. -Records of recycling plants and workshops -Sales records dealers	-Recovery projections -SWOT diagram

	-Interviews with collection workers, street sweepers, and waste collection entrepreneurs -Social surveys and interviews about recovery and reuse within households and commercial establishments	
-Flow of waste -Flow of materials	-Waste flow analysis -Material balances -Carbon and nitrogen balance	-Flow diagrams -Material balance diagrams
-Collection efficiency -Collection techniques -Collection rate	-Time and motion studies -Survey of percent filling of containers -Visual analysis of discharge at the disposal facility	-Results in seconds per household or per connection -Results in time per ton and time per distance
-Description of current practices in collection, transfer, and disposal	-Analysis of annual reports, budgets, documents -Interviews with collection workers, street sweepers, waste collection entrepreneurs -Photos, slides, videos -Field visits/observations	-Maps -Photo and video-documentation -Descriptive text
-Resource analysis	-Fleet and equipment inventories -Lists of municipal buildings from cadaster or other sources -Field visits/observation -Budget -Financial reports of previous years.	-Lists -Descriptions of unused equipment and building

2.3.3. ICTs that aid SWM

ICTs are being widely used as a solution to answer all the increasing problems in SWM. Hannan et. al (2015) divided the existing ICTs in SWM systems in four categories: spatial technologies, identification technologies, data acquisition technologies and data communication technologies. Most SWM systems are implemented based on the first three categories. Data communication technologies are usually present in most SWM systems.

Figure 2 – Technologies in SWM systems - (Hannan et al., 2015)



2.3.3.1. Spatial Technologies

Spatial technologies are the most widely used ICTs in environmental modeling, as spatial analysis is very important for many environmental studies. These technologies are effective to handle complex spatial information and providing platforms for the integration of various models, interfaces, and sub-systems as well (Hannan et al., 2015).

Spatial technologies can be divided into three main types: GIS; GPS; Remote Sensing.

Geographic Information Systems (GIS) are information technologies that store, analyze, and display both spatial and non-spatial data (Parker, 1988). In SWM systems, its applications include site selection for landfills, trash bins, and transfer stations; planning and management; optimization of schedules and routes based on historical data or predicted data; waste generation estimation based on socioeconomic data; risk assessment (Hannan et al., 2015).

The Global Positioning System (GPS) is a satellite-based navigation system, developed by the U.S Department of Defense, that provides continuous positioning and timing information, anywhere in the world under any weather conditions (El-Rabbany, 2002). GPS is mainly used in a SWM context to track collection vehicles, measuring the time and, therefore, delays in waste transfer stations; route optimization based on static data; collection monitoring; and implementation of efficient billing (Hannan et al., 2015).

Remote sensing includes all methods of obtaining pictures or other forms of electromagnetic records of the Earth’s surface from a distance, and the treatment and processing of the picture data (White, 1977). It is used for disposal site selection; environmental features and impact monitoring for solid waste disposal sites; and environmental impact assessment of buried waste (Hannan et al., 2015).

2.3.3.2. Identification Technologies

There are two different identification technologies used in SWM: Barcode and RFID.

Barcode is an electronic data interchange medium that contains machine-readable dichromatic marks that encodes information for objects labeling using an arrangement of geometric symbols (Lu et. al, 2013). Applications range from minimizing avoidable waste; reduce landfill space; risk management; and facilitate advanced waste disposal (Hannan et al., 2015).

RFID is an electronic data storage system where there are data exchanges between a data-carrying device and a reader, using magnetic or electromagnetic fields (Finkenzeller, 2010). RFID systems are extensively used for tracking collection vehicles, driver activities, and bins; efficient billing and promoting incentive-based recycling programs; sorting and recycling by capturing bin level data for early identification of waste (Hannan et al., 2015).

2.3.3.3. Data acquisition Technologies

Data acquisition technologies have been substituting traditional manual acquisition because of their high efficiency, cheaper long-term operational costs, and less manpower requirement (Hannan et al., 2015). In a SWM context, there are two technologies used: Sensors and Imaging technology.

A sensor is a device that receives a signal or stimulus and responds with an electronic signal. Sensors and their associated circuits are used to measure various physical properties such as temperature, force, pressure, flow, position, light intensity, etc. (Wilson, 2004). In SWM, various types of sensors have been used for the measurement of bin fill levels; routing and schedule optimization; and collection monitoring (Hannan et al., 2015).

Imaging is the activities of sensing, capturing, storing, manipulating, and displaying a digital image by synthesizing image sensors and post-digital processing (Hannan et al., 2015). It is used for bin fill level management; and sorting of plastic waste (Hannan et al., 2015).

2.3.3.4. Data communication Technologies

SWM communication technologies divide themselves into two groups: long- and short-range communications.

These technologies are used in projects to complement other technologies and the decision between long- or short-range depends on the system and function it is attributed.

For long-range communications, GSM or GPRS are usually the go-to. Global System for Mobile communications (GSM) is a 2G type of network and it is a globally accepted standard for digital cellular communication technology for transmitting mobile voice (Hannan et al., 2015). General Packet Radio Service (GPRS) is a 2.5G type of network that improves wireless access to packet data networks (Hannan et al., 2015).

For short-range communications, ZigBee, Wi-Fi or Bluetooth are usually used. ZigBee is a cost-effective, reliable, low-power wireless network (Hannan et al., 2015). Wi-Fi is a wireless technology broadly used in the mobile connection of home and small office networks (Hannan et al., 2015). Bluetooth is a wireless peer-to-peer technology that eliminates the requirement for cable connections between devices such as cell phones, etc. (Hannan et al., 2015).

2.3.4. Challenges in the implementation of ICTs in SWM

Hannan et. al (2015) also highlighted several shortcomings in the implementation of ICTs in SWM.

Firstly, the incompleteness of ICTs integration in SWM systems was underlined. There is a need to produce a system that can try to solve every aspect of an efficient SWM system, by integrating all three types of technologies with data communications technologies.

Secondly, there is a lack of enough data. Various studies (Arebey et al., 2012; Yang et al., 2008) affirm that a lack of enough information is the main barrier to do efficient planning and design for SWM systems. Existing research focuses on the statistical and survey-related partial data on waste generation, collection, or recycling (Hannan et al., 2015).

Furthermore, Hannan et al. (2015) pointed up the high costs of network structures; the deficiency of real-time bin status information; the negligence of adding source segregation facilities; the absence of dynamic scheduling and routing; and the negligence in environmental impacts as definite problems that hinder SWM systems.

2.3.5. Waste collection, transfer and transportation

Waste collection is the activity in solid waste management with higher costs (Jacobsen et al., 2013). Therefore, local authorities see the collection and transportation of waste as the most difficult operational problem to develop an integrated waste management system (Nuortio et al., 2006).

The urgency in cost reduction makes this SWM element one on which researchers have focused extensively, tackling questions regarding its efficiency and effectiveness, such as the optimization of routing and scheduling of trucks (Das & Bhattacharyya, 2015; Eisenstein & Iyer, 1997; Minciardi et al., 2005; Mourão & Almeida, 2000; J. Teixeira et al., 2004), and vehicle fleet size (Lau et al., 2003).

2.4. BUSINESS INTELLIGENCE

Advances in Information Systems research led to the Business Intelligence (BI) concept. The term was first conceptualized in 1958 as a system that concerned itself with the admission or acquisition of new information, its dissemination, storage, retrieval, and transmittal to the action points it serves. (Luhn, 1958).

More recently, Negash (2004) refers to the term as a data-driven process that combines data storage and gathering with knowledge management to provide input into business decision-making. The current, most widely used definition is Chen et al. (2012) definition that covers most of the existing literature perspectives and refers to BI as “the techniques, technologies, systems, practices, methodologies, and applications that analyze critical business data to help an enterprise better understand its business and market and make timely business decisions” (Božič & Dimovski, 2019).

2.4.1. Business Intelligence Architecture

Figure 3 – Business Intelligence Architecture - (Chaudhuri et al., 2011)

A BI system usually is comprised of different components as showed in Figure 1.

The first element of a BI system is the data sources. In the first phase of a BI project, one has to identify which information is relevant to meet the system requirements. This information will be diverse and can take a plenitude of forms such as excel spreadsheets, enterprise databases, social media data, official documents, etc.

Afterward, as the information takes different formats, there is a need to clean the data from possible errors and combine it into a single source of truth. This process is called Extract, Transform, Load (ETL)

The uniformed data is then loaded into a data warehouse which is a repository of data that aims to produce analysis to support decisions. Furthermore, data can be loaded into a mid-tier server where more complex processes can take place, such as data-mining and text-analytics, before being loaded into a front-end application

Finally, the user has various options to digest this data and perform the required analysis. Spreadsheets, Dashboards, and Reports are examples of the front-end applications that can be used for the intended purpose.

2.4.2. Business Performance Management

Many data warehouse implementations end up with the development of Business Performance Management (BPM) systems (Ramesh Sharda, Dursun Delen, 2017). The term BPM refers to the business processes, methodologies, metrics, and technologies used by enterprises to measure, monitor, and manage business performance. It encompasses three key components (Ramesh Sharda, Dursun Delen, 2017):

1. A set of integrated, closed-loop management and analytic processes (supported by technology) that addresses financial as well as operational activities.
2. Tools for businesses to define strategic goals and then measure and manage performance against those goals.
3. A core set of processes, including financial and operational planning, consolidation and reporting, modeling, analysis, and monitoring of key performance indicators (KPIs), linked to organizational strategy.

2.4.2.1. Key Performance Indicators (KPIs)

KPIs represent a strategic objective and measure performance against a goal (Ramesh Sharda, Dursun Delen, 2017). According to Eckerson (2009), KPIs are multidimensional which means they have a variety of distinguishing features, such as:

- Strategy: KPIs embody a strategic objective.
- Targets: KPIs measure performance against specific targets. Targets are defined in strategy, planning, or budget sessions and can take different forms.
- Ranges: Targets have performance ranges
- Encodings: Ranges are encoded in software, enabling the visual display of performance
- (e.g., green, yellow, red).
- Time Frames: Targets are assigned time frames by which they must be accomplished.
- Benchmarks: Targets are measured against a baseline or benchmark. The previous year's results often serve as a benchmark.

Therefore, KPIs should possess four intrinsic characteristics (Juice Analytics, 2010):

- Actionability;
- Common Interpretation;
- Transparent, simple calculation;
- Accessible, credible data.

Table 3 - Choosing the perfect metric - (Juice Analytics, 2010)

	Description	Common mistakes
Actionable	It is clear the source of the problem or necessary actions when the metric goes up, down, flat or off-target	It is too broad for specific groups to impact (e.g. customer satisfaction). Focus on absolute measure

		rather than changes (e.g. total sales vs. change in sales)
Common Interpretation	People in the organization recognize what the metric means	It uses data definitions that aren't well understood (e.g. leads vs prospects)
Transparent, simple calculation	How the metric is generated is shared and easy to understand	Attempting to create a compound metric that combines a bunc of factors
Accessible, credible date	The data can be acquired with modest effort from a source that people trust	Pursuing the perfect metric that is hard to gather rather than using a close proxy

2.4.2.2. Dashboards

Dashboards are one of the most powerful methods of data analysis in a BI system. There are universal visual dashboard design features and functional dashboard design features that optimize speed, accuracy, consistency of performance management by enabling cognitive fit with different types of users (Velcu-Laitinen & Yigitbasioglu, 2012; Yigitbasioglu & Velcu, 2012).

Functional features of dashboards describe what a dashboard can do. Some desired features include (1) real-time notifications; (2) drill-down capabilities; (3) scenario analysis; (4) presentation flexibility/theory-guided format selections, and (5) external benchmarking.

Visual features relate to the principles of visualizing data. A careful dashboard development has to take into consideration aspects related to (1) the number of pages; (2) the use of colors; (3) Use of grid lines for 2D & 3D graphics; (4) the High-data ink ratio, etc.

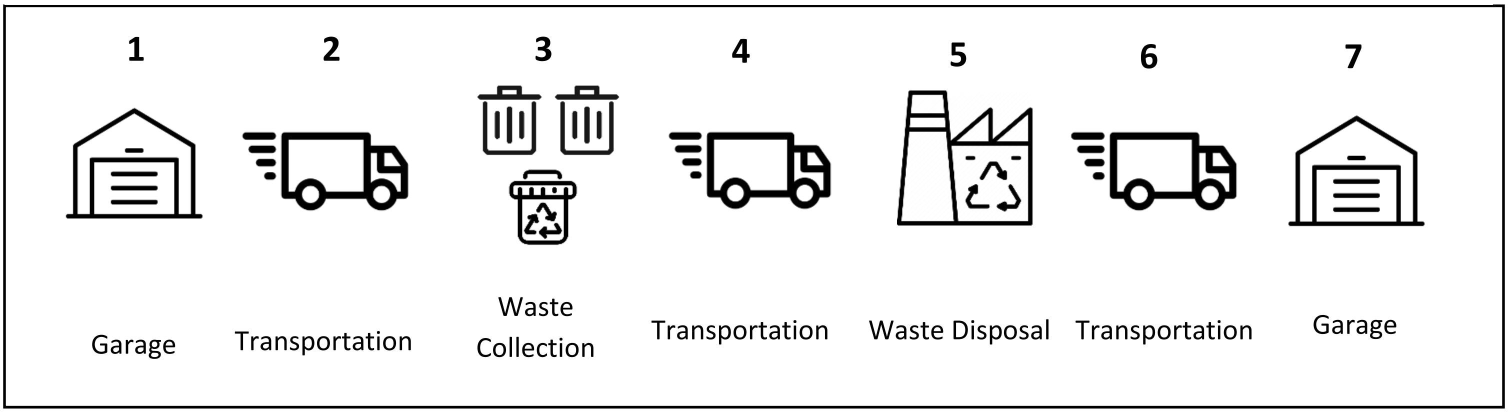
3. CONCEPTUAL MODEL

In this chapter, the fifth step of DSR will be addressed – the design of the artifact. A concept will be created which will assist the creation of the BI infrastructure that will lead to the development of the dashboards – the artifact. A comprehensive breakdown of the DMHU's requirements for the project, the operational processes that characterize DMHU activity, and the ideation of a process, which will lead to the decision of key performance indicators that measure and monitor operations. This will represent not only the foundation work for the next chapter where the artifact will be developed, but also for future works that intend to develop monitoring projects for a similar circuit-based waste collection infrastructure.

3.1. Process Flows

As stated before, the main responsibility of DMHU is the collection and transportation of waste. Therefore, its principal operational process and the focus of our BI system are waste collection circuits. A comprehensive breakdown of a collection circuit can be found in Figure 4.

Figure 4 – DMHU Waste Collection circuit



A circuit begins when a truck leaves the garage to collect waste from a set of PRS (*Pontos de Recolha* - Collection Points) in a pre-determined route. These collection points are composed of one or more bins. After every PRS has been collected, trucks must travel into a designated place for disposals, such as treatment stations, landfills, or transfer stations. The truck then returns to the garage and the circuit is considered complete.

Different types of circuits specialize in different types of waste collected. The periodicity of the collection also varies between the type of waste, but generally, most circuits are completed daily. Sometimes trucks may only dispose of waste the day after collection, therefore it might take more than one day to complete the circuit. A single daily circuit may also be completed by more than one truck. Currently, there are 1037 active circuits that DMHU supervises.

3.2. REQUIREMENTS

From the various meetings with DMHU, some concerns were raised about the difficulty in monitoring and analyzing the performance of truck circuits. Therefore, the new BI system must be able to answer the need for efficiency by monitoring:

1. Daily circuit driving distances;
2. Daily circuit completion times;
3. Total Waste collected per type of waste;

3.3. KEY PERFORMANCE INDICATORS

Before proceeding towards the development of the monitoring dashboards, it is required to gather the correct KPIs on which the circuit performance is going to be assessed. Therefore, a collection of potential KPIs will be collected either as a result of the literature review as well as discussions with DMHU about adequate KPIs for the industry. These indicators can be grouped in two regarding their analysis purposes: Collection and Distance&Time.

3.3.1. Collection KPIs

These KPIs need to track the amount of waste collected and the type of waste collected. These indicators must then be analyzed by geolocation and seasonality to identify possible trends in waste generation and schedule routes accordingly to population needs.

Table 4 – Collection Indicators

KPI	Category	Measure	Designation	Calculated	Data origin	Author
KPI1	Collection	Organic Waste Collected	Food scraps, yard (leaves, grass, brush) waste, wood, process residues	Total kg of Organic Waste Collected	Weighing scales, sensors	(Zaman, 2014); (Hoornweg & Bhada-Tata, 2012)
KPI2	Collection	Plastic Waste Collected	Bottles, packaging, containers, bags, lids, cups	Total Kg of Plastic Waste Collected	Weighing scales, sensors	(Zaman, 2014); (Hoornweg & Bhada-Tata, 2012)
KPI3	Collection	Paper & Cardboard Waste Collected	Paper scraps, cardboard, newspapers, magazines, bags, boxes, wrapping paper, telephone books, shredded paper, paper beverage cups. Paper is organic unless it is contaminated by food residue.	Total Kg of Paper Waste Collected	Weighing scales, sensors	(Zaman, 2014); (Hoornweg & Bhada-Tata, 2012)

KPI4	Collection	Metal Waste Collected	Cans, foil, tins, non-hazardous aerosol cans, appliances (white goods), railings, bicycles	Total Kg of Metal Waste Collected	Weighing scales, sensors	(Zaman, 2014); (Hoornweg & Bhada-Tata, 2012)
KPI5	Collection	Glass Waste Collected	Bottles, broken glassware, light bulbs, colored glass Cans,	Total Kg of Glass Waste Collected	Weighing scales, sensors	(Zaman, 2014); (Hoornweg & Bhada-Tata, 2012)
KPI6	Collection	Other Waste Collected	Textiles, leather, rubber, multi-laminates, e-waste, appliances, ash, other inert materials	Total Kg of Waste Collected	Weighing scales, sensors	(Zaman, 2014); (Hoornweg & Bhada-Tata, 2012)
KPI7	Collection	Recycling Waste collected	Recycling of municipal waste includes material recycling and composting/anaerobic digestion.	Total Kg of Waste Collected	Weighing scales, sensors	(Zaman, 2014); European Environment Agency; DMHU
KPI8	Collection	Total Residential Waste Collected	Total Organic, Plastic, Paper & Cardboard, Metal, Glass and other wastes collected on routes that serve predominantly single and multi-family dwellings	Total tons of waste collected by Residential circuits	Weighing scales, sensors	(Hoornweg & Bhada-Tata, 2012; Parekh et al., 2015; Zaman, 2014)
KPI9	Collection	Total Industrial Waste Collected	Total Organic, Plastic, Paper & Cardboard, Metal, Glass and other wastes collected on industrial routes that serve light and heavy manufacturing, fabrication, construction sites, power, and chemical plants.	Total tons of waste collected by Industrial circuits	Weighing scales, sensors	(Hoornweg & Bhada-Tata, 2012; Parekh et al., 2015; Zaman, 2014)
KPI10	Collection	Total Commercial Waste Collected	Total Organic, Plastic, Paper & Cardboard, Metal, Glass and other wastes collected on routes that serve areas predominantly occupied	Total tons of waste collected by Commercial circuits	Weighing scales, sensors	(Hoornweg & Bhada-Tata, 2012; Parekh et al., 2015;

			by stores, hotels, restaurants, markets, office buildings.			Zaman, 2014)
KPI11	Collection	Total Institutional Waste Collected	Total Organic, Plastic, Paper & Cardboard, Metal, Glass and other wastes collected on routes that serve areas predominantly occupied by schools, hospitals (non-medical waste), prisons, government buildings, airports.	Total tons of waste collected by Institutional circuits	Weighing scales, sensors	(Hoornweg & Bhada-Tata, 2012; Parekh et al., 2015; Zaman, 2014)
KPI12	Collection	Total Municipal Services Waste Collected	Total Organic, Plastic, Paper & Cardboard, Metal, Glass and other wastes collected on activities such as street cleaning and landscaping on parks, beaches, other recreational areas. It also includes water and wastewater treatment plants	Total tons of waste collected on Municipal Services circuits	Weighing scales, sensors	(Hoornweg & Bhada-Tata, 2012; Parekh et al., 2015; Zaman, 2014)
KPI13	Collection	Total Process Waste Collected	Industrial process wastes, Scrap Materials, off-specification products from heavy and light manufacturing	Total tons of waste collected on specialized Process circuits	Weighing scales, sensors	(Hoornweg & Bhada-Tata, 2012; Parekh et al., 2015; Zaman, 2014)
KPI14	Collection	Total Medical Waste Collected	Infectious wastes (bandages, gloves, cultures, swabs, blood and body fluids), hazardous wastes (sharps, instruments, chemicals), radioactive waste from cancer therapies, pharmaceutical wastes	Total tons of waste collected on specialized Medical circuits	Weighing scales, sensors	(Hoornweg & Bhada-Tata, 2012; Parekh et al., 2015; Zaman, 2014)
KPI15	Collection	Total Agricultural Waste Collected	Spoiled food wastes, agricultural wastes (rice husks, cotton stalks, coconut shells, coffee	Total tons of waste collected on specialized Agricultural circuits	Weighing scales, sensors	(Hoornweg & Bhada-Tata, 2012; Parekh et al., 2015;

			waste), hazardous wastes (pesticides)			Zaman, 2014)
KPI16	Collection	Total Municipal Solid Waste Collected	Total Residential, Industrial, Commercial, Institutional, Municipal, and Construction Waste.	Total tons of waste collected by MSW circuits	Weighing scales, sensors	(Hoornweg & Bhada-Tata, 2012; Parekh et al., 2015; Zaman, 2014)
KPI17	Collection	Average MSW collected in a collection day	Average MSW collected in a collection day per circuit	Average MSW collected in a collection day per circuit	Weighing scales, sensors	DMHU
KPI18	Collection	Average MSW collected per PRS	Average MSW collected per PRS per circuit	Total MSW / Number of PRS	Weighing scales, sensors	DMHU
KPI19	Collection	Average MSW collected per hour of work	Average MSW collected per hour of work	Total MSW / effective hours of work	Weighing scales, sensors	DMHU
KPI20	Collection	Recycling Rate	Percentage of waste that ends up recycled	Recycling Waste collected / Total Municipal Solid Waste Collected	Weighing scales, sensors	European Environment Agency; DMHU
KPI21	Collection	Share of Waste deposited in landfills	Percentage of waste that ends up in landfills	Total Landfill Waste / Total Municipal Solid Waste Collected	Weighing scales, sensors	European Environment Agency
KPI22	Collection	Total Selective Waste Collected		Total tons of waste collected by specialized circuits	Weighing scales, sensors	DMHU

3.3.2. Distance & Time

These KPIs focus on the overall efficiency of circuit completions. These track collection routes by analyzing their driving distances and the duration of collection shifts.

Table 5 – Distance & Time Indicators

KPI	Category	Measure	Designation	Calculated	Data origin	Author
KPI23	Distance	Total Daily Circuit Distance	Total kilometers made by a truck in a particular route, starting and ending at a garage, per day. It	Total Kilometres at the arrival – Total Kilometres at the departure	GPS, Internal Data	(Kaza et al., 2018); (C. A. Teixeira et al.,

			includes the bin collection and final disposal			2014); DMHU
KPI24	Time	Total Daily Circuit Duration	Total time spent on a particular route, starting and ending at a garage, per day. It includes the bin collection and final disposal	Arrival Time (at the garage) – Departure Time (at the garage)	GPS, Internal Data	(C. A. Teixeira et al., 2014); DMHU
KPI25	Time	Effective Circuit duration	Time spent traveling between collection bins and time spent unloading	Sum of the duration of all the trucks that execute the circuit	GPS	(C. A. Teixeira et al., 2014); DMHU
KPI26	Distance	Effective Circuit distance	Distance traveled between collection bins and distance traveled to unload	Sum of the distance of all the trucks that execute the circuit	GPS	(C. A. Teixeira et al., 2014); DMHU
KPI27	Time	Average Time per PRS	The average time that takes to unload bins into the truck and replace the bins in their place	Time a truck departs from a PRS - Time the truck stops at a PRS	GPS	DMHU
KPI28	Time	Transport Duration	The travel duration from the last PRS collected, i.e.when a truck reaches maximum capacity, and the deposition location. If a circuit takes more than one freight (truck unloading) to be completed, it is also included the second and consequent time durations from the last PRS collected and the deposition location of the second freight.	Sum of the times between the last collection point and the deposition site, and return to the circuit, of all the freights carried out.	GPS	DMHU
KPI29	Distance	Transport Distance	The distance from the last PRS collected, i.e. when a truck reaches maximum capacity and the deposition location. If a circuit takes more than one freight (truck	Sum of the distances between the last collection point and the disposal site, and return to the circuit, of all the freights carried out.	GPS	DMHU

			unloading) to be completed, it is also included the second and consequent distances from the last PRS collected and the deposition location of the second freight.			
KPI30	Time	Duration at the Deposition Site	Time required to empty the truckload from its entrance at the deposition site (i.e. transfer station, landfill, incinerator, composting) to its exit.	Sum of the times at the deposition site (time of departure from deposition site - time of arrival at deposition site), of all freight, carried out.	GPS	DMHU
KPI31	Distance	The distance at the Deposition Site	The distance required to empty the truckload from its entrance at the deposition site (i.e. transfer station, landfill, incinerator, composting) to its exit.	Sum of the distances at the deposition site (kilometers at departure from deposition site - kilometers on arrival at deposition site), of all the freight carried out.	GPS	DMHU
KPI32	Time	Duration from and to garage	Time from the garage to the first collection point, plus the time from the disposal site (from the last freight) to the garage.	Time from the garage to the 1st collection point + time from the disposal site (from the last freight) to the garage.	GPS	DMHU
KPI33	Distance	Distance from and to garage	Distance from the garage to the first collection point, plus the distance from the disposal site (from the last freight) to the garage.	Distance from the garage to the 1st collection point + distance from the disposal site (from the last freight) to the garage.	GPS	DMHU
KPI34	Distance/Collection	Collection efficiency	Measure that reflects the density of waste production in the urban fabric. Ratio between the amount of waste collected per circuit/day and the	MSW collected per circuit/effective distance of the circuit.	GPS	DMHU

			effective distance of the circuit.			
KPI35	Distance	Circuit concentration coefficient (%)	Measure of dispersion between the circuit location, the garage and the waste disposal site. Ratio of the actual circuit distance to the total circuit distance/day	Effective circuit distance/Total circuit distance	GPS	DMHU
KPI36	Distance/Time	Average Travel Speed	Ratio between the total distance of the circuit and the total time to complete the circuit. Ratio between the total distance of the circuit and the total time to complete the circuit.		GPS	DMHU

3.4. KPI Decision Process

The final decision on which KPIs are going to be included in the artifact is going to follow a process that consists of two phases:

1. Firstly, from the list of potential KPIs, a selection is going to be carried out using the following criteria: (1) actionability; (2) common Interpretation; (3) simple calculation.
2. Secondly, the (4) accessibility of data will be assessed according to the data provided by DMHU. Future projects may adjust the KPIs used considering the granularity and quality of data provided.

4. PROOF OF CONCEPT

In this chapter, the sixth phase of the DSR methodology will be addressed – the development of the artifact.

4.1. DATA

The DMHU data comes from different platforms which are not connected. Internal information such as worker's info, fleet data, and circuit information is stored in a platform called PGIL, while other information is kept in excel spreadsheets.

Important data for analysis mostly comes from two main business processes: (1) worker’s shift registrations (figure 15 in Annexes), in which is registered the shift’s duration and the initial and final kilometers of collection trucks measured in the odometer; and (2) the disposition of freights (figure 16 in Annexes), in which the waste weight is registered at the disposition site.

Future projects may further the BI infrastructure by including GPS data of truck fleets, Sensor data, etc.

4.2. KEY PERFORMANCE INDICATORS

Subsequently, the KPI decision process identified 11 Collection KPIs and 5 Time/Distance KPIs on which DMHU business can be analyzed using available data. Some indicators needed some adjustment, adapting to DMHU needs (e.g., Top 5 Circuits by Average Daily Plastic Waste Collected).

4.2.1. Collection KPIs

- **Total Municipal Solid Waste Collected**

Total tons of waste collected by MSW circuits. Reveals essential data on total waste collected by DMHU, and important trends regarding total waste generation in Lisbon.

- **Total Selective Waste Collected**

Total tons of selective waste collected by MSW circuits. Reveals trends on separation of recyclable waste in Lisbon’s households.

- **Selective Rate**

Percentage of waste that is non-undifferentiated, i.e. waste collected from specialized circuits.

- **Total Count of Freights**

Total count of truck freights that executed circuits. Unlike the total count of shifts, this indicator adds an infrastructure element (availability of trucks and route efficiency).

- **Total Rejected Freights at Deposition**

Freights that had their disposal refused at the deposition site. Trend abnormalities in this indicator may reveal infrastructure deficiencies.

- **Top 5 Circuits by Average Daily Plastic Waste Collected**

Circuits that collect more plastic waste per completion. Reveals important geographic data about plastic waste generation.

- **Top 5 Circuits by Average Daily Paper & Cardboard Waste Collected**

Circuits that collect more paper and cardboard waste per completion. Reveals important geographic data about paper cardboard waste generation.

- **Top 5 Circuits by Average Daily Glass Waste Collected**

Circuits that collect more glass waste per completion. Reveals important geographic data about glass waste generation.

- **Recycling Rate**

Percentage of waste that ends up recycled. Unlike the total selective waste collected, the recycling rate includes the infrastructure capabilities to recycle selective waste for other purposes, since some selective waste can end up in landfills as well.

$$Recycling\ Rate = \frac{Recycling\ Waste\ Collected}{Total\ Municipal\ Solid\ Waste\ Collected} \times 100$$

- **Share of Waste deposited in landfills**

Percentage of waste that ends up in landfills. A key goal of EU waste policy is to cut the amount of waste sent to landfills, setting as a goal the total share of municipal waste landfilled to 10% by 2035 (European Environment Agency, n.d.).

$$Share\ of\ Waste\ deposited\ in\ landfills = \frac{Total\ Landfill\ Waste}{Total\ Municipal\ Solid\ Waste\ Collected} \times 100$$

- **Urban waste density by Circuit**

The ratio between the quantity of waste collected per circuit/day and the effective distance of the circuit. Reflects the density of waste products inside the urban fabric.

$$Urban\ Waste\ Density = \frac{Total\ Municipal\ Solid\ Waste\ Collected}{Total\ Kilometers\ Traveled}$$

- **Collection Efficiency by Circuit**

The ratio between the quantity of waste collected per circuit/day and the working hours/day.

$$Collection\ Efficiency = \frac{Total\ Municipal\ Solid\ Waste\ Collected}{Total\ Shift\ Hours\ Completed}$$

4.2.2. Time/Distance KPIs

- **Total Distance Traveled**

Total kilometers made by a truck in a particular route, starting and ending at a garage. It includes the bin collection and final disposal. An important indicator for analyzing the relevancy of circuits and how often they are completed.

- **Average Daily Distance Traveled**

Average kilometers made by a truck per day. Reveals information about the distances workers have to drive daily. Can be used to compare performance over time.

- **Average Distance Traveled per circuit**

Average kilometers made by a truck in a particular route. Standardizes the normal driving distances for a specific route.

- **Total Shifts Completed**

Like the Total Distance Traveled, this indicator is used to prove the relevancy of circuits in the overall operation, i.e. how often they are completed. It can also be used to detect anomalies in completion registrations, as it is highly unlikely for a circuit to be completed 3 or 4 times a day.

- **Average Daily Shifts Completed**

Can be used to analyze the evolution of how often circuits are completed and compare it over time.

- **Average Daily Shift Duration**

An important indicator that highlights the duration norm for specific circuit completions. Circuits that take too long may be subject to route optimizations. Anomalies can also be easily spotted, like 10-hour shifts as a result of multiple shifts being registered at the same time.

4.3. DATA MODEL

The main business processes are described in (3.1) and constitute the basis of the proposed data model: it must analyze the collection, disposal, and transportation of waste.

After identifying the business processes, to build the data model it is necessary to declare the grain, identify the facts and identify the dimensions. Therefore, a bus matrix was made to simplify the process (Figure 5).

Figure 5 – Bus Matrix

Fact Table	Granularity	Facts	Date	Circuit	Worker	Truck	Disposal Site	Waste valorization	PRS	Type of Waste	Task	Waste origin
Analysis of circuit performance												
Escala	1 row for every Shift completed	Time and distance traveled	X	X	X	X					X	
Frete	1 row for every Freight deployed	Amount of Waste disposed	X	X	X	X	X	X		X	X	X
Colecta	1 row for every PRS collected	Amount of Waste collected	X	X					X			

Accordingly, the data model will include 3 fact tables and 9 dimensions:

- **Fact Escala (*Fact Shift)***: Represents every shift completed by DMHU employees. Data comes from worker's shift registrations. The main facts are the duration and distance traveled during the shift.

- **Fact Frete *(Fact Freight)***: Represents the disposal phase of waste collection. Data comes from waste weight registrations at the disposal site. The main fact is the amount of waste disposed of.

- **Fact Colecta *(Fact Collection)***: Represents the collection phase of waste collection. Currently, the data does not exist inside DMHU system. Data from this table is derived from the waste weight registrations at the disposal site, divided by the amount of PRS in the completed circuit. This is done merely as a concept and to be able to do geo-location analysis of the data. Future projects can use correct data collected from sensors at every PRS, for example.

- **Dim Data *(Dim Date)***: Data comes from an original excel spreadsheet. Represents the calendar year 1996 to 2020. Includes time hierarchies such as Semester-Quarter-Month. Every fact table is associated with this table.

- **Dim Circuito *(Dim Circuit)***: Data regarding circuit properties such as type of circuit, dynamic/non-dynamic, active/non-active.

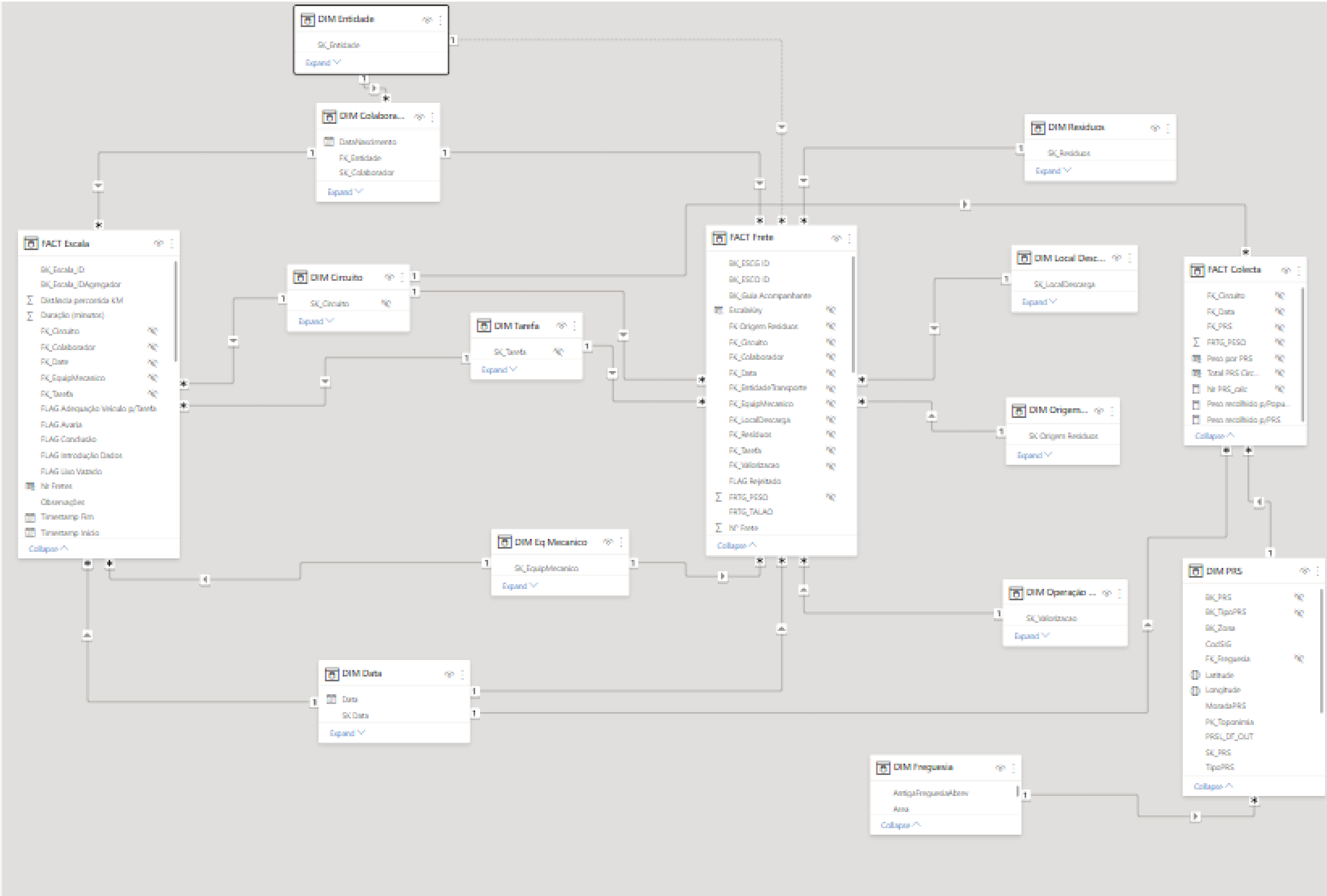
- **Dim Colaborador *(Dim Employee)***: Internal information regarding DMHU personnel, such as function, birthday, and belonging entity.

- **Dim Eq Mecanico *(Dim Mechanical Equipment)***: Internal Information regarding collection trucks

- **Dim Local Descarga *(Dim Disposal Site)***: Data regarding where waste is disposed of.

- **Dim Operação Valorização *(Dim Valorization)***: Data on how waste is disposed of.

Figure 6 - Data Model



4.4. Integration and Data Prep

The dashboard construction starts with the ETL (2.4.1). This is the first process buildout phase, where the quality of the data provided will be insured. As this project is only a concept and does not provide a fully integrated solution with the company data, data preparation will be entirely done inside Power BI, using its Query Editor. Any data transformations, such as dealing with missing values, removing unnecessary data, category-formation were done in this phase. Tables were also merged and Surrogate Keys were created using the Editor.

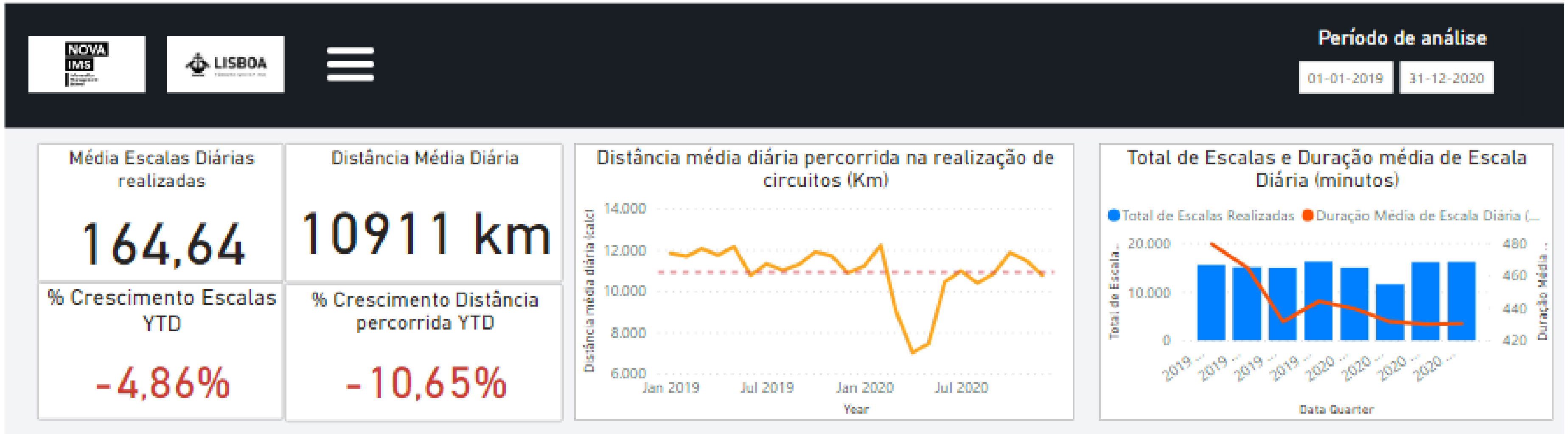
4.5. Measures

To calculate complex indicators from the data provided, it is necessary to create measures. These are described in table 6 (Annexes).

4.6. Dashboard

The final hurdle in the artifact buildout is the construction of dashboards. Six dashboards were made: 4 Collection Dashboards (Figure 8-11), 1 Time/Distance Dashboard (Figure 7), and 1 visual auxiliary dashboard (Figure 12) for circuit consultation. Alongside the visual representations, there is also a menu window that lets the user filter data to fit their needs.

Figure 7 – Time/Distance Analysis - Overview



TipoCircuitoAbrev	Distância média por circuito	Distância média diária	Duração média de Escala Diária (horas e min)	Total de Escalas Realizadas	Média Escalas Diárias	Total Distância	Total Distância YTD	Total Distância YTD SPLY	% Crescimento total Distância YTD	Densidade do Lixo urbano (Tn/Km)	Eficiência da recolha (Tn/Hr)
PaP Indiferenciado	**75 km**	**3226 km**	**07 h 38 min**	**35.541**	**49**	**2.351.953**	**1.094.873**	**1.257.080**	**-12,90%**	**0,11**	**1,01**
PaP Seletivas	**59 km**	**1156 km**	**07 h 34 min**	**14.284**	**21**	**776.841**	**329.077**	**447.764**	**-26,51%**	**0,04**	**0,34**
P0203MK	50 km	50 km	07 h 39 min	530	1	25.043	6.625	18.418	-64,03%	0,02	0,14
P0204MK	75 km	75 km	07 h 19 min	494	1	36.601	19.174	17.427	10,02%	0,01	0,12
E0204MK	50 km	50 km	07 h 09 min	476	1	23.135	11.539	11.596	-0,49%	0,01	0,08
E0703	53 km	53 km	07 h 49 min	212	1	9.999	3.804	6.195	-38,60%	0,05	0,34
E0205	75 km	75 km	07 h 54 min	203	1	14.042	4.930	9.112	-45,90%	0,03	0,27
E0803 (S3227)	53 km	53 km	07 h 33 min	203	1	9.866	4.074	5.792	-29,66%	0,05	0,33
E0509MK (S3240)	59 km	59 km	07 h 43 min	201	1	11.009	4.651	6.358	-26,85%	0,03	0,24
E0714 Int (Antigo E0506)	60 km	60 km	07 h 58 min	201	1	11.007	4.143	6.864	-39,64%	0,03	0,23
E0701 (S3234)	57 km	57 km	07 h 41 min	200	1	10.521	3.651	6.870	-46,86%	0,05	0,38
E0801 (S3226)	55 km	55 km	07 h 28 min	200	1	10.233	3.601	6.632	-45,70%	0,04	0,33
E0510 (Antigo E0601)	60 km	60 km	07 h 26 min	198	1	10.938	4.324	6.614	-34,62%	0,04	0,35
E0702 (S3216)	54 km	54 km	07 h 43 min	198	1	9.860	3.375	6.485	-47,96%	0,07	0,46
Total	**63 km**	**10911 km**	**07 h 26 min**	**120.186**	**165**	**7.964.787**	**3.758.361**	**4.206.426**	**-10,65%**	**0,08**	**0,76**

Figure 8 - Collection Analysis - Overview

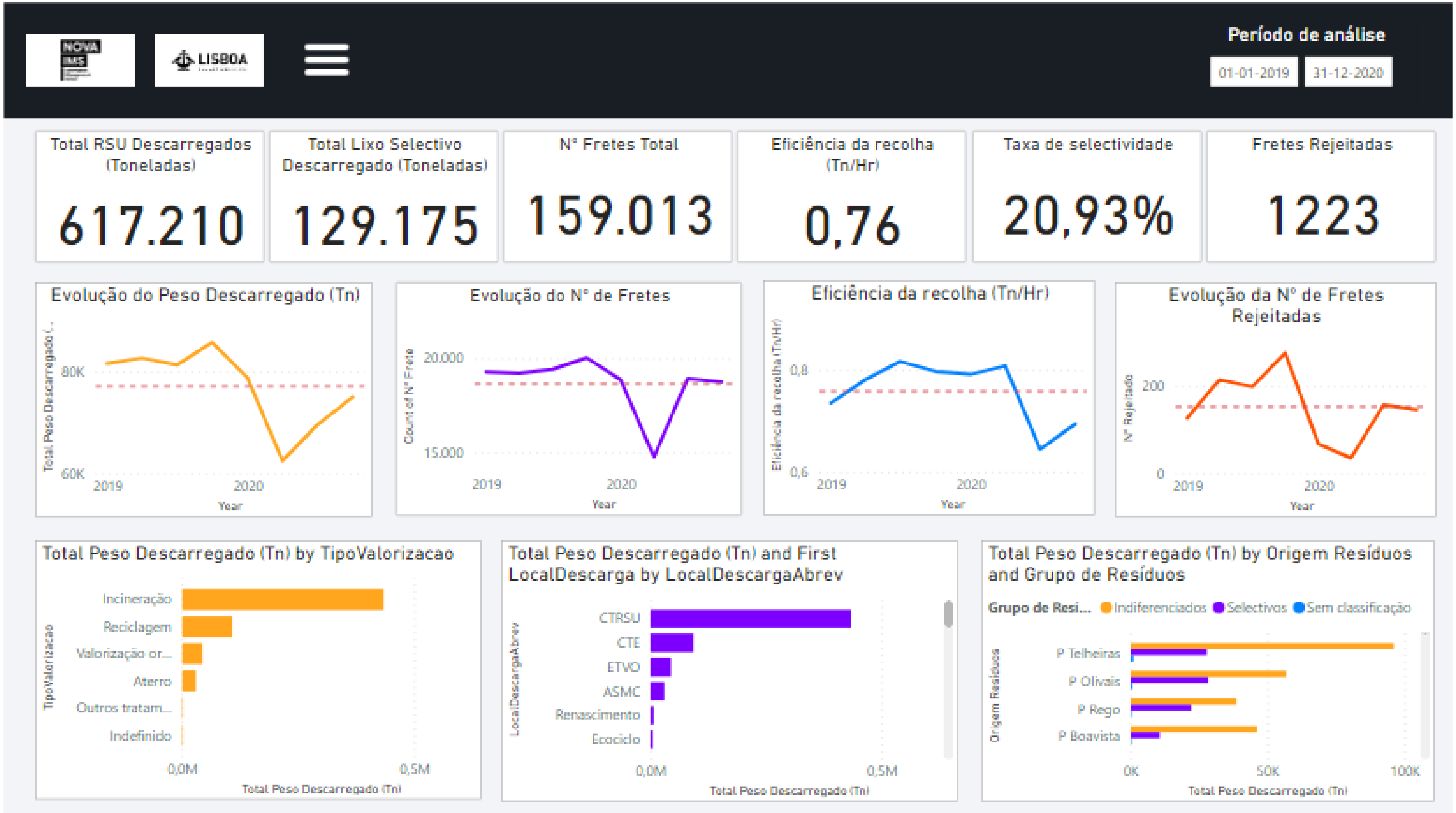


Figure 9 – Collection Analysis - Heatmap

Figure 10 - Collection Analysis – Type of Waste/ Valorization

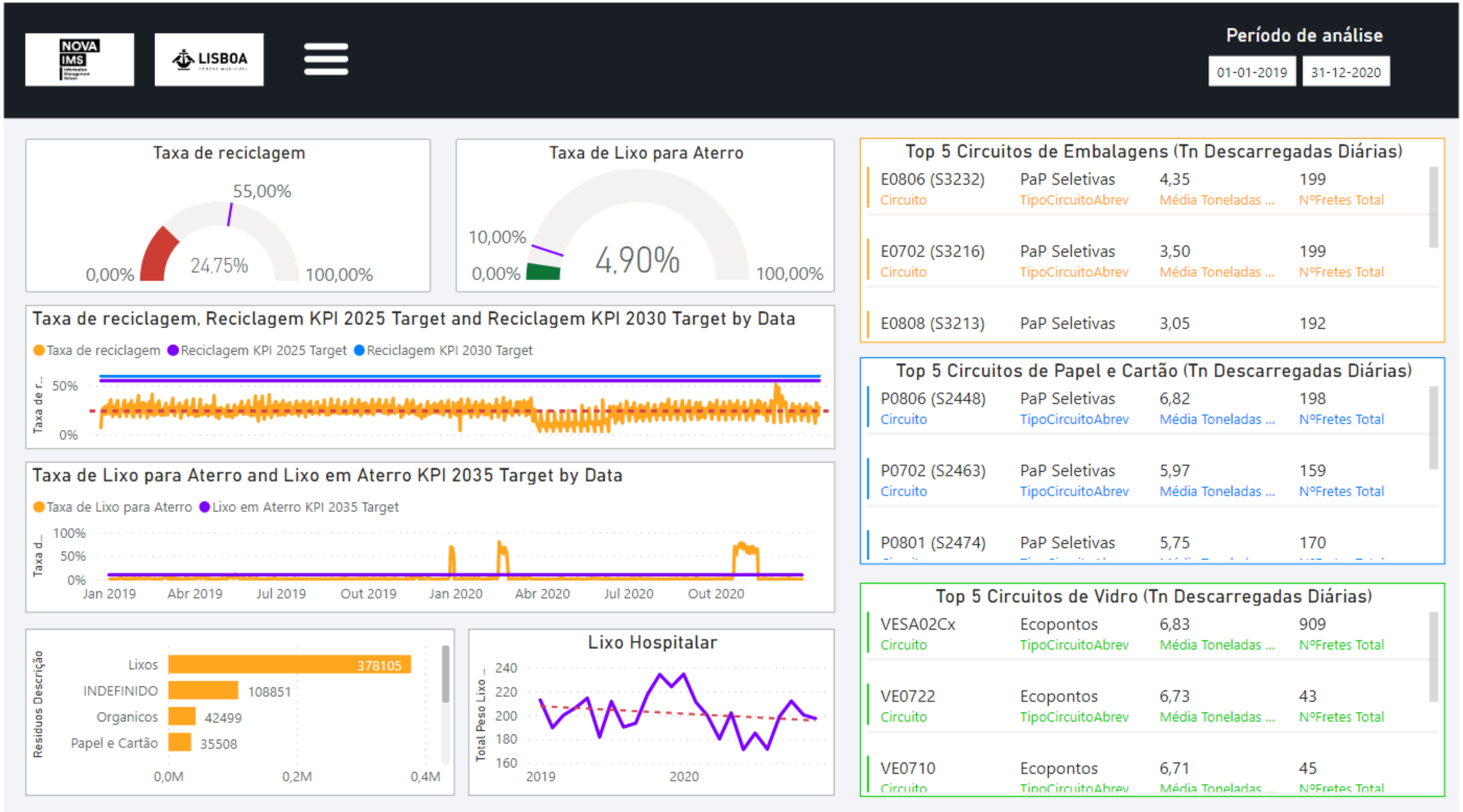


Figure 11 – Collection Analysis – Efficiency vs Density

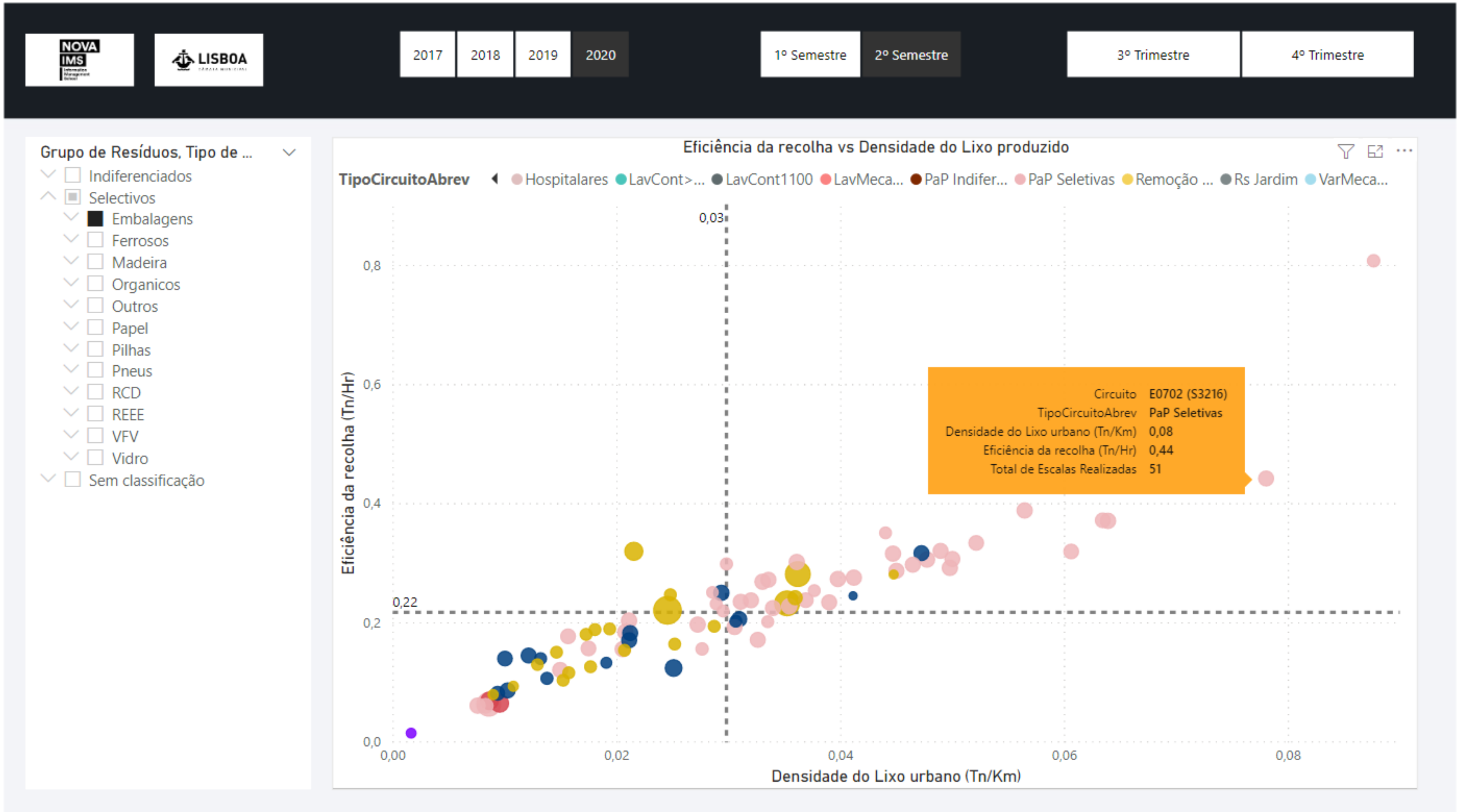


Figure 12 – Circuit Consultation

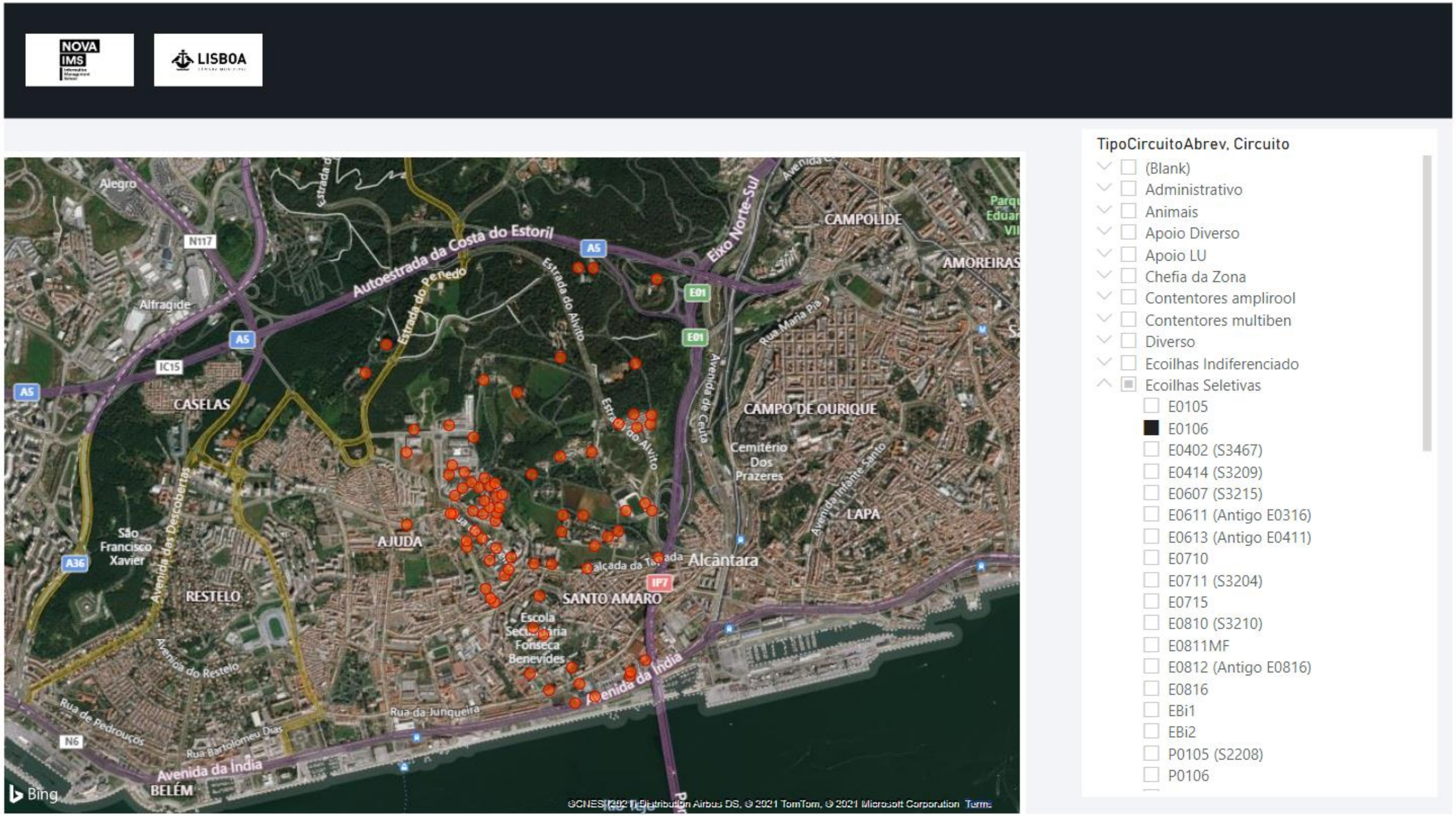
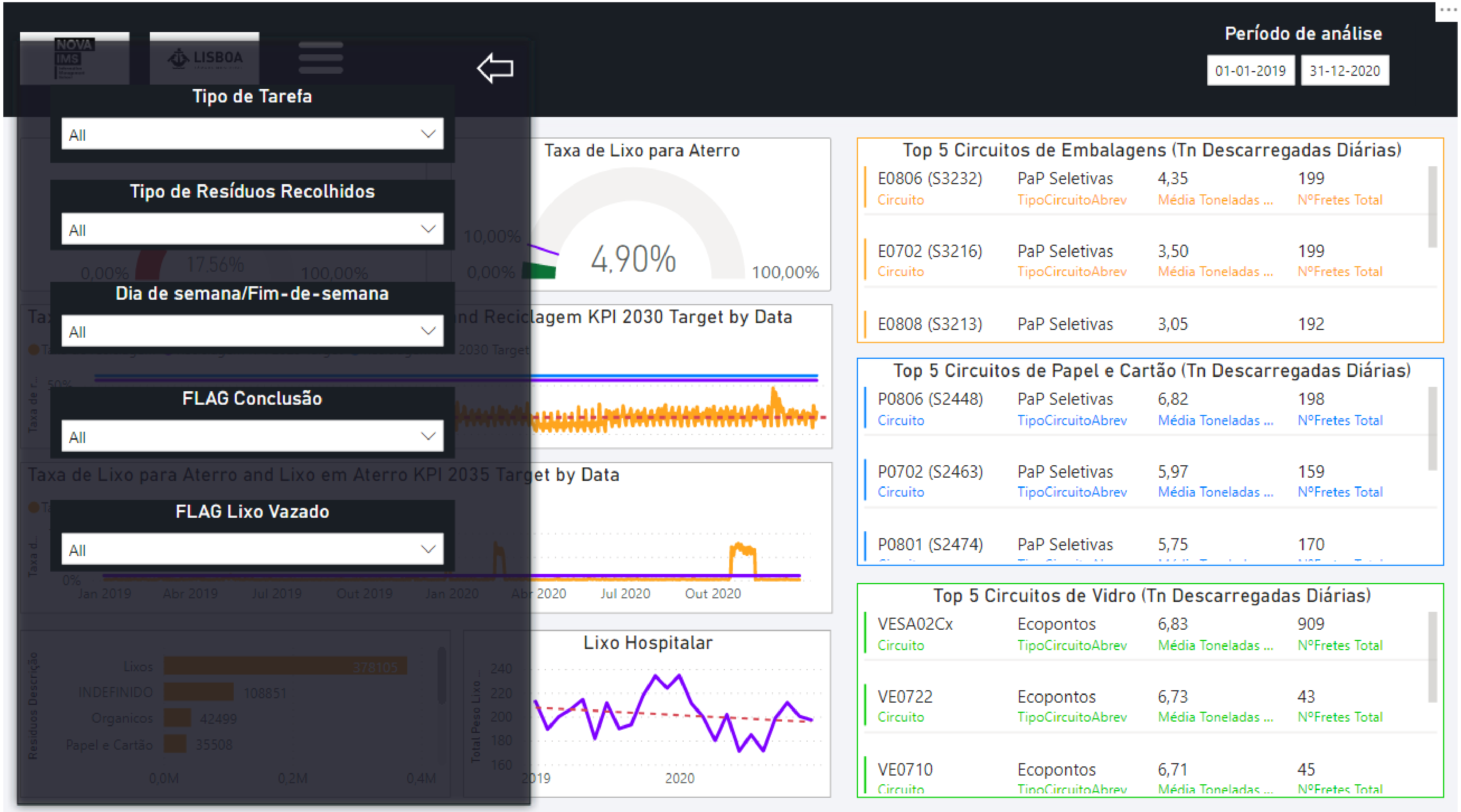


Figure 13 -Collection Analysis – Filter Menu



5. ANALYSIS OF RESULTS

In this chapter, we will move towards the seventh phase of our project: the evaluation of the artifact. Observations and measurements will be described and examined if they present themselves as a satisfactory solution to the problems.

5.1. COLLECTION DASHBOARDS

5.1.1. Overview

The first Collection Dashboard serves as an introductory guide for the user. It intends to quickly inform about key indicators such as the Total Municipal Solid Waste Collected**.**

In the first row of the dashboard, there are six cards with different measures: ***Total RSU Descarregados*** (Total Municipal Solid Waste Collected) ***; Total Lixo Selectivo Descarregado*** (Total Selective Waste Collected) ***; Nº Fretes Total (***Total Count of Freights); ***Eficiência de Recolha*** (Collection Efficiency)***; Taxa de seletividade*** (Selectivity Rate)***; and Fretes Rejeitadas*** (Rejected Freights). These represent a snapshot of the selected timespan. In figure 8, we can analyse the period between 01/01/2019 and 31/12/2020. We can examine that the total municipal solid waste collected in these two years was 617.210 tons of waste and 129.175 tons of selective waste, which represents a 20,93% selective rate. The total number of freights for this period was 159.013 and the total number of rejected freights was 1223. We can also check that the average collection efficiency for the totality of circuits in this two years was 0,76 tons of waste collected per hour of work.

In the second row, there are four line charts that represent the evolution through time of some of the first row metrics. The first line chart represent the evolution of how much waste was collected in Lisbon. In figure 8, we can clearly check a huge drop in the second quarter of 2020, result of the curfews caused by the Covid-19 pandemic. This same drop is observed in the line charts of the total number of freights and number of freights rejected. However, the same drop in the second quarter did not apply to the collection efficiency chart. We can check that during the second quarter of 2020, the collection efficiency registered a spike, perhaps due to the decreased hours of work. Surprisingly, this measure dropped in the third and fourth quarter, registering values below the average, contrasting with the other metrics that returned to average values post-curfews.

In the last row, three bar charts are informing the user about important elements of the waste collection process: how it is treated, where it is disposed of, and where it is collected from. In the first chart, we can observe that the most common way of disposing the waste collected is incineration (433.908 tons), followed by recycling (108.406 tons), organic valorization (44.370 tons), and landfill (30.252 tons). In the second chart, we can check that the *Central de Tratamento de Resíduos Solidos Urbanos* is the disposing site where most of the urban waste end up (433.906 tons). In the last chart, we can observe that most of the waste is registered as from *P Telheiras* (95.982 tons of undifferentiated waste, 27.941 tons of selective waste and 1.167 tons of not classified waste).

5.1.2. Type of Waste/ Valorization

This second Dashboard presents two different objectives: firstly, it intends to dive deeper into the collection process of specific types of waste, i.e. analyzing and identifying circuits crucial for the collection of that type of waste in Lisbon; secondly, it intends to provide more information regarding the treatment of waste.

The dashboard starts with two gauges that measure the ***Taxa de Reciclagem*** (Recycling Rate) and the ***Taxa de Lixo para Aterro*** (Share of Waste deposited in Landfills). Both Indicators have a target that represents KPIs already described in 4.2.1. We can observe in figure 10, that the Recycling Rate between 01/01/2019 and 31/12/2020 was 24,75%, which is lower than the 2025 KPI Target of 55%. The Share of Waste Deposited in Landfills at the same period was 4,90%, which meets the 2035 target of less than 10%. Visually, meeting desired targets or not is represented by the colors green and red. Below the two gauges, 2 line charts represent the daily values of these metrics. We can observe in figure 10 that the recycling rate has been always under the desired 55% and that the share of waste deposited in landfills has risen during some periods, like the month of November of 2020. These unusual values are explained by DMHU as periods where usual treatment facilities are unavailable and the department has to find a solution for the deposition of waste.

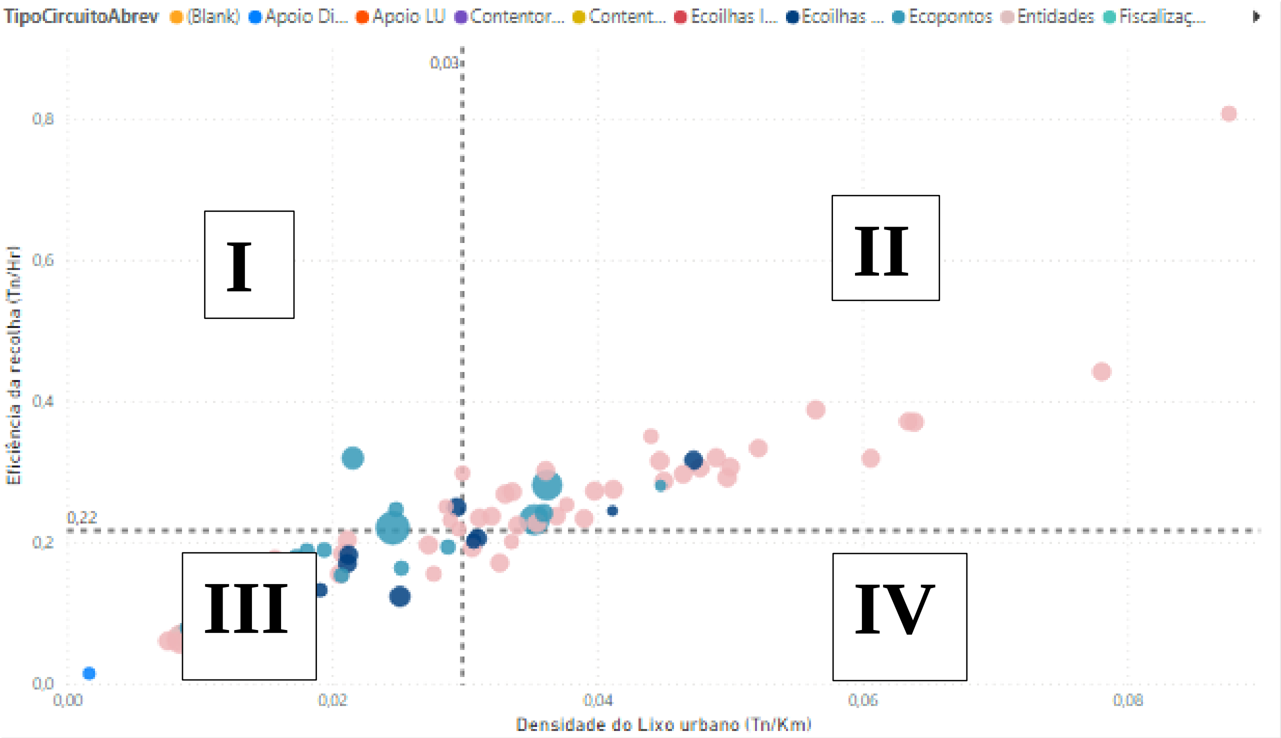
Below, we find two different descriptive visuals: one bar chart with the **Total Municipal Solid Waste Collected by Type of Waste**; and a line chart with the evolution of a special type of waste – medical waste. We can observe in figure 10 that the most common type of waste collected is undifferentiated waste (378.105 tons), followed by undefined (108.851 tons), organic waste (42.499 tons), Paper & Cardboard (35.508 tons), Glass (24.723 tons) and Plastic (23.725 tons). Regarding **medical waste**, we surprisingly observe a spike between November 2019 and January 2020, and a slump during the curfew months of 2020.

Next to these, 3 multi-row cards inform the most important circuits by Daily Waste Disposed Of. Each card represents the top 5 circuits by type of waste (Plastic, Paper & Cardboard, Glass). We can observe that even though some circuits have a low number of freight completions (VE0722 and VE0710 for example), they still register a high average for the daily waste disposed of. This means that the zone where the circuit operates generates high amounts of this type of waste and may be under-served.

5.1.3. Efficiency vs Density

In this dashboard (figure 11), a scatter chart is used to analyze numerous circuits in regards to two metrics: ***Eficiência de recolha*** (Collection Efficiency) and ***Densidade do lixo urbano*** (Urban Waste Density). For a correct use of this chart, the user has to first select the type of waste specialization the circuits are going to be compared, as comparing a circuit that collects paper will naturally register lower weight values than a circuit that collects plastic, on average.

Figure 14 – Efficiency vs Density quadrants



This chart is divided into four quadrants: the first quadrant represents circuits that register higher efficiency than average and lower waste density than average; the second represents circuits that register both higher density and efficiency than average; the third represents circuits that register lower density and efficiency than average; and the fourth quadrant represents circuits that register lower efficiency than average but higher waste density than average.

The purpose of this chart is to identify abnormal circuits. A healthy circuit infrastructure is represented by a diagonal, where circuits that collect waste in zones where its generation is smaller, will also have an efficiency naturally smaller, and vice-versa. However, those circuits that are included either in the first or fourth quadrant may be case for further study as they might be subject for route optimization in the future.

5.1.4. Heatmap

In this dashboard, the objective is to give the user a visual assistant to the waste generation in Lisbon. As the table Fact Table was created using artificial data, i.e. the weights registered in Fact Frete were divided by the number of PRS, offering the possibility for an in-depth location based analysis on waste generation; this dashboard is merely a concept using data not available right now, such as sensor data.

Red zones represent higher ***Peso recolhido p/PRS*** (Weight collected per PRS), while blue zones represent the opposite. The user also can drill the map by zone and perish.

5.2. DISTANCE & TIME DASHBOARD

5.2.1. Overview

This dashboard has the main purpose to give the user information regarding shift completions, shift durations and distance traveled during shifts.

The dashboard starts with four Cards that represent four measures: Average Daily Shifts Completed, Average Daily Distance Traveled, % YTD Growth of Shift Completions, % YTD Growth of Distance Traveled. In figure 8, we can observe that DMHU completes on average 165 Shifts per day and the totality of their workers travel on average 10.911 km daily. We can also observe how both the number of Shift completions and Distance Traveled values for 2020 have decreased when compared to 2019 (-4,86% Shift completions and -10,65% Distance traveled).

Next to the cards, there is a line chart representing the monthly evolution of the Daily Distance Traveled. We can observe how the values were below the average between the months of March of 2020 and June of 2020, a result of the Covid-19 curfews.

Afterward, we have a line and stacked column chart contrasting two different metrics: the totality of shifts completed and the average duration of a daily shift. We can observe that the number of shifts completed dipped in the second quarter of 2020, due to the Covid-19 pandemic. More surprisingly, we can also observe how the daily duration of shifts has been falling since the first quarter of 2019.

Finally, we have Matrix where circuits are analyzed for numerous measures: **Average Circuit Distance; Average Daily Distance; Average Shift Duration, Total Shift Completions, Average Daily Shifts, Total Distance Traveled, Total Distance Year-To-Date, Total Distance Year-to-Date Same Period Last Year, % Total Distance YTD Growth, Collection Efficiency, Waste Density**. All these metrics are supposed to be compared between types of circuits and between individual circuits. For example, we can observe in figure 7 that the most common type of circuit is the Porta-a-Porta Indiferenciado, which has an average distance traveled per circuit of 75 km, an average daily distance traveled of 3226 km, and an average shift durations of 07 hr 38 min. There were 35.541 Porta-a-Porta Indiferenciado circuits completed between 01/01/2019 and 31/12/2020, registering 49 average daily shifts completed. In these two years, it registered a total of 2.351.953 km: 1.094.873 between 01/01/2020 and 31/12/2020, and 1.257.080 between 01/01/2019 and 31/12/2019, a decrease of 12,90%. These types of circuits registered an average waste density of 0,11 tons of waste per km traveled and average collection efficiency of 1,01 tons of waste per hour worked.

5.3. DMHU FEEDBACK

The solution was well received by the Department, highlighting the practical and prescriptive potential of some of the dashboards such as the 'Efficiency vs Density' dashboard. DMHU is interested in developing an integrated solution with their company's data, alongside expanding the model so it includes new data deriving from new technologies (a truck GPS project is currently ongoing). The receptivity of DMHU towards the solution presented seems to indicate that a BI solution is indeed valuable for complex monitoring problems such as solid waste management.

6. CONCLUSIONS

In this chapter, we will move towards the seventh, eighth, and ninth phases of our DSR methodology: firstly, we will make sure to clarify the learning achieved; afterward, we will present key decisions and limitations of our research; and, finally, we will try to generalize the developed artifact for a class of problems.

The purpose of this project was to discover if a Business Intelligence solution would make sense in an SWM context. To answer this question, a thorough investigation into three different topics was made: the Smart City context, how solid waste management is executed and its challenges, and finally an introduction on how BI is helpful in a monitoring context.

Firstly, the Smart City concept was presented, revealing how today's cities have been discovering new ways to improve the quality of life of their citizens by using data available, through the use of new technologies. We found that Smart City research has a clear need for real data projects as most of the research on this topic uses simulated data, highlighting the clear necessity for a structured approach to this problem. Secondly, the concept of Solid Waste Management was introduced, along with its main challenges, frameworks, and new technologies. Finally, a brief description of business intelligence was made, introducing its principal elements and how it is a valuable tool for performance monitoring activities.

Afterward, an artifact was built for the Department of Urban Sanitation of Lisbon as conceptual proof on how a BI solution can be valuable for this type of necessity. The solution was well received as stated in (5.3). Nonetheless, one of the main limitations of this project is that it is not an integrated solution. There is a real need for the automation of processes in DMHU that this project does not answer.

Even though the quantity of data is significant, Power BI was a surprisingly effective tool for digesting and cleaning data into the model. Future work may focus on the construction of a data warehouse and ETL pipeline, using other enterprise database systems.

To conclude, we can affirm that BI can be used as a solution for not only solid waste management monitoring but also other complex infrastructural performance assessments. The flexibility of BI operations, such as data drilling, allows for the condensation of numerous individual processes into a digestible form. Measures like distances, durations, and process completions can be then evaluated and abnormalities found easily. Other activities may benefit from this, such as Public Transportation Monitoring and Freight Transportation Monitoring (Shipping, Cargo aircraft, etc.).

7. BIBLIOGRAPHY/REFERENCES

Anschütz, J., IJgosse, J., & Scheinberg, A. (2004). Putting Integrated Sustainable Waste Management into Practice. In *Waste.Watsan.Net*. http://www.waste.watsan.net/content/download/561/4346/file/ISWM ass eng screen.pdf

Anthopoulos, L. (2015). Understanding the smart city domain: A literature review. In *Transforming city governments for successful smart cities* (pp. 9–21). https://doi.org/10.1016/s0267-3649(96)90014-x

Arebey, M., Hannan, M. A., Begum, R. A., & Basri, H. (2012). Solid waste bin level detection using gray level co-occurrence matrix feature extraction approach. *Journal of Environmental Management*, *104*, 9–18. https://doi.org/10.1016/j.jenvman.2012.03.035

Bose, S., & Kielhauser, C. (2019). *Bridging the Infrastructure Gap : Tools for Creating Investable Infrastructure Project Pipelines* (Issue November). http://www3.weforum.org/docs/WEF_Bridging_the_Infrastructure_Gap.pdf

Božič, K., & Dimovski, V. (2019). Business intelligence and analytics for value creation: The role of absorptive capacity. *International Journal of Information Management*, *46*(February 2018), 93–103. https://doi.org/10.1016/j.ijinfomgt.2018.11.020

Camero, A., & Alba, E. (2019). Smart City and information technology: A review. *Cities*, *93*(May), 84–94. https://doi.org/10.1016/j.cities.2019.04.014

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

Chaudhuri, S., Dayal, U., & Narasayya, V. (2011). An overview of business intelligence technology. *Communications of the ACM*, *54*(8), 88–98. https://doi.org/10.1145/1978542.1978562

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

Dameri, R. P. (2013). Searching for Smart City definition: a comprehensive proposal. *International Journal of Computers & Technology*, *11*(5), 2544–2551. https://doi.org/10.24297/ijct.v11i5.1142

Das, S., & Bhattacharyya, B. K. (2015). Optimization of municipal solid waste collection and transportation routes. *Waste Management*, *43*, 9–18. https://doi.org/10.1016/j.wasman.2015.06.033

Dresch, A., Pacheco Lacerda, D., & Valle Antunes, J. A. (2018). Design-science research: A Method for Science and Technology Advancement. In *Research Methods: Information, Systems, and Contexts: Second Edition*. https://doi.org/10.1016/B978-0-08-102220-7.00011-X

Eisenstein, D. D., & Iyer, A. V. (1997). Garbage collection in Chicago: A dynamic scheduling model. *Management Science*, *43*(7), 922–933. https://doi.org/10.1287/mnsc.43.7.922

European Environment Agency. (n.d.). *Diversion of waste from landfill in Europe*.

Fazio, M., Celesti, A., Puliafito, A., & Villari, M. (2015). Big data storage in the cloud for smart environment monitoring. *Procedia Computer Science*, *52*(1), 500–506. https://doi.org/10.1016/j.procs.2015.05.023

Finkenzeller, K. (2010). RFID handbook Aplications, Technology. In *Jone Willey & Sons*. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:RFID+handbook+:+Applications,+Technology,+Security+and+Privacy#0%5Cnhttp://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:RFID+handbook#4

Giffinger, R., Fertner, C., Kramar, H., & Meijers, E. (2007). City-ranking of European Medium-Sized Cities. *Digital Agenda for Europe*, 1–12.

Hall, R. E., Bowerman, B., Braverman, J., Taylor, J., & Todosow, H. (2000). The vision of a smart city.

2nd International Life …, *28*, 7. ftp://24.139.223.85/Public/Tesis_2011/Paper_Correction_4-15-09/smartycitypaperpdf.pdf

Hannan, M. A., Abdulla Al Mamun, M., Hussain, A., Basri, H., & Begum, R. A. (2015). A review on technologies and their usage in solid waste monitoring and management systems: Issues and challenges. *Waste Management*, *43*, 509–523. https://doi.org/10.1016/j.wasman.2015.05.033

Hevner, A., & Chatterjee, S. (2012). Integrated Series in Information Systems Volume 28. In *Springer* (Vol. 28).

Hollands, R. G. (2008). Will the real smart city please stand up? Intelligent, progressive or entrepreneurial? *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. In *Macrocognition Metrics and Scenarios: Design and Evaluation for Real-World Teams*. https://doi.org/10.1201/9781315593173-4

Ismagilova, E., Hughes, L., Dwivedi, Y. K., & Raman, K. R. (2019). Smart cities: Advances in research—An information systems perspective. *International Journal of Information Management*, *47*(December 2018), 88–100. https://doi.org/10.1016/j.ijinfomgt.2019.01.004

Jacobsen, R., Buysse, J., & Gellynck, X. (2013). Cost comparison between private and public collection of residual household waste: Multiple case studies in the Flemish region of Belgium. *Waste Management*, *33*(1), 3–11. https://doi.org/10.1016/j.wasman.2012.08.015

Juice Analytics. (2010). *A Guide to Creating Dashboards People Love to Use* (Issue November 2009).

Kaza, S., Yao, L., Bhada-Tata, P., & Van Woerden, F. (2018). What a waste 2.0: a global snapshot of solid waste management to 2050. In *Urban Development Series*.

Kim, T. hoon, Ramos, C., & Mohammed, S. (2017). Smart City and IoT. *Future Generation Computer Systems*, *76*(July 2014), 159–162. https://doi.org/10.1016/j.future.2017.03.034

Lau, H. C., Sim, M., & Teo, K. M. (2003). Vehicle routing problem with time windows and a limited number of vehicles. *European Journal of Operational Research*, *148*(3), 559–569. https://doi.org/10.1016/S0377-2217(02)00363-6

Luhn, H. P. (1958). A Business Intelligence System. *IBM Journal of Research and Development*, *2*(4), 314–319. https://doi.org/10.1147/rd.24.0314

Marceau, J. (2008). Innovation in the city and innovative cities. *Innovation: Management, Policy and Practice*, *10*(2–3), 136–145. https://doi.org/10.5172/impp.453.10.2-3.136

Minciardi, R., Paolucci, M., & Trasforini, E. (2005). A new procedure to plan routing and scheduling of vehicles for solid waste collection at a metropolitan scale. *Waste Management*, *24*, 227–295.

Mourão, M. C., & Almeida, M. T. (2000). Lower-bounding and heuristic methods for a refuse collection vehicle routing problem. *European Journal of Operational Research*, *121*(2), 420–434. https://doi.org/10.1016/S0377-2217(99)00045-4

Negash, S., & Gray, P. (2008). Business intelligence. In *Handbook on decision support systems 2* (pp. 175–193). Springer. https://doi.org/10.4018/978-1-59904-931-1.ch008

Nuortio, T., Kytöjoki, J., Niska, H., & Bräysy, O. (2006). Improved route planning and scheduling of waste collection and transport. *Expert Systems with Applications*, *30*(2), 223–232. https://doi.org/10.1016/j.eswa.2005.07.009

Parekh, H., Yadav, K., Yadav, S., & Shah, N. (2015). Identification and assigning weight of indicator influencing performance of municipal solid waste management using AHP. *KSCE Journal of Civil Engineering*, *19*(1), 36–45. https://doi.org/10.1007/s12205-014-2356-3

Parker, H. (1988). The unique qualities of a geographic information system: a commentary. *Photogrammetric Engineering & Remote Sensing*, *54*(11), 1547–1549.

Ramesh Sharda, Dursun Delen, E. T. (2017). *Business Intelligence, Analytics, and Data Science*. https://1lib.eu/book/3510837/95d324?regionChanged=&redirect=3970486

Simon, H. A. (2019). The Sciences of the Artificial. In *The Sciences of the Artificial*. https://doi.org/10.7551/mitpress/12107.001.0001

Strand, M., & Syberfeldt, A. (2020). Using external data in a BI solution to optimise waste management. *Journal of Decision Systems*, *29*(1), 53–68. https://doi.org/10.1080/12460125.2020.1732174

Teixeira, C. A., Russo, M., Matos, C., & Bentes, I. (2014). Evaluation of operational, economic, and environmental performance of mixed and selective collection of municipal solid waste: Porto case study. *Waste Management and Research*, *32*(12), 1210–1218. https://doi.org/10.1177/0734242X14554642

Teixeira, J., Antunes, A. P., & De Sousa, J. P. (2004). Recyclable waste collection planning - A case study. *European Journal of Operational Research*, *158*(3), 543–554. https://doi.org/10.1016/S0377-2217(03)00379-5

Velcu-Laitinen, O., & Yigitbasioglu, O. M. (2012). The use of dashboards in performance management: Evidence from sales managers. *International Journal of Digital Accounting Research*, *12*(November 2011), 39–58. https://doi.org/10.4192/1577-8517-v12_2

Washburn, D., & Sindhu, U. (2009). Helping CIOs Understand "Smart City" Initiatives. In *Growth* (p. 17). http://c3328005.r5.cf0.rackcdn.com/73efa931-0fac-4e28-ae77-8e58ebf74aa6.pdf

Yang, K., Zhou, X. N., Yan, W. A., Hang, D. R., & Steinmann, P. (2008). Landfills in Jiangsu province, China, and potential threats for public health: Leachate appraisal and spatial analysis using geographic information system and remote sensing. *Waste Management*, *28*(12), 2750–2757. https://doi.org/10.1016/j.wasman.2008.01.021

Yigitbasioglu, O. M., & Velcu, O. (2012). A review of dashboards in performance management: Implications for design and research. *International Journal of Accounting Information Systems*, *13*(1), 41–59. https://doi.org/10.1016/j.accinf.2011.08.002

Zaman, A. U. (2014). Identification of key assessment indicators of the zero waste management systems. *Ecological Indicators*, *36*, 682–693. https://doi.org/10.1016/j.ecolind.2013.09.024

8. ANNEXES

Figure 15 - 2021_02_07_escala_2017_2020.xlsx (Excel file containing Shift Data)

ESCG_ID	ESCG_DT	ESCG_DTM_INICIO	ESCG_DTM_FIM	ESCG_MN	ESCG_MN	ESCG_MN	ESCG_KM_	ESCG_KM_	ESCG_HR_	ESCG_HR_	ESCG_TUR	CRC_ID	RCM_ID	ECO_ID	RSDG_ID	TTA_ID	ESCG_OBS	ES
1394283	1/2/2017	1/2/2017 5:30 AM	1/2/2017 9:00 AM	330	540	210					M	13122		20769		57		
1394284	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570					M	13122		18211		57		
1394226	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570					M	16383			1	7	Circuito nã	
1394272	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570	443978	444065			M	8381	272	18107	1	39		
1394273	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570	217223	217275			M	7824	426	4871	1	137	Circuito da	
1394274	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570	103413	103633			M	7797	2464	3240	1	137	Circuito da	
1394275	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570	202970	203056			M	7836	2545	5618	1	137	Circuito da	
1394276	1/2/2017	1/2/2017 5:30 AM	1/2/2017 8:30 AM	330	510	180	0	0			M	7832	2362	17963	1	137	Circuito da	
1394279	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570	128487	128573			M	7808	2898	8804	1	137	Circuito da	
1394281	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570	533735	533798			M	7756	211	8558	1	39		
1394285	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570	218699	218773			M	7756	2348	4476	1	39		
1394495	1/2/2017	1/2/2017 5:30 AM	1/2/2017 12:30 PM	330	750	420	0	0			M	7756	216	19760	1	39		
1394497	1/2/2017	1/2/2017 5:30 AM	1/2/2017 6:00 AM	330	360	30	112436	112457			M	13122	2935	17359		57	Abastecer	
1394498	1/2/2017	1/2/2017 5:30 AM	1/2/2017 6:00 AM	330	360	30					M	13122		6747		57		
1394499	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570	0	0			M	7758	214	913	1	39		
1394500	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570	391342	391406			M	7759	208	544	1	39		
1394501	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570	326217	326278			M	7759	267	6074	1	39		
1394506	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570	234845	234893			M	7760	2349	7876	1	39		
1394508	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570	0	0			M	16231	210	621	1	39		
1394136	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570	0	0			M	8219	361	20775	12	43		
1394137	1/2/2017	1/2/2017 5:30 AM	1/2/2017 12:30 PM	330	750	420	202200	202304			M	8230	2562	1372	10	142		
1394138	1/2/2017	1/2/2017 5:30 AM	1/2/2017 9:00 AM	330	540	210	144078	144096			M	8136	2895	38122	1	137		
1394139	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570	440112	440184			M	8146	2437	3649	12	43		
1394140	1/2/2017	1/2/2017 5:30 AM	1/2/2017 3:00 PM	330	900	570	227284	227394			M	7853	2565	3322	1	138		
1394141	1/2/2017	1/2/2017 5:30 AM	1/2/2017 12:30 PM	330	750	420	309872	309977			M	7877	2387	6713	1	138		

Figure 16 - 2021_02_07_fretes_2017_2020.xlsx (Excel file containing Freight Data)

ESCG_ID	ESCO_ID	FRTG_NR	ORS_ID	RSDG_ID	LDES_ID	TOPV_ID	CRC_ID	ENT_ID_TI	FRTG_DTN	FRTG_DT_	FRTG_HR_	FRTG_TALAO	FRTG_PES	FRTG_GUI	FRTG_YN_REJEITADO
1773177		1	233	10	18	4	16008	19006	2020-12-3	2020-12-3	02:13	2004034108	3980		0
1773148		1	233	10	18	4	14461	19006	2020-12-3	2020-12-3	01:19	2004034095	3840		0
1773148		2	233	10	18	4	14461	19006	2020-12-3	2020-12-3	04:06	2004034135	4080		0
1773168		1	1	10	18	4	16137	19006	2020-12-3	2020-12-3	02:17	2004034111	4940		0
1773169		1	1	10	18	4	16138	19006	2020-12-3	2020-12-3	01:31	2004034098	3460		0
1773251		1	1	10	18	4	16038	19006	2020-12-3	2020-12-3	01:01	2004034091	3880		0
1773166		1	233	10	18	4	15025	19006	2020-12-3	2020-12-3	03:01	2004034124	4620		0
1773179		1	233	10	18	4	16051	19006	2020-12-3	2020-12-3	00:28	2004034085	1060		0
1773179		2	233	10	18	4	16051	19006	2020-12-3	2020-12-3	02:47	2004034117	1060		0
1773167		1	233	10	18	4	15026	19006	2020-12-3	2020-12-3	02:23	2004034112	4200		0
1773178		1	233	10	18	4	16011	19006	2020-12-3	2020-12-3	01:33	2004034100	3620		0
1773150		1	1	10	18	4	14527	19006	2020-12-3	2020-12-3	01:34	2004034101	3520		0
1773147		1	1	10	18	4	14375	19006	2020-12-3	2020-12-3	01:32	2004034099	3100		0
1773147		2	1	10	18	4	14375	19006	2020-12-3	2020-12-3	03:49	2004034133	3220		0
1773151		1	1	10	18	4	14532	19006	2020-12-3	2020-12-3	02:16	2004034110	3780		0
1773151		2	1	10	18	4	14532	19006	2020-12-3	2020-12-3	03:45	2004034132	1720		0
1773171		1	1	10	18	4	16039	19006	2020-12-3	2020-12-3	01:45	2004034103	2940		0
1773171		2	1	10	18	4	16039	19006	2020-12-3	2020-12-3	04:06	2004034134	2200		0
1773172		1	1	10	18	4	16040	19006	2020-12-3	2020-12-3	01:00	2004034089	3600		0
1773172		2	1	10	18	4	16040	19006	2020-12-3	2020-12-3	03:14	2004034128	2820		0
1773149		1	38	10	18	4	14526	19006	2020-12-3	2020-12-3	02:14	2004034109	1340		0
1773188		1	38	10	18	4	16353	19006	2020-12-3	2020-12-3	00:59	2004034088	3360		0
1773124		1	19	1	11	7	7838	19006	2020-12-3	2020-12-3	02:33	2001079600	5620		0
1773249		1	19	1	11	7	7832	19006	2020-12-3	2020-12-3	01:45	2001079579	4080		0
1773045		1	19	1	11	7	7808	19006	2020-12-3	2020-12-3	01:21	2001079555	3940		0
1773159		1	19	1	11	7	7809	19006	2020-12-3	2020-12-3	01:16	2001079552	5080		0
1773062		1	19	1	11	7	7824	19006	2020-12-3	2020-12-3	01:46	2001079580	4780		0
1773044		1	17	1	11	7	7806	19006	2020-12-3	2020-12-3	02:06	2001079588	9560		0
1773065		1	17	1	11	7	7822	19006	2020-12-3	2020-12-3	02:12	2001079591	6800		0
1773046		1	17	1	11	7	7823	19006	2020-12-3	2020-12-3	[illegible]	2001079567	11200		0

Table 6- Measures

Métrica	Tabela	Indicador	Fonte de dados (Tabela)	Cálculo	Descrição
Total Peso Descarregado (Tn)	Fact Frete	Total Municipal Solid Waste Collected	Fact Frete	`CALCULATE(Divide(SUMX('FACT Frete','FACT Frete'[FRTG_PESO]) ,1000))`	Total tons of waste collected by MSW circuits.
Total Peso Lixo Selectivo	Fact Frete	Total Selective Waste Collected	Fact Frete; DIM Residuos	`CALCULATE([Total Peso Descarregado (Tn)],Filter(RELATEDTABLE('DIM Residuos'),'DIM Residuos'[Grupo de Resíduos]="Selectivos"))`	Total tons of selective waste collected by MSW circuits.
`NºFretes Total`	Fact Frete	Total Count of Freights	Fact Frete	`CALCULATE(COUNTROWS('FACT Frete'))`	Total count of truck freights that executed circuits.
Eficiência da recolha	Fact Escala	Collection Efficiency	Fact Frete; Fact Escala	`[Total Peso Descarregado (Tn)]/([Duração Total (minutos)]/60)`	The ratio between the quantity of waste collected per circuit/day and the working hours/day.
Taxa de seletividade	Fact Frete	Selective Rate	Fact Frete; DIM Residuos	`Calculate(Divide([Total Peso Lixo Selectivo],[Total Peso Descarregado (Tn)]))`	Percentage of non-undifferentiated waste collected
Fretes Rejeitadas	Fact Frete	Rejected Freights	Fact Frete	`CALCULATE(COUNTX('FACT Frete','FACT Frete'[FLAG Rejeitado]),'FACT Frete'[FLAG Rejeitado]="Rejeitado")`	Total Count of Reject Freights at deposition

Total Peso Reciclagem	Fact Frete	Recycling Rate	Fact Frete; DIM Operação Valorização	`CALCULATE([Total Peso Descarregado (Tn)],Filter(RELATEDTABLE('DIM Operação Valorizacao'),Or('DIM Operação Valorizacao'[TipoValorizacao]="Reciclagem",'DIM Operação Valorizacao'[TipoValorizacao]="Valorização orgânica")))`	Total weight of Recycled waste collected
Taxa de reciclagem	Fact Frete	Recycling Rate	Fact Frete; DIM Operação Valorização	`[Total Peso Reciclagem]/[Total Peso Descarregado (Tn)]`	Percentage of Collected Waste that ends up being recycled
Total Peso Aterro	Fact Frete	Share of Waste deposited in landfills	Fact Frete; DIM Operação Valorização	`CALCULATE([Total Peso Descarregado (Tn)],Filter(RELATEDTABLE('DIM Operação Valorizacao'),'DIM Operação Valorizacao'[TipoValorizacao]="Aterro"))`	Total weight of waste that end up on landfills
Taxa de Lixo para Aterro	Fact Frete	Share of Waste deposited in landfills	Fact Frete; DIM Operação Valorização	`[Total Peso Aterro]/[Total Peso Descarregado (Tn)]`	Percentage of Collected Waste that ends up on landfills
Total Peso Lixo Hospitalar	Fact Frete	Medical Waste Collected	Fact Frete; DIM Circuito	`CALCULATE([Total Peso Descarregado (Tn)],Filter(RELATEDTABLE('DIM Circuito'),'DIM`	Total weight of medical waste

				`Circuito'[TipoCircuitoAbrev ]="Hospitalares") )`	
Toneladas de Vidro Descarregadas	Fact Frete	Glass Waste Collected	Fact Frete; Dim Residuos	`CALCULATE([Total Peso Descarregado (Tn)],Filter(RELATEDTABLE(' DIM Residuos'),'DIM Residuos'[Tipo de Resíduos] ="Vidro") )`	Total weight of glass waste
Média Toneladas Descarregadas Diárias (Vidro)	Fact Frete	Glass Waste Collected	Fact Frete; Dim Residuos; Dim Data	`AVERAGEX(VALUES('DIM Data'[Data].[Date]),[Toneladas de Vidro Descarregadas])`	Average Daily Tons of Glass Deposited
Toneladas de Embalagens Descarregadas	Fact Frete	Plastic Waste Collected	Fact Frete; Dim Residuos	`CALCULATE([Total Peso Descarregado (Tn)],Filter(RELATEDTABLE(' DIM Residuos'),'DIM Residuos'[Tipo de Resíduos] ="Embalagens") )`	Total weight of plastic waste
Média Toneladas Descarregadas Diárias (Embalagens)	Fact Frete	Plastic Waste Collected	Fact Frete; Dim Residuos; Dim Data	`AVERAGEX(VALUES('DIM Data'[Data].[Date]),[Toneladas de Embalagens Descarregadas])`	Average Daily Tons of Plastic Deposited
Toneladas de Papel e Cartão Descarregadas	Fact Frete	Paper & Cardboard Waste Collected	Fact Frete; Dim Residuos	`CALCULATE([Total Peso Descarregado (Tn)],Filter(RELATEDTABLE(' DIM Residuos'),'DIM Residuos'[Tipo de Resíduos] ="Papel") )`	Total weight of paper waste

Média Toneladas Descarregadas Diárias (Papel e Cartão)	Fact Frete	Paper & Cardboard Waste Collected	Fact Frete; Dim Residuos; Dim Data	`AVERAGEX(VALUES('DIM Data'[Data].[Date]),[Toneladas de Papel e Cartão Descarregados])`	Average Daily Tons of Paper Deposited
Densidade do Lixo Produzido	Fact Escala	Urban Waste Density	Fact Frete; Fact Escala	`[Total Peso Descarregado (Tn)]/[Total distância percorrida]`	Urban Waste Generation Density
Peso recolhido por PRS	Fact Colecta	-	Fact Colecta	`CALCULATE(SUMX('FACT Colecta','FACT Colecta'[Peso por PRS]))`	-
Total de Escalas Realizadas	Fact Escala	Total Shifts Completed	Fact Escala	`CALCULATE(COUNTX('FACT Escala','FACT Escala'[BK_Escala_ID]))`	Total shifts completed in the selected period
Média Escalas Diárias	Fact Escala	Average Daily Shifts Completed	Fact Escala; Dim Date	`AverageX(Values('DIM Data'[Data]),[Total de Escalas Realizadas])`	Average shifts completed per day
Total Escalas YTD	Fact Escala	Total Shifts Completed	Fact Escala; Dim Data	`CALCULATE(TOTALYTD([Total de Escalas Realizadas],'DIM Data'[Data].[Date]))`	Total shifts completed year-to-date
Total Escalas YTD SPLY	Fact Escala	Total Shifts Completed	Fact Escala; Dim Data	`CALCULATE([Total Escalas YTD],DATEADD('DIM Data'[Data],-1,YEAR))`	Total shifts completed YTD, in the same period of the previous year.
% Crescimento Escalas YTD	Fact Escala	Total Shifts Completed	Fact Escala; Dim Data	`[Total de Escalas Realizadas YTD]/[Total Escalas YTD SPLY]-1`	Total shifts completed growth rate

Total Distância percorrida	Fact Escala	Total Distance Traveled	Fact Escala	`calculate(sumx('FACT Escala', 'FACT Escala'[Distância percorrida KM]))`	Total kilometers traveled in the selected period
Distância Média Diária	Fact Escala	Average Daily Distance Traveled	Fact Escala Dim Data	`AverageX(Values('DIM Data'[Data]),[Total Distância])`	Average kilometers made by a truck per day.
Distância média por circuito	Fact Escala	Average Daily Distance Traveled	Fact Escala Dim Data	`var dist=Round(AverageX(values('DIM Circuito'[Circuito]),[Distância média diária (calc)]),0) return dist&" km"`	Average circuit distance
Total Distância YTD	Fact Escala	Total Distance Traveled	Fact Escala Dim Data	`CALCULATE(TOTALYTD(SUM('FACT Escala'[Distância percorrida KM]),'DIM Data'[Data].[Date]))`	Total distance traveled year-to-date
Total Distância YTD SPLY	Fact Escala	Total Distance Traveled	Fact Escala Dim Data	`CALCULATE(TOTALYTD(SUM('FACT Escala'[Distância percorrida KM]),DATEADD('DIM Data'[Data],-1,YEAR)))`	Total distance traveled YTD, in the same period of the previous year.
% Crescimento Total Distância YTD	Fact Escala	Total Distance Traveled	Fact Escala Dim Data	`[Total Distância YTD]/[Total Distância YTD SPLY]-1`	Total distance traveled growth rate
Duração Total (minutos)	Fact Escala	-	Fact Escala	`calculate(sumx('FACT Escala', 'FACT`	Total working minutes spent on shifts

				Escala'[Duração (minutos)]))	
Duração Média de Escala Diária (minutos)	Fact Escala	Average Daily Shift Duration	Fact Escala; Dim Data; Dim Circuito	AverageX(VALUES('DIM Circuito'[Circuito]), AverageX(Values('DIM Data'[Data].[Date]),[Duração Total (minutos)]))	Average total minutes spent on a particular circuit per day
Duração média de Escala Diária (horas e min)	Fact Escala	Average Daily Shift Duration	Fact Escala; Dim Data; Dim Circuito	var horasNo=INT(MOD([Duração Média de Escala Diária (minutos)],1440)/60) var minutosNo=INT(MOD(MOD([Duração Média de Escala Diária (minutos)],1440),60)) return FORMAT(horasNo,"#00")&" h "&FORMAT(minutosNo,"#00")&" min"	Average hours & minutes spent on a particular circuit per day