Strategic location of citizen service centers

Application to the Portuguese case

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ABSTRACT

The improvement of the public services’ performance in Portugal has been on the political agenda since 1980 and has led to the launch of the Public Administration Reform Program. This program has evolved throughout the years towards a citizen-oriented approach with a concern for service quality.
Within this reform, the citizen assistance network was established in 1999 with the deployment of the first Lojas de Cidadão (meaning Citizen Shops) which promote the concentration of several services on the same facility to improve the service quality as well as the citizen’s experience.
The Administrative Modernization Agency (AMA) – the public institute responsible for the development of administrative modernization in Portugal and for managing the aforementioned network – is focused on improving the public services’ distribution and, more specifically, in further expanding the current network of 51 citizen shops, to increase the proximity between the public administration and the citizens.
A multi-period hierarchical optimization model is developed to support the decision making related to the location of new citizen shops and kiosks in the network. The model has two conflicting objectives of equity and cost; it receives as inputs the demand projections, costs involved, and an accessibility measure, and provides as outputs the information on where and when to locate each facility, the expected costs, and the equity measure for the network. Finally, the applicability of the model is illustrated through the resolution of the case study described. The optimization of the current network in terms of equity is also analyzed.

Keywords: Public sector; Facility location; Location-allocation; Citizen service center; Public Administration Reform.

RESUMO

A melhoria do desempenho dos serviços públicos em Portugal tem estado na agenda política desde 1980 e levou ao lançamento do programa de Reforma da Administração Pública. Este programa tem evoluído ao longo dos anos na direção de uma abordagem orientada para o cidadão com enfâse na qualidade de serviço.

Dentro desta reforma, a rede de atendimento ao cidadão foi estabelecida em 1999 com a abertura das primeiras Lojas de Cidadão, que promovem a concentração de diversos serviços no mesmo local para melhorar a qualidade de serviço, assim como a experiência do cidadão.

A AMA (Agência para a Modernização Administrativa) – o instituto responsável pelo desenvolvimento da modernização administrativa em Portugal e pela gestão da rede de lojas acima mencionada – está focada em melhorar a distribuição dos serviços públicos e, mais especificamente, em expandir a rede de 51 lojas de cidadão, para aumentar a proximidade entre a administração pública e os cidadãos.

Foi desenvolvido um modelo de otimização hierárquico e multi-período para apoiar os decisores no processo de decisão relacionado com a localização de novas lojas e quiosques na rede. O modelo tem dois objetivos contraditórios de equidade e de custo; recebe como *inputs* as projeções da população, os custos envolvidos, e uma medida de acessibilidade, e fornece como *ouputs* a informação sobre onde e quando localizar cada infraestrutura, os custos esperados, e a medida de equidade da rede. Finalmente, a aplicabilidade do modelo é ilustrada através da resolução do estudo do caso descrito. A otimização em termos de equidade da rede atual também é analisada.

Palavras-chave: Sector público; Localização de infraestruturas; Localização-alocação; Lojas de cidadão; Reforma da Administração Pública.

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ACRONYMS

AMA – *Agência para a Modernização Administrativa* (Administrative Modernization Agency)

AT – *Autoridade Tributária* (Tax and Customs Authority)

CS – Citizen Shop

DGAJ – *Direção-Geral da Administração da Justiça* (Directorate-General of Justice Administration)

DM – Decision-maker

EC – *Espaço do Cidadão* (Citizen Spot)

FCLP – Fixed Charge Location Problem

FLP – Facility Location Problem

GAMS – General Algebraic Modeling System

IAPMEI – *Agência para a Competitividade e Inovação* (Agency for Competitiveness and Innovation)

IEFP – *Instituto do Emprego e Formação Profissional* (Employment and Vocational Training Institute)

IGLC – *Instituto para a Gestão das Lojas do Cidadão* (Institute for the Management of Citizen Shops)

IMPIC – *Instituto dos Mercados Públicos, do Imobiliário e da Construção* (Institute of Public Markets, Real Estate and Construction)

INE – *Instituto Nacional de Estatística* (Portuguese Institute of Statistics)

IRN – *Instituto dos Registos e Notariado* (Institute of Registries and Notaries)

ISS – *Instituto da Segurança Social* (Social Security Institute)

LTC – Long-Term Care

MCLP – Maximal Covering Location Problem

MILP – Mixed Integer Linear Programming

MO – Multi-objective

OECD – Organization for Economic Co-operation and Development

PRACE – *Programa de Reestruturação da Administração Central do Estado* (General Government Restructuring Program)

SSK – Self-Service Kiosk

TTPC – Travel Time per Citizen

UMIC – *Agência para a Sociedade do Conhecimento* (Agency for Knowledge Society)

Chapter 1 INTRODUCTION

This chapter presents the context in which our problem arises, and it highlights both the purpose and the structure of the master's dissertation. In section 1.1, a brief contextualization of the problem is provided. In section 1.2, the purpose and objectives of the present work are presented. Finally, in section 1.3 the methodology applied is described, and in section 1.4 the structure and outline of the document are provided.

1.1 Problem Contextualization

Over the years, there has been a general pressure in the governance of many member countries of the Organization for Economic Co-operation and Development (OECD) towards the enhancement of public services. In particular, Portugal faces challenges such as the need to reform its organization and human resources' management, in order to create an efficient public administration, and to meet social demands through cost-effective service delivery (OECD, 2013b).

The existing administrative structures have become obsolete and have hindered Portugal from developing an efficient public administration. The impact of this pressure, and the related deterioration of public services over the past years, has been strongly felt by public administrations and has forced them to reconsider the way they relate to society, question their role in the economy and review the way they function.

This concern to improve the performance of public services has arisen around 1980 and led the Portuguese Government to launch a Public Administration reform program. Even though Portugal still has challenges to overcome, the successive governments have implemented several modernizing initiatives over the years, some of which were considered best practices among the OECD countries. One of the milestones accomplished consists of the establishment of the *Lojas de Cidadão*, meaning Citizen Shops, which are the Portuguese citizen service centers whose concept is to offer several diverse services in one place, co-locating different state and private entities, aiming to improve the relationship between the citizens (or companies) and the public administration, as well as the customer experience.

One of the challenges and objectives for the future, in line with the *Grandes Opções do Plano* (the document that delineates the main priorities of the Government Program), outlined by the 21st Government, is to expand the physical channel of the citizen assistance network. Within this context, the Administrative Modernization Agency (AMA) must undergo a decision-making process regarding the selection of a robust set of long-term physical locations for the citizen shops and kiosks, so as to maximize the accessibility to all citizens. This process is undoubtedly an intricate one as it must take into consideration several factors such as the existing demand, its distribution, the travel distances/times between the citizens and the facilities, the involved costs, among others. Facility location decisions are crucial in the design of systems for both private and public companies. They aim to select the best location for the facilities, so that they can meet the customers demand in the best way possible while considering the trade-offs between costs and customer satisfaction. Thereby, these decisions have a significant impact on the organization's cost structure in the long-term, as well as on the level of service it can achieve.

The present work arises within this context. It is intended to inform AMA's decision, concerning the definition of new citizen shops and kiosks' physical location, in a way that improves citizens' accessibility to public services. To support such decision-making process, the development and implementation of a mathematical model are considered to be appropriate.

1.2 Purpose and Objectives of the Master's Dissertation

The purpose of the present work is to support AMA's decision-making process regarding the location of new citizen shops and kiosks, namely through the development and implementation of a mathematical model, which aims at improving the equity between citizens in the access to public services.

The following intermediate objectives are aimed in order to attain the aforementioned purpose:

- To describe the Portuguese Public Administration Reform and, particularly, the citizen assistance network (which consists of one of its initiatives), including its current constraints, the existing vision for the future and the related opportunities regarding the network's expansion;
- To elaborate a literature review on facility location problems, to gain a comprehensive knowledge of the models commonly utilized to support the solution of this type of problems;
- To develop and validate a mathematical model suitable for the solution of the presented problem;
- To collect and treat data, namely through the definition of assumptions, in order to apply it to the problem under study;
- To apply the model to the current situation and considering different future scenarios;
- To analyse the obtained results and identify meaningful insights from the analysis.

1.3 Methodology

The methodology followed to solve the presented problem throughout the dissertation is presented below. It comprises seven steps which are represented in Figure 1.

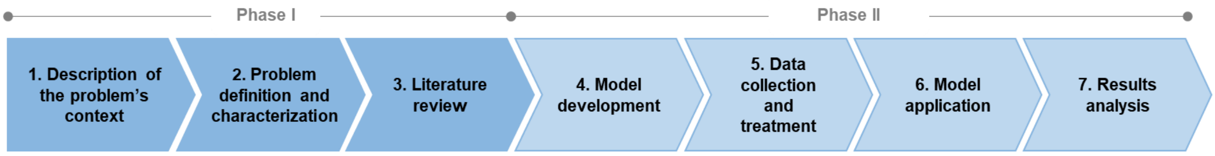


Figure 1 – Master's dissertation methodology

1. **Description of the problem's context**

   In this first step, a description of the problem's context is presented. In this stage, the Public Administration Reform Program is described, including the several milestones completed thus far, and the objectives defined by AMA for 2018 and the future are presented with the aim to better understand the problem's framework.

2. **Problem definition and characterization**

   The second step consists of defining and characterizing the problem, aiming to provide a comprehensive understanding and analysis of the latter within the aforementioned context. The problem's characterization is presented, including the breakdown of the citizen assistance network structure, and the detailing of its channels. Further detail is presented on the relevant channel for this study – the citizen shops' channel. Thus, it is possible to identify the current challenges faced, and the opportunities related to this network, in which our problem is inserted.

3. **Literature review**

   The third step consists of conducting a survey of the work developed in the field of facility location problems to gain a comprehensive knowledge of the most common formulations in the field, so as to help in the future process of selecting the appropriate model to address the problem. In this stage, the mathematical optimization models of relevant articles in the literature are analyzed, with a particular focus on discrete location problems. Moreover, the application of such models within the public services sector, in several geographies, is analyzed.

4. **Model development**

   The fourth step consists of, based on the conducted literature review, selecting the basic type of model to be used and developing the mathematical formulation to address the problem. In this step, the model is implemented using an adequate software, and the simplification strategies adopted to reduce the model's complexity, while still guaranteeing the significance of the results, are defined.

5. **Data collection and treatment**

   The fifth step consists of collecting and treating the available relevant data and defining the assumptions in case relevant data is not available, in order to ensure the viability of the model.

6. **Model application**

   In the sixth step, the model is applied to the case study, in order to test its applicability to a real-world context problem.

7. **Results analysis**

   The seventh and final step of the methodology consists of the analysis of the results obtained. A comparison between the results obtained from the model's application to different scenarios (including the "as is" scenario) is studied, and different solutions are presented and discussed. Furthermore, a sensibility analysis to the most critic parameters is conducted, in order to evaluate the potential impact of its variation. The improvement opportunities for the model are identified.

1.4 Master's dissertation structure

The dissertation is structured as follows:

- **Chapter 1 – Introduction:** In the present chapter, the subject of the master's dissertation is briefly described. It encompasses a short description of the problem's context, the objectives pursued, and the structure of the document.

- **Chapter 2 – Case Study:** In the second chapter, the context of the problem is further detailed, and a characterization and analysis of the problem are presented, namely, the citizen assistance network and the different channels it comprises are presented, along with different relevant analyses to the study. To conclude, the challenges of the current network are identified, as well as the opportunities and objectives to be pursued in the network's future strategy, in which our problem is inserted.
- **Chapter 3 – Literature Review:** With the aim to support the location decision for the citizen shops and kiosks, we resort to the literature, reviewing and analyzing some of the work and models developed in this field. In this chapter, we define the objectives and core concepts of the location models, present a taxonomy of the latter, briefly explain each basic discrete location model and present and analyze several applications in the public service sector.
- **Chapter 4 – Mathematical Model Definition:** In the fourth chapter, the formulation of the mathematical model to support the decision-making process related to the location of new citizen shops and kiosks is presented. The simplification strategies adopted to reduce the model's complexity are defined.
- **Chapter 5 – Case Study Resolution:** The data collection and treatment processes are outlined and the data to be considered for the model application is presented. In this chapter, the results of the model application are presented, through a scenarios' analysis and a sensibility analysis.
- **Chapter 6 – Final Remarks and Future Work:** The most important results and conclusions of the master's dissertation are presented, followed by the considerations for future work.

Chapter 2 CASE STUDY

This chapter presents the problem being regarded and further explores the context in which it arises. In section 2.1, the context in which the problem arose is detailed. In section 2.2, the network under study is described along with its characteristics. In section 2.3, the infrastructures which will be the focus of this master's dissertation are further detailed, and several network analyses are presented. Lastly, in section 2.4, the future strategy for the network and the problem definition are presented.

2.1 The Portuguese Public Administration Reform Program

"(…) Portugal needs an efficient public administration to enable private sector development in a competitive global environment, as well as to meet social demands through cost-effective service delivery, at a time when the public finances need to be strengthened. Important reforms of the State, including its organization and human resource management, are therefore urgently needed to face these challenges"

In "Portugal: Reforming the State to Promote Growth", OECD, 2013,
Better Policies Series, p. 3, Paris: OECD Publishing

Similarly to other Organization for Economic Co-operation and Development (OECD) member countries, the Portuguese governance has been under pressure. The existing administrative structures have become obsolete and have hindered Portugal from developing an efficient public administration. The impact of this pressure, and the related deterioration of public services over the past years, has been strongly felt by public administrations and has forced them to reconsider the way they relate to society, question their role in the economy and review the way they function.

This concern to improve the performance of public services has arisen around 1980 and led the Portuguese Government to launch a Public Administration reform program. The focus of the reform throughout the years revolved around privatization, debureaucratization, and proximity to the citizen, from 1990 to 2000, and then, from 2000 on, the focus shifted to efficiency, effectiveness, and quality, which continue to be the focus until today (Madureira & Ferraz, 2010) (Figure 2).

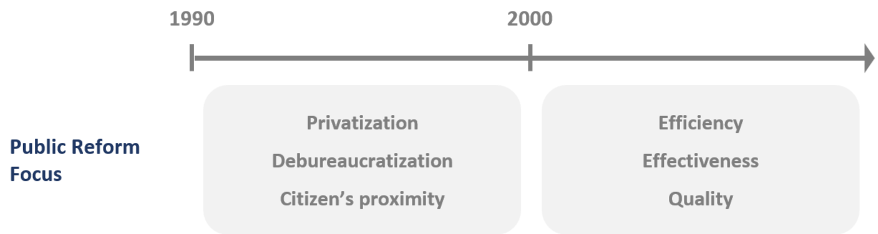


Figure 2 - Portuguese Public Administration Reform focus since 1990. Adapted from Madureira and Ferraz (2010)

The initiatives of the reform program have consisted not only in "changing structures, work methods and procedures, but also in intervening in the prevailing organizational culture" (OECD, 1996, p. 9). A citizen-oriented approach and concern for the service quality are some of the key components of the Portuguese Public Administration Reform Program. As such, the public management is becoming ever more centered on citizens and their interests, relying on the centralization of services, and on the decentralization of the related responsibilities.

According to the OECD (1996), the way Portugal has been dealing with the public management reform can be described as a ‘movement’, because regardless of political changes, the modernization work continued. This movement created its own internal dynamics and cadre of reformers, relying on continuity of thinking, and building on previous work.

Even though Portugal still has challenges to overcome, the successive governments have implemented several modernizing initiatives over the years (Figure 3), some of which were considered best practices among the OECD countries, and achieved various milestones, such as:

- The creation of the ***Secretariado para a Modernização Administrativa***, meaning Secretariat for Administrative Modernization, in 1986, whose main goal was to promote the innovation and modernization of the public administration, implementing pragmatic initiatives more citizen-oriented, in which the citizen started being recognized as the client, contrarily to the previous operating model. These initiatives were possible through a change in the administration attitude and culture, which started working to provide information to the citizen, and towards the debureaucratization, with focus on increasing the quality and effectiveness of the public services management.
- The establishment of ***Lojas de Cidadão***, meaning Citizen Shops, first launched in Portugal in the late 1990s, which are a great illustration of the citizen-centric paradigm: these shops are based on the one stop shop concept which consists of the concentration of several services on the same physical location to improve the service quality and maximize the citizen’s comfort.
- The creation of the ***Programa de Reestruturação da Administração Central do Estado* (PRACE)**, in 2005, meaning General Government Restructuring Program, whose objectives are to modernize and streamline the central administration, to improve the quality of the services provided to the citizen, and to create more proximity and dialog with the citizen (PRACE, 2006).
- The launch of the **Simplex program** in 2006, the Administrative and Legislative Simplification Program, which is a collaborative and nationwide simplification program towards the co-creation of new online public services, the optimization of existing ones and towards the debureaucratization of the relationship between public institutions and civil society (European Comission, 2017). This program contemplated, for instance, the creation of the *Cartão de Cidadão* (meaning Citizen’s Card), which is an identification document that grouped and replaced five cards from different public services. It also envisaged *Empresa na Hora* service (meaning On the Spot Firm) which enables one to set up companies at a single desk without filling any application form and in less than one hour (“What Is Simplex ?,” n.d.).

Other initiatives consist of the creation of INFOCID, the Citizen Portal and the Citizen Spots, which are further explained in the sections identified in Figure 3.

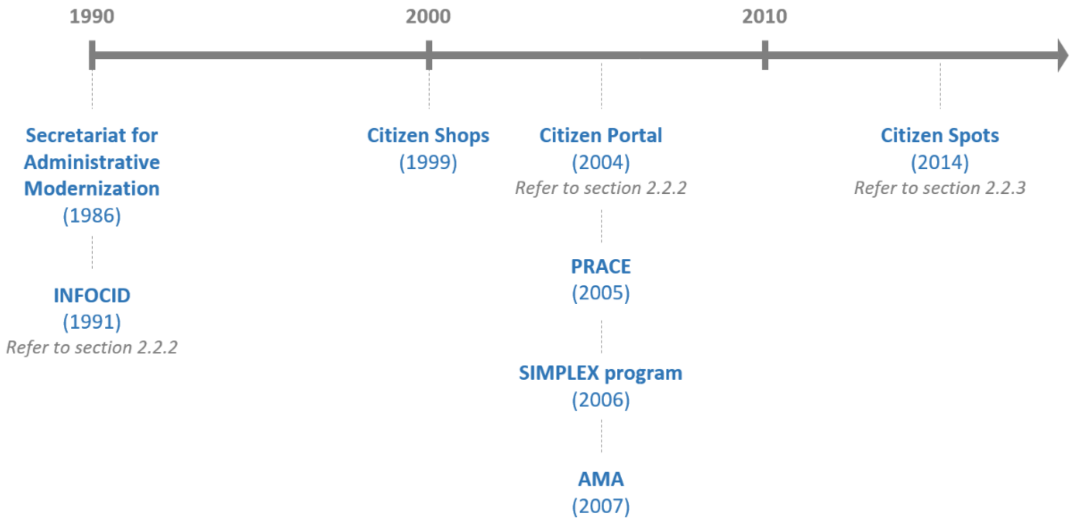


Figure 3 - Reform Program milestones

In 2007, under the PRACE program, the *Agência para a Modernização Administrativa* (AMA), meaning Administrative Modernization Agency, was established. AMA is the public institute responsible for the promotion and development of administrative modernization in Portugal, and that wields the power of the Prime Minister's Office in the fields of administrative modernization, simplification, and digital administration, under the supervision and tutelage of the Deputy Secretary of State for Administrative Modernization (AMA, 2016). The Agency is the result of the integration of the functions of the Institute for the Management of Citizen Shops (IGLC), which ceased to exist, the function related with digital administration which were previously performed by the Agency for Knowledge Society (UMIC), and some of the functions performed by Agency for Competitiveness and Innovation (IAPMEI).

AMA's main goals are to carry out cross-department initiatives to modernize public services and to promote the cooperation between all the entities involved, towards the following strategic goals (AMA, 2018):

- To improve the public services' distribution quality;
- To implement technological infrastructures to support the administrative modernization;
- To simplify the interactions between public administration and its customers.

Thereby, in line with the *Grandes Opções do Plano* (the document that delineates the main priorities of the Government Program) outlined by the 21st Government, AMA established strategic lines of action, (which constitute the Plan of Activities for 2018), which aim to improve the services provided, to bring closer the state and its citizens and companies, to promote the simplification, as well as to develop innovative solutions that meet the needs of the public services' customers.

AMA's strategic lines of action may be divided into 3 axes: assistance/service (front office), digital transformation (back office) and simplification (core). All axes of action target the relationship between the public administration and the citizens, the companies, and among the public administration entities themselves (Neves, n.d.), as shown in Figure 4.

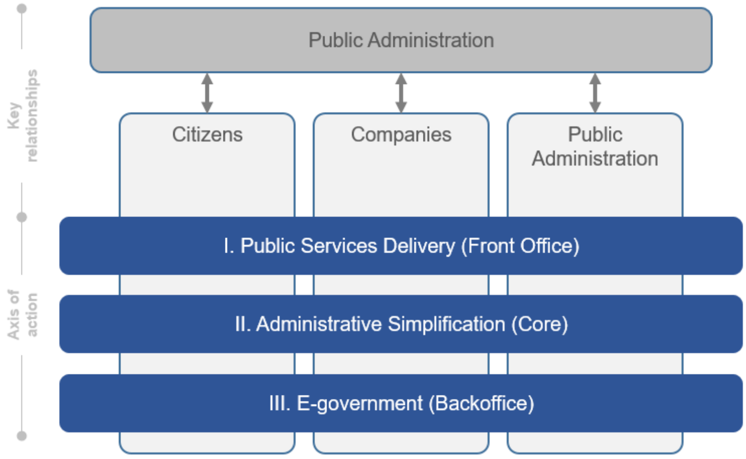


Figure 4 - AMA's axes of action. Adapted from "Agency for the Public Services Reform", by Paulo Neves, n.d, p. 7.

The analysis carried out in this dissertation shall be focused on the "Public Services Delivery" axis, namely, on its usage towards the improvement of the relationship between the Public Administration and citizens. Therefore, the description of the existing services delivery channels targeted to the citizens will be presented in the following section.

2.2 Citizen Assistance Network

The citizen assistance network is currently composed of three different types of channels: face-to-face, online and for digital service support. The main characteristics of each channel are described below.

2.2.1 Face-to-face Channel – *Loja do Cidadão*

As mentioned before, in 1999, the Portuguese Government launched an initiative, within its effort to modernize the public services' network, which aimed to improve the relationship between the citizen and the public administration, and to deliver their services to the citizens with greater proximity and comfort. Therefore, in 1999, the two first citizen shops were established in Lisbon and in Porto. These shops are citizen service centers, whose concept is to offer several different public services in one place, co-locating different state and private entities, enabling the customers to resolve different errands with different entities, in the same space, and to, hopefully, enable them to resolve all errands in one visit.

The new operating model was developed to enhance the service provided to the citizens and companies and to better meet their needs. The integrated model provides comfort and convenience to the citizens, by avoiding cost in terms of time and travel, and, on the other hand, it offers advantages to the entities, as they can share resources, infrastructures, and platforms, driving efficiency and cost reduction.

Regarding the management of the shops' network, it was initially assured by the Institute for the Management of Citizen Shops (IGLC), having this responsibility then been transferred to AMA in 2007 when this agency was created.

Presently, there are 51 citizen shops. From 1999 through December 2017, the citizen shops network has provided services to more than 155 million citizens (AMA, 2016).

This face-to-face channel is the object of the present study and, consequently, it will be analyzed in more detail in section 2.3.

2.2.2 Online Channel – *Portal do Cidadão*

In 1991, under the supervision of the Secretariat for Administrative Modernization, the information system named INFOCID was released, resulting from the cooperation between 50 different departments from almost all existing Ministries. INFOCID was a global and integrated system which provided a free and easy access to information about different public services. Besides the advantages it brought to the citizen, this initiative improved the internal functioning of the public administration, as it was able to integrate and to offer information about services of distinct origins, on a single point of contact. This public information system was interdepartmental and oriented towards the citizen's needs. During the first years, the system was only available on multimedia kiosks, but in 1995 it became available on the internet, so it could be accessed from the citizens' personal computers (Cardoso, 2012).

With time, the system evolved, turning into a Public Administration portal, and in 2001 it was transformed into the *Portal do Governo* (Government Portal). Later, in 2004, when the new Portuguese e-government portal was launched by the Agency for Knowledge Society (UMIC) (called *Portal do Cidadão,* meaning Citizen Portal), the Government Portal functions were integrated into the *Portal do Cidadão* (Gouveia, 2004). The management responsibility of the portal was then passed to AMA when this entity took over the electronic administration functions.

The Citizen Portal is still in use as of 2018, and it is the online channel available, which allows to interact and access information of public services, and which resulted from the merger of different entities' portals so the citizen could access all services in one channel, in a simple and intuitive way (AMA, 2016). Currently, it offers more than 1860 services from a total of 592 entities ("Sobre o Portal," 2015). Some examples of these services provided are the alteration of the address on the Citizen Card, the request for online certificates, the establishment of companies, commercial registration, among others (AMA, 2016).

Indubitably, the digital access has become one of the state's priorities, and the progressive digital access to public services in Portugal has been a success. The interactions between the citizens and the Public Administration have been increasing over time and, currently, there are only a few services that are not available online.

2.2.3 Digital Service Support Channel – *Espaço de Cidadão*

Despite the investment in developing the online channel, studies show that the citizen's use of the services available online does not increase proportionally to the increase in offer and sophistication of those same public services (European Comission, 2016). As shown in Figure 5, in several of the European Union countries, there is a significant gap between the online availability of public services and the individuals' utilization of such services.

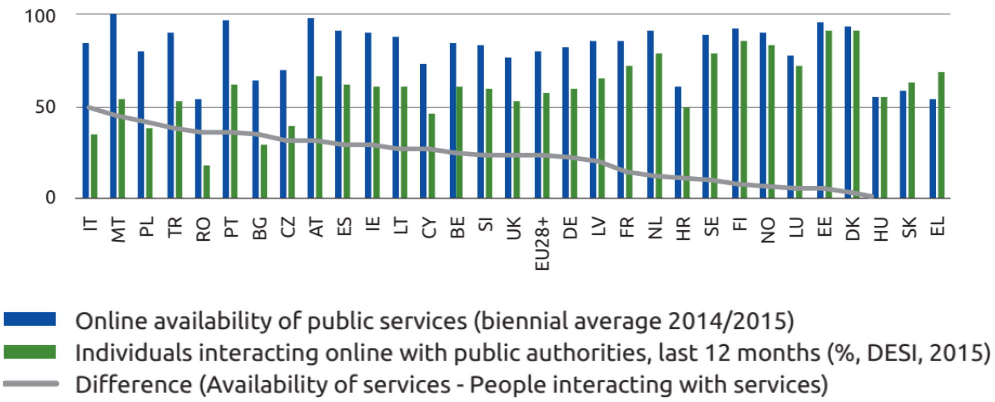


Figure 5 - Online availability versus the use of eGovernment services; sorted by the gap between these indicators. Reprinted from "eGovernment Benchmark 2016", by European Commission, 2016, Final Insight Repot*, 1, p. 42. Copyright 2016 by European Union.*

In face of this gap, and in order to minimize it, the Government wishes to invest not only in the development of the online channel, but also in initiatives to increase the citizen's use of the online available public services, and to make this channel the citizen's preferred way of interacting with the different entities and public administration, hence, transforming the online services utilization in a mass utilization by the citizens and economic agents (Decree-Law no. 74/2014 of May 13th, 2014).

Within this framework, in order to guarantee the effectiveness and efficiency of these initiatives and to promote territorial and social cohesion, it is also important to note that not all Portuguese citizens have the same internet usage habits, and there is still a percentage of the population that does not have internet access and, thus, cannot acquire these services online, and another part of the population that does not know or wish to acquire these services online. Therefore, within this scope, it was decided to install and develop a complementary network to the *Loja de Cidadão* network, of spaces destined to provide digital assistance to the citizens, aiming to facilitate the citizen's access to this digital channel and to all its advantages (Decree-Law no. 74/2014 of May 13th, 2014). As mentioned before, it is important to provide special attention to those citizens which do not have the means to access the available online services, or to those that do not know or want to use them. Therefore, in 2014, the complementary network called *Espaços do Cidadão,* meaning Citizen Spot, was established, which aimed, on the one hand, to provide digital assistance and to give the citizen the knowledge necessary for him to be able to use the digital channel autonomously, and on the other hand, to serve as a single point of contact between the citizens and the different types of services and agencies of the Public Administration (Decree-Law no. 74/2014 of May 13th, 2014) .

With regard to the installation and management of *Espaços Cidadão*, in an effort towards the delegation of power, this may be executed by the parishes in articulation with AMA (the entity responsible for the management of both the Citizen Shops and Spots) (Decree-Law no. 105/2017 of August 29th, 2017).

Presently, there are 533 operational Citizen Spots, offering approximately 200 public services, such as: the request of a new password or real estate certificate with the tax authority, declaration of expenses to the Public Administration health subsystem, solution of issues concerning employment and professional training, alteration of the address on the Citizen Card, request of the European health insurance card or utilization of e-invoice services, among others (AMA, 2016).

2.3 Citizen Shops

As previously mentioned, the Citizen Shops are the Portuguese citizen service centers, created in line with the one stop shop concept, where several different public services are offered in a single location, allowing the citizens to access a large range of public and private services in one place only.

2.3.1 Portfolio

Since the opening of the first two stores in 1999, 49 more shops have been opened throughout Portugal, totaling 51 as of April 2018. As we can observe in Figure 6, the growth of the shops' network was slower at first, and then increased after 2008. In the years of 2000 and 2001, 4 shops opened in the two years, and then until 2008, only 2 more opened in 2003 and 2007. Only after that, the opening of new shops increased significantly, having 43 new shops been opened from 2009 to 2018.

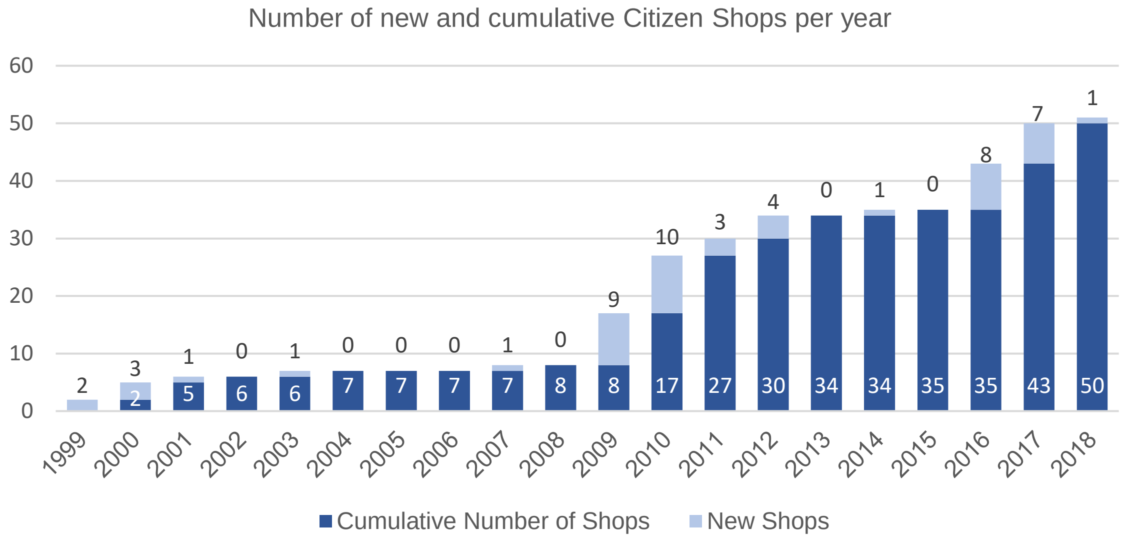


Figure 6 - Number of new and cumulative Citizen Shops per year. Source: Data provided by AMA

As the shops were being opened throughout the years, the shops' concept evolved, and their format changed, therefore, nowadays we can distinguish 3 different generations and formats of shops. The shops of the 1st generation are located in the big urban centers, have a big area and are located in buildings strictly occupied by the shop. Contrarily, the 2nd generation shops have a smaller dimension, are usually integrated into existent facilities, and offer different services according to the needs of the different regions. In the 2nd generation shops, new methods of modernization were established, impacting and increasing the proximity to the customers and the delivery quality of public services. (Council of Ministers Resolution no. 87/2008 of May 27th, 2008). Some of the novelties introduced were the possibility to access the online channel with the assistance of a collaborator, and the creation of multiservice counters where the citizen can resolve different matters related to different Ministries. An example of a multiservice counter is the 'I lost my wallet counter' where one can request the replacement of the personal documents. In these shops it is also possible to resolve issues related to the municipal services, thus contributing towards debureaucratization, and towards a faster and more efficient way of solving matters (Martins, 2009). The 3rd generation of stores was opened in the headquarters of the municipalities or autarchies. This third generation of shops was implemented in state infrastructures in an attempt to reduce the costs associated with the installation of new shops. This way, these installations do not have accrued rent costs, for example, nor human resources costs, as it is usually not necessary to hire more people to integrate the shops. This streamlining of costs by utilizing the states' infrastructures also intends to comply with the agreement made in line with the Economic and Financial Assistance Program (*Programa de Assistência Económica e Financeira*) between the Portuguese State, the International Monetary Fund, the European Commission and the European Central Bank (Decree-Law no. 74/2014 of May 13th, 2014). By installing the new shops at local autarchies, it is also intended to increase the flexibility of the shops' management, as it can be of the responsibility of the local autarchies, or of the entities present in the store, or of AMA (Decree-Law no. 74/2014 of May 13th, 2014). Analyzing the evolution of the shops, it is easy to see that the Government's commitment and vision are moving towards a greater empowerment of the municipalities, increasing their intervention, through cooperation with the central administration. They intend to create a closer management, which will be assured by an entity who knows the territory and fully comprehends the needs of its inhabitants in matters related to the access to public services. It is the Government's intention to strengthen the local autarchies intervention, through the decentralization of the management and installation responsibilities of the Citizen Shops and Spots (Decree-Law no. 105/2017 of August 29th, 2017).

2.3.2 Geographical Distribution

The geographical location of the 51 existing shops across mainland Portugal (the scope of this study) can be observed in Figure 7. There is at least one shop per district, Lisbon, Viseu and Porto being the districts with the most shops, with 8, 7 and 6 shops, respectively; and Beja, Évora, Guarda, Leiria, Portalegre, and Viana do Castelo the districts with the fewest amount of shops – only 1 per district (Table 1). Extending our analysis to a smaller scale, when analyzing the municipalities, the shops are present in only 50 of the 278 mainland municipalities of Portugal. With this analysis, we are able to conclude that there is an unequal distribution of the shops throughout the country and that the citizen's access to the latter differs in terms of distance and time.

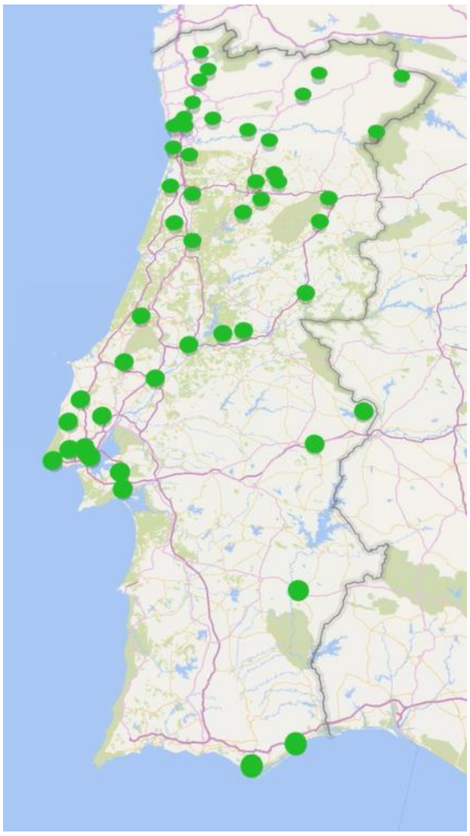


Figure 7 – Shops' geographic distribution across mainland Portugal. Source: Data provided by AMA

Table 1 - Number of Citizen Shops per district

District	Citizen Shops
Aveiro	5
Beja	1
Braga	2
Bragança	2
Castelo Branco	2
Coimbra	2
Évora	1
Faro	2
Guarda	1
Leiria	1
Lisboa	8
Portalegre	1
Porto	6
Santarém	5
Setúbal	2
Viana do Castelo	1
Vila Real	2
Viseu	7
Total	**51**

2.3.3 Demand

Between the Citizen Shops foundation in 1999 and 2017, as previously mentioned, the network has served approximately 155 million citizens in total, and specifically, in 2017, there were approximately 9,3 million visits to the Citizen Shops network (Data provided by AMA, 2018).

As shown in Figure 8 and Figure 9, the Citizen Shops in the metropolitan areas of Lisbon, Portugal's capital, and Porto, Portugal's second biggest city, present a higher average demand per store, which is justified by both cities population and population density. Namely, in 2017, the shop in Laranjeiras, located in Lisbon, presents the highest annual demand among the 51 shops (1 418 674 visitors), representing 14,0% of the total annual demand. The Citizen Shop in Porto presents the second highest demand (811 681 visitors), representing 8,0% of the total annual demand. Marvila's shop opened in 2012, also in the metropolitan area of Lisbon, and its demand (383 678 visitors) , which represents 3,8% of the total, was considerably higher when compared to the average of the remainder shops, but not as high as the first two shops mentioned above. The remaining 48 shops have an average annual demand of 152 933 visitors, representing an average of 74,1% of the total demand.

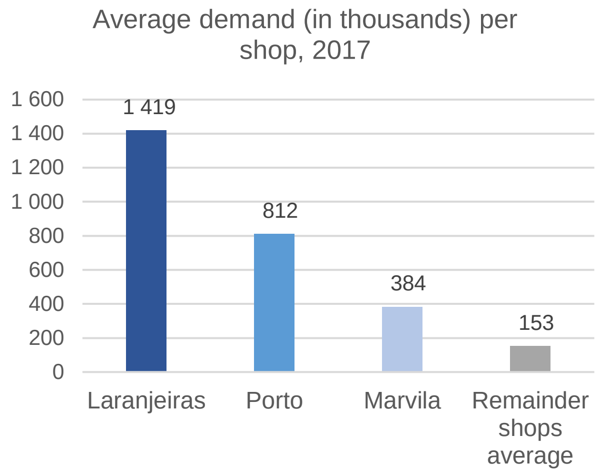


Figure 8 - Average demand per shop, 2017. Source: Data provided by AMA

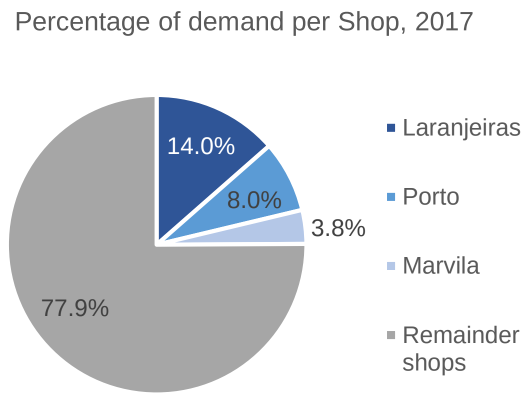


Figure 9 - Demand per shop as a percentage of the total demand of the Citizen Shop's network. Source: Data provided by AMA

In Figure 10, we can see that the demand of the Laranjeiras and Porto shop has always been significantly higher than the average of the remainder shops throughout the years. On the other hand, the Marvila shop does not show such a significant deviation (as previously observed in the analysis of the year 2017). In this graph, we see an increase in demand up to approximately 2008, and from then on, a decrease. This trend can be explained by the few openings of shops up to 2008, which resulted in a higher demand per shop, and then after 2008, with the opening of several shops, the demand was further spread out through the different shops.

Within the network of *Lojas de Cidadão,* each shop offers a different set of services. Nonetheless, there are four core services/entities which are present at almost every shop:

1. *Instituto da Segurança Social* (ISS) (Social Security Institute);
2. *Instituto dos Registos e Notariado* (IRN) (Institute of Registries and Notaries);
3. *Autoridade Tributária* (AT) (Tax and Customs Authority);
4. *Espaço do Cidadão* (EC) (Citizen Spot).

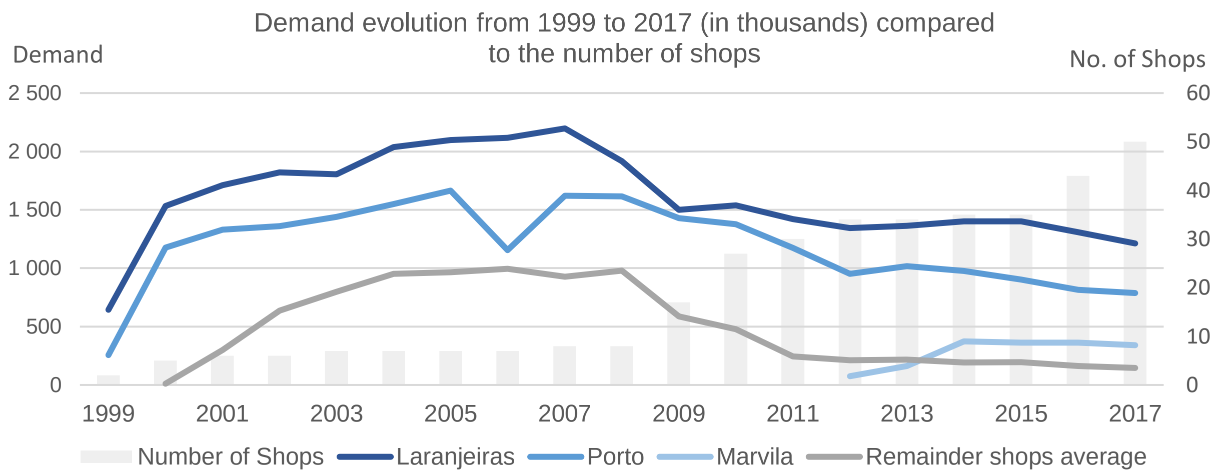


Figure 10 - Demand evolution from 1999 to 2017 (in thousands) compared to the number of shops. Source: Data provided by AMA

Other examples of entities located in the shops are the *Direção-Geral da Administração da Justiça* (DGAJ) (Directorate-General of Justice Administration), the *Instituto do Emprego e Formação Profissional* (IEFP) (Employment and Vocational Training Institute), the *Instituto dos Mercados Públicos, do Imobiliário e da Construção* (IMPIC) (Institute of Public Markets, Real Estate and Construction), public utility companies, transit and mobility companies, service desks for consumer complaints, post office, public banks, private entities, among others.

According to the Decree-Law no. 105/2017 of August 29th, it is mandatory by law that the installation of a new shop integrates, at least, two of the public services mentioned in points 1 to 3. Therefore, the following analysis of the different services' demand in the shops is focused on these 3 entities and also on the Citizen Spot (which is sometimes located within the citizen shops). In Figure 11, we can verify that the four core entities together meet more than half of the demand (63,1%). The entity with the highest demand is the IRN meeting 24,9% of the total demand, followed by the ISS with 15,4%, and then by AT and EC with 11,6% and 11,2%, respectively.

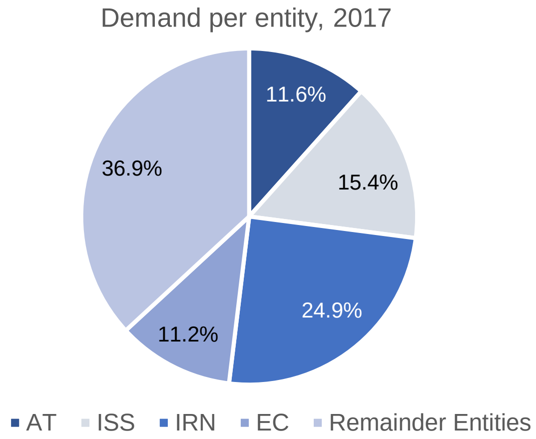


Figure 11 - Demand per entity, 2017. Source: Data provided by AMA

After having analyzed the different dimensions related to the Citizen Shops, and also based on observation of the shops' operation, we detected some challenges in the current network; as we have seen, the integrated model of the shops has brought many advantages to the citizens, nevertheless, it has also brought some disadvantages, such as the increase of the waiting times – according to the data provided by AMA, currently 67% of the time the citizen spends in a shop, is time spent waiting. On the other hand, even though the majority of services is available online, the citizens either find it difficult to use them or are unaware of their existence. This unawareness is due to lack of advertisement related to the online services, and to the fact that the collaborators at the Citizen Shops generally do not inform the customers that such services are available online. Additionally, as a side effect of such integrated system with several entities and services at one location, the process of deciding which option to select at the number booth has become extremely complex, and consequently, there are a lot of mistakes in the selection of the number for the right desk, causing entropy later in the process, as the citizens have to be redirected to the right desk.

In face of the challenges presented, and in line with the Government's plans and objectives to give continuity to the modernization project of the public services network, AMA has developed a future strategy and vision for the Citizen Shop's network, which will be detailed in the next section.

2.4 Future Strategy

To assure the continuity of the modernization of the public administration, the 21st Constitutional Government has defined specific lines of action and measures to move towards this direction (Proposta de Lei n.º 99/XIII, 2018). In agreement with these lines of action, AMA has defined its own objectives for the future. Their vision is to improve the delivery of public services to the client, reaching out to build better relationships with the citizens; to have a service network that offers equal access to the citizens; and to offer an effective and proactive service, in a welcoming environment, where the citizen is the center and focus.

In order to reach these goals, AMA has defined lines of actions in terms of their 3 axes of action previously presented: assistance, simplification, and digital transformation. Considering, for instance, the digital transformation axis, AMA is planning on improving the services offered online, increasing the citizen's awareness of the latter's existence, and improving the channel's user-experience. This initiative alone has several advantages: on the one hand, it expands the citizen's access to online services and his experience using this channel, and on the other hand, as the online channel progresses, the demand of the shops will also likely decrease, consequently decreasing the waiting times, and hence, improving the customer experience at the shops. AMA also intends to develop an app where the citizen can access the same services offered online, but through their smartphone, being even closer to the customer.

Regarding the face-to-face channel, it is a specific commitment of the 21st Constitutional Government, to further expand the network of *Lojas de Cidadão*, in order to fully fulfill its ground objective of creating proximity between the public administration and the citizens (Decree-Law no. 105/2017 of August 29th, 2017).

2.4.1 Problem Definition

This dissertation is in line with this commitment to expand the physical network and it focuses on the expansion of the physical network of shops. The expansion and improvement of the physical network of shops is essential to guarantee its accessibility to all citizens and consequently continue to develop a better relationship with the latter. The physical channel is also important to assure the provision of services that due to infeasibility or security reasons, may not be offered through the online channel. Furthermore, this channel is also important to guarantee the equality in accessibility among the citizens, because, as previously referred, there is a percentage of the population that does not possess the means, knowledge or will to acquire the services through the digital channel.

Regarding this topic, it is important to note that, in 2016, in Portugal, more than one-fifth of the population were still non-internet users (Eurostat, 2018). Knowing that the utilization of the internet depends significantly on the age and level of formal education (Eurostat, 2018), below we perform and present an analysis of the Portuguese population in terms of age and education to understand the citizens' behavior regarding the use of the internet to acquire such services. This analysis was based on the data retrieved from the Portuguese Institute of Statistics' website, *Instituto Nacional de Estatística* (INE).

According to OECD Data website, "the working age population is defined as those aged 15 to 64" (OECD, 2018). Based on this definition, we concluded that in 2016, in Portugal, 64,9% (10,6% plus 54,3%) of the population is working age population, 21,1% of the population is in the 65+ age category, and the remainder 14,0% of the population is aged between 0 to 14 (Figure 12). Based on the same data (data from INE), we have also performed a separate analysis in the metropolitan areas of Lisbon and Porto, to verify if the population percentages of the different age groups would vary significantly, however, we have concluded that although the percentages vary slightly, they are similar enough to perform this analysis globally (the maximum variation was of 2 percentage points).

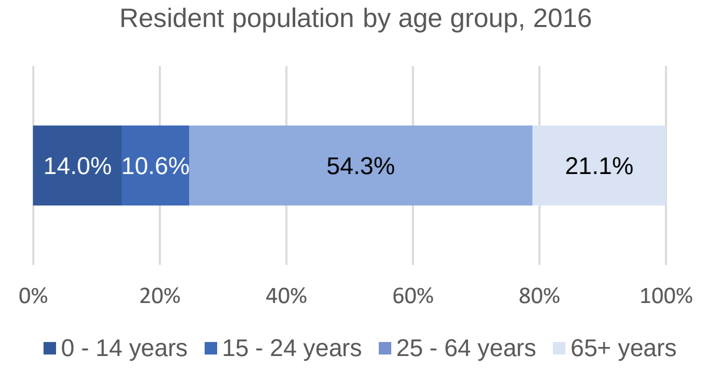


Figure 12 – Resident population by age group, 2016. Source: Data retrieved from INE

In terms of formal education (highest completed level of education), considering mainland Portugal, 18,8% of the population has no complete level of education, 55,0% have concluded the primary education (completed 4th grade), 13,5% have completed secondary education (12th grade), 0,8% have had post-secondary education (such as technical education), and the remainder 11,9% have completed superior education (any kind of degree in a university). By analyzing the places of residence, we can observe that in the metropolitan areas of Porto and Lisbon, the percentage of population without any complete level of education is smaller, and the percentage of population with secondary and superior education is higher, especially in the metropolitan area of Lisbon (Figure 13).

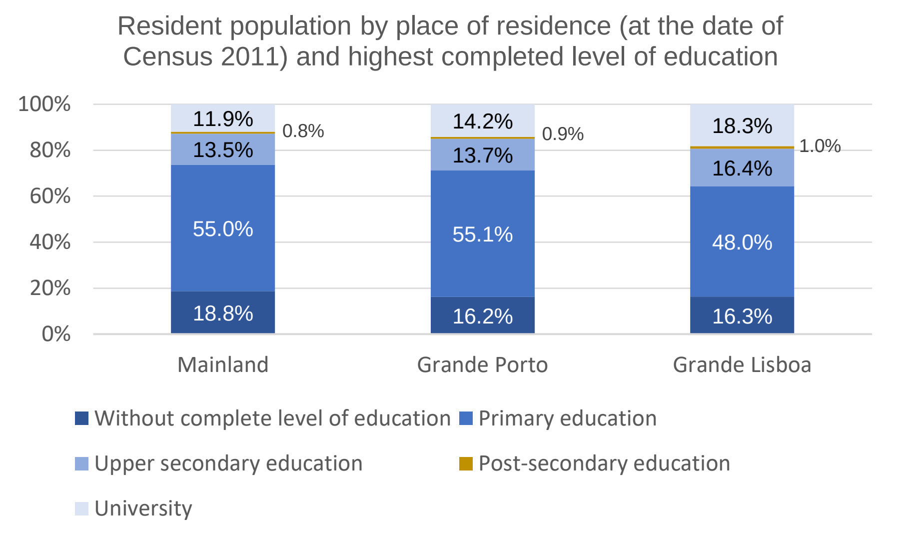


Figure 13 - Resident population by place of residence and highest completed level of education, 2011. Source: Data retrieved from INE, Census 2011

Retrieving the data available in the OECD Stat website (OECD, 2013a), we have performed an analysis and were able to conclude that in Portugal, in 2013, the percentages of individuals that used the Internet for using public authorities' services were 29,2% of all individuals aged 16-74. When analyzing the data by age group, the percentages were: 28,5% of the individuals aged 16-24; 39,0% of the individuals aged 25-54; and 11,2% of the individuals aged 55-74. Concerning the individuals aged 16-74, but analyzing the level of education attained, 67,6% of the individuals with a high level of education used the internet to access public services; 51,0% of the individuals with a middle level of education; and 12,3% of the individuals with a lower level of education (Table 2).[1]

*Table 2 - **A**. Percentage of Individuals using the internet for using public authorities' services by age group. **B.** Percentage of Individuals aged 16-74 using the internet for using public authorities' services by formal education. Source: Data retrieved from OECD Stat*

A

Individuals aged 16-24	28,5%
Individuals aged 25-54	39,1%
Individuals aged 55-74	11,2%

B

Individuals with a high level of educational attainment	67,5%
Individuals with a middle level of educational attainment	51,0%
Individuals with no or a low level of educational attainment	12,3%

After performing these analyses, we can deduce that there is still a considerable amount of the population that is non-internet user, and another considerable part that does not use the internet regularly, nor to access to public services. Subsequently, we could verify that our project to expand the physical network of shops could, in fact, have a great impact and contribution to the citizen's equity and accessibility to public services.

[1] The data by levels of education/educational attainment until 2013 are classified according to ISCED 1997. For more information on ISCED, please see: International Standard Classification of Education (ISCED)

Within this expansion of the citizen service network, besides this objective which is one of AMA's operational goals, AMA is currently exploring the creation of a new channel – the kiosk channel. The concept behind it is the creation of a set of physical locations, where the citizen can acquire a selection of services which are currently provided in the Citizen Shops. The difference is that these kiosks will not have human resources at the locations, as the support/assistance, if necessary, will be provided in a virtual/remote way, through virtual assistants and/or call centers. The kiosk would provide the services that make up the majority of the demand (except for the services that for security or infeasibility reasons may not be provided), aiming to improve the distribution quality of the public services, further increasing the proximity to the citizen through a capillary network, and aiming to improve the quality of the service, reducing the waiting times and improving customer experience.

To summarize, the objective to expand the physical network might be accomplished through the two different channels, the kiosk channel and/or the citizen shop's channel. Throughout this dissertation, we will develop a model to help choosing the optimal locations for the infrastructures of these two channels.

2.5 Chapter Conclusions

In this chapter, the context of the problem was presented, providing a description of the evolution of the Portuguese Reform Program launched in 1980. This reform was initiated to answer the Portuguese Public Administration goals to improve the performance of public services. These objectives included increasing proximity to the citizen, cost-effectiveness, administration flexibility, and delegating authority to lower levels. Furthermore, one of their key goals was to change the public service values and mission, moving towards a more citizen-orientated approach, quality of service, and results-orientation. Within this context, we presented different initiatives and milestones that were accomplished regarding this framework, such as the creation of Secretariat for Administrative Modernization, in 1986; the establishment of the *Lojas de Cidadão,* in 1999; the creation of PRACE, in 2005; and the launch of the Simplex program, in 2006. To summarize, the main objectives behind these initiatives were to modernize and streamline the central administration, to implement more citizen-oriented and pragmatic initiatives, to improve the quality of the services, and to create more proximity and dialog with the citizens.

Following the contextualization of the problem, a characterization and analysis of the problem itself were presented, describing the structure and organization of the network under study – the citizen assistance network – as well as its strategic importance. This breakdown of the structure, and the description of the existing interdependencies between the channels, allowed us to gain a comprehensive knowledge of the system, which will be essential for the development of the remaining work. The different channels comprised in the referred network were presented, allowing the observation of the evolution of each channel, the efforts made towards bringing the public administration closer to the citizens, the simplification of the processes, and the improvement of the citizen's experience over the last years.

Afterward, the citizen shops channel was analyzed to further detail, and different relevant analyses to the study were presented. It was possible to identify some of the challenges of the current network such as the unequal distribution of the shops throughout the country (citizens' access to the shops differs in terms of distance), and the increased demand in the shops located in the metropolitan areas of Lisbon and Porto. Thus, we concluded that there is still room for improvement related to the citizen’s access to the shops and services.

Finally, in the last section of the chapter, the problem under study was detailed. The 21st Constitutional Government has made a commitment to further expand the network of *Lojas de Cidadão* with the aim to improve the delivery of public services, reaching out to build better relationships with the citizens and to have a service network that offers equal access to the latter. This improvement opportunity to expand and decentralize the network, has led us to the challenge of locating the new citizen shops and kiosks (possible new channel being explored) – the focus of this study. Additionally, an analysis of the Portuguese population was conducted to corroborate the motivation and impact of the physical network expansion.

In order to support the development of a mathematical model to help the decision-makers in an informed decision related to the network expansion, we will define the concepts related to this problem, and review the literature regarding facility location problems in the next chapter, so as to help us gain an extensive knowledge of common models in the field, and how they are applied to solve similar problems.

Chapter 3 LITERATURE REVIEW

With the aim to support the location decision for the future citizen shops and kiosks, we resort to the literature, reviewing and analyzing some of the work and models developed in this field, in order to gain a more comprehensive knowledge of the subject and, hence, support the development of the required mathematical model.

In this chapter, we intend to perform an analysis and to summarize the main location models reviewed in the literature. In section 3.1, we will start by defining the objectives and core concepts of the location models. Then, in section 3.2 a taxonomy of the location models is presented, and along with it, the primary focus of this dissertation is highlighted. In section 3.3, we focus on discrete location models as these are especially important to the present study, and each basic discrete location model is briefly explained. To conclude, in section 3.4, several applications in the public service sector are presented and analyzed, and in section 3.5 the main chapter conclusions are presented.

3.1 Facility Location Problems (FLPs)

Practically every company, whether private or public, has had to make a decision related to facility location. The aim of such decisions is to choose the location that can meet the customers demand in the best way possible while considering the trade-offs between costs and customer satisfaction. Location decisions have a great influence on costs and can lead to either increased or decreased competitiveness, and thus, the prosperity or failure of private and public-sector facilities depends partly on the locations chosen for their facilities (Daskin, 1995; Fredriksson, 2017).

Facility location decisions are crucial strategic planning decisions in the design of systems for both private (e.g. warehouses, plants, retail facilities, etc.) and public organizations (e.g. police and fire stations, ambulances, hospitals, post offices, etc.). This is due to the fact that these decisions are long-term investments involving high costs – they have a long-lasting impact in the operational and logistical decisions and comprise high capital expenditure in the acquisition and construction of infrastructures (Owen & Daskin, 1998). Thus, in order to make the investments profitable, the facilities are expected to remain in operation for an extended period of time, and therefore, when making location decisions, we must, not only, evaluate the performance of the facilities according to the system's current state, but also ensure that their performance remains lucrative during the facility's existence, and that they efficiently deal with change in parameters such as market demand, internal and external factors, populations shifts, environmental changes, among others. Thereby, defining robust facility locations is a demanding task, and it requires the decision-maker (DM) to incorporate the uncertainty associated with the future into his/her decisions (Arabani & Farahani, 2012; Owen & Daskin, 1998).

The study of the location problem was formally initiated in 1909 when Alfred Weber (Weber, 1909) studied how to locate a warehouse to minimize the total distance between the facility and its several customers. Throughout the years, the Facility Location Problem (FLP) has been studied within the field of Operations Research, with researchers developing algorithms and formulations for both the private and public sector. The location theory and its applications have been explored in several different fields and numerous models have been developed (ReVelle & Eiselt, 2005).

Regardless of the context of the problem, and in spite of the differences between formulations and models, there are certain key features which, generally, apply to all problems: a set of spatially distributed customers whose locations are known (demand points/demand nodes), a set of candidate facilities to serve the customers whose locations have to be determined according to a particular objective function, a space in which customers and facilities are located, and a given metric used to measure the distances, times or costs between demand points and facilities (Melo, Nickel, & Saldanha-da-Gama, 2009; ReVelle, Eiselt, & Daskin, 2008).

Therefore, through the use of such models, according to Daskin (1995) we can answer different questions, such as, "(i) How many facilities should be sited?, (ii) Where should each facility be located?, (iii) How large should each facility be?, and (iv) How should demand for the facilities' services be allocated to the facilities?" (p. 3). The answers to these questions are deeply related to the context of the problem, and to its objective function. On the one hand, there are desirable facilities which we want to locate the nearest to the customer, as these bring advantages to the latter, such as the location of hospitals; on the other hand, other times, we deal with undesirable or obnoxious facilities which we want to distance from the customers, as these have negative perceived effects, or bring disadvantages to the customer, for example, the location of waste recycling facilities (Barbati & Piccolo, 2016; Daskin, 1995).

Regarding question (iv), for instance, we can deduct that it is necessary for some models to take into consideration the demand allocation, besides the set of information previously mentioned. As so, FLPs also take into consideration the allocation of demands to facilities. In some cases, the demand may not be split between facilities (e.g. retail store must be supplied by one warehouse only), in other cases, demands can be served by any available facility (e.g. ambulance services), this is also the case of the problem studied in this dissertation. It is therefore important that the models reflect the diverse demand allocation policies in order to correctly allocate the demands (or fractions of the demand) to the different facilities (Daskin, 1995).

Given the different application of location problems, from traditional applications involving warehouses, to power plants and landfills, we can hence conclude that modeling location problems requires a thorough understanding of the context and real-world operations that should be incorporated in the model. Nonetheless, as Daskin (1995) refers, it isn't always imperative for the model to reflect all the details involved in the real-world operations, as this can generate extremely complex models, and, in fact, parsimonious models can generally provide better results than complex ones. Thus, to determine what should be exogenously defined and what should be endogenously determined by the model is of great importance. When creating a model we aim to identify and trace the tradeoffs between the objectives, while maintaining a comprehensive and flexible approach, reflecting the complexity of the real-world operation necessary to ensure the credibility of the model (Arabani & Farahani, 2012; Daskin, 1995).

In the next section, we present a taxonomy for the location models along with which we will highlight the primary focus of this dissertation.

3.2 Location Models' Taxonomy

As previously mentioned, location models have had different successful applications within diverse areas and with diverse purposes such as the location of gas stations, emergency services (fire stations, police stations, ambulances, etc.), sewage treatment stations, among others. They differ in terms of the decision-makers' objectives, among other aspects, but notwithstanding there is some common ground. To classify the location problems, Daskin (1995) suggested a taxonomy which we have adapted, introducing slight changes. Below, some of the taxonomy elements will be highlighted due to their relevance to the current work, and to help identify the primary focus of the latter.

Continuous versus Discrete Location Models

The models may differ in terms of how the demand and candidate facility locations are represented (Daskin, 1995). In **continuous models**, demand and facilities may be located anywhere in the feasible region; on the other hand, in **discrete models**, demand and facilities can be established only at candidate locations that can include the demand points (Ahmadi-Javid, Seyedi, & Syam, 2017). In this dissertation, we will focus on discrete location models.

Distance Metrics

Location models can also be distinguished by the **distance metric** used (the method of measuring distances). At the time of publication of Daskin's book, in 1995, some of the most commonly used distance metrics were the Euclidean or straight-line distance metric[2], and the Manhattan or right-angle distance metric[3] (Daskin, 1995). Nonetheless, as technology evolved, currently the most common practice is to use metrics of real travel time/distance to represent the cost. The use of such measures allows the model to take into consideration the geographical conditions, for example, if a facility is located on top of a mountain, it will be harder to reach, and this will be reflected in the distances/travel times, and hence impact the calculations. The evolution of technology makes geographical data, more specifically road and travel time data, increasingly available and ready to use (Fredriksson, 2017).

It is important to note that throughout this dissertation, the terms "travel distances" and "travel time" will be used interchangeably to represent the "cost" of traveling from one location to another.

Number of Facilities to Locate

Regarding the **number of facilities to locate**, this characteristic may be exogenously specified (e.g. the decision-maker specifies that only 5 new facilities are to be located), or endogenously determined within the model, being part of the outputs of the model. Regarding the models in which the number of facilities is exogenously determined, it is also common to distinguish between single-facility location problems and multiple facility location problems (Daskin, 1995). The problem regarded in this dissertation is a multifacility problem, in which the number of facilities will be determined endogenously.

[2] $d[(x_i, y_i), (x_j, y_j)] = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$

[3] $d[(x_i, y_i), (x_j, y_j)] = |x_i - x_j| + |y_i - y_j|$

Static versus Dynamic Location Models

Concerning the inputs of the model, these may be **static**, meaning they do not vary with time, or **dynamic**, in which they are time-dependent. Within dynamic problems, different inputs may depend on time, such as demands and costs (Daskin, 1995).

In real-world operations, location problems are generally dynamic, as inputs are rarely constant throughout time, even so, most location models are static. In these static models, a single representative set of inputs is taken into account and the problem is solved for a representative period. On the other hand, when using dynamic models, they focus on the issues involved in locating facilities over an extended horizon which capture the temporal aspects of real-world problems (Arabani & Farahani, 2012; Owen & Daskin, 1998). Therefore, these models include several periods of time, which allow us to capture, for example, the hourly variation in the services average demand, the disparities between spatial patterns of demands throughout the periods (e.g. differences within the week, month or year), and to account for variations in demands or costs over a period of years (Daskin, 1995; Owen & Daskin, 1998). Nevertheless, when dealing with dynamic problems, we have to determine not only where, but also when to locate, relocate or close the facilities. In some models, it is assumed that when a facility is opened it must remain in place and operation during the planning horizon, contrarily, in other models, facilities may be opened, closed, or relocated during the future periods (Arabani & Farahani, 2012).

Deterministic versus Stochastic Models

Similarly to the inputs of the models which may be static or dynamic, the outputs may also be **deterministic** (certain) or **stochastic** (subject to uncertainty). To determine robust facility locations which will perform well under a number of possible customizations of the model's parameters is one of the main goals of DMs. This is due to the fact that when dealing with location problems over a period of time, the main parameters such as cost and demand determination are likely to be subjected to uncertainty (Arabani & Farahani, 2012; Daskin, 1995; Owen & Daskin, 1998). Thus, location facility models may also be classified as **deterministic** or **stochastic**. In the latter, different uncertainty modelling approaches may be explored ranging from simple sensitivity analysis to stochastic models or robust optimization models.

Private versus Public Sector Problems

Problems may be related to companies either in the private or public sector. Within the **private sector**, the goals are usually related to profit maximization, efficiency, and effectiveness – they seek to allocate resources, costs, rewards, or burdens in the most efficient or effective way (Marsh & Schilling, 1994; Serra & Marianov, 2004), and the costs and benefits of the investments are usually measured in monetary units. Moreover, an increase or decrease in cost or benefit generally affects the same stakeholders, thus making the cost/benefit analysis easier to perform. On the other hand, within the **public sector** not all the costs and benefits may be converted into monetary units (e.g. value of a human life, environmental costs of pollution), and besides the objectives referred above, the nonmonetary objectives often play a key role in this sector (e.g. equity) (Barbati & Piccolo, 2016; Cardoso, Oliveira, Barbosa-Póvoa, & Nickel, 2015). Additionally, regarding the context of the sector, occasionally, political decisions and restrictions may constraint the optimization of the system. Furthermore, the stakeholders who support the costs of the investments might not be the same as the ones who take advantage of the benefit brought by the investment. For example, the investments in public schools affect the children that attend those schools and their parents, however, it does not impact other members of the population, such as the elderly who also support the costs of the investment (Daskin, 1995). As mentioned before, the problem studied in this dissertation is within the public-sector framework.

Single versus Multi-Objective Models

A model can be composed of a **single objective**, or by more than one (**multi-objective**), usually depending on the nature of the problem. One of location modeling's purposes is to identify tradeoffs which can be accomplished, for instance, by varying the input parameters of a single objective model, or by using a model with multiple objectives.

The most frequent objectives are related to the minimization of distances, costs of locations and transportation. However, when dealing with problems in the public sector, some of the most common objectives are the attainment of equity, the universality of service and efficiency (Marianov & Serra, 2002). The fairness and equity of the services distribution play a decisive role in the field, and thus, efforts to find means of measuring equity and its inclusion in the models' formulations have been developed throughout the years, having had a significant growth in the recent years (Marsh & Schilling, 1994). One of the first reviews about the subject was performed by Marsh & Schilling (1994), and since then authors such as ReVelle and Eiselt (2005) have also highlighted and discussed the attainment of equity as an objective, and more recently several more papers have been published exploring this measure (Cardoso et al., 2015; Cardoso, Oliveira, Barbosa-Póvoa, & Nickel, 2016; Khodaparasti et al., 2016; Mitropoulos, Mitropoulos, Giannikos, & Sissouras, 2006; Smith, Harper, & Potts, 2013).

Capacitated versus Uncapacitated Facilities

Models may differ regarding the inclusion of parameters to account for the capacity of a facility – **capacitated –** or, on the other hand, treat facilities as having unlimited capacity – **uncapacitated**. Furthermore, in other models the capacity of a facility is determined endogenously, thus being an output of the model.

Hierarchical versus Single-Level Models

The systems studied may be **single-leveled** in which the facilities are similar to each other, for example, in terms of the services offered, or **hierarchical** in which the system has a hierarchy of facilities with flows between them (e.g. clinics, which are the lower level facilities, refer clients to the hospitals, which in turn are the higher-level facilities). According to Narula (1986), we can distinguish between successively inclusive facility hierarchies, in which the services provided at the lower level are also provided at the higher levels, and between successively exclusive facility hierarchies, in which the services offered at the different levels are not equal (some services are only available at the lower level facilities, or at the higher level facilities). Additionally, systems differ in terms of the customer's choice of facility – in some, customers may choose the facility they want to visit, however, in others, they must start by visiting the lowest level facility, and then, from there, be redirected to the higher-level facilities.

To conclude, through the introduction of Daskin's (1995) suggested model's taxonomy, the primary focus of this dissertation has been specified. Such taxonomy is still used and has been explored by several authors in their works. Additionally to the highlighted elements, in the problem under study, the facilities are desirable, meaning it is assumed that the closer the facility is to the demand points, the better the service level provided; and the demand of the physical network is relatively inelastic for a number of services which have few or no substitutes (namely, the ones not offered online), and for which we assume that the related demand is largely independent of the level of service.

In light of the taxonomy presented and of the type of problem being studied, in the next section, the basic models for discrete location problems are introduced, along with a brief explanation of their objectives, and some of their limitations.

3.3 Discrete Location Problems' Basic Models

As mentioned in the previous section, the problem under study is a discrete location problem. This type of problems encompass an important set of applications of location modeling and theory (Ahmadi-Javid et al., 2017). Thus, several extensions to basic discrete problems have been developed and studied in the field of facility location.

In this section, a short overview of the basic discrete location models is presented, not aiming to provide a full review of all the models developed up to this moment. As examples, some of the main literature reviews in the field are referenced. Daskin (1995) in his book thoroughly describes these models, presenting several formulations. Owen and Daskin (1998), in their article, present us different models and variations of static, dynamic and stochastic location problems. ReVelle and Eiselt are also important references in this field, having published the article Location analysis: a synthesis and survey (ReVelle & Eiselt, 2005), which reviews approximately four decades of facility location problems, algorithms and formulations in the private and public sector, compiling relevant information of this research field, and directing the reader to other articles within each topic.

To formulate such models, in general, a set of binary variables are used along with a linear objective function. Within the different models, the binary variables can be employed to decide the location of the infrastructures (to represent if a facility is positioned at a certain location), to represent if a demand point is covered, to represent if a demand point is assigned to a certain facility, among others.

Regarding the classification of this type of problems, Daskin (2008) presented a classification for discrete location problems which divides them into three categories: covering-based problems, median-based problems, and other problems. This classification is shown in Figure 14.

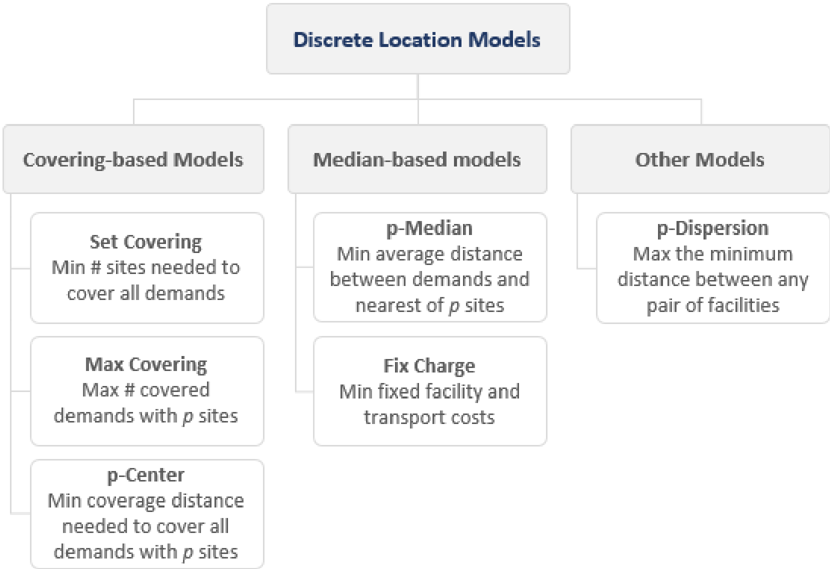


Figure 14 - Breakdown of discrete location models. Adapted from "What you should know about location modeling", by M. S. Daskin, 2008, *Naval Research Logistics, 55 (4), p. 285. Copyright 2008 by Wiley Periodicals, Inc.*

These models fall under the desirable facilities category, in which it is assumed that the nearer the facility is to the demand, the better the service level provided. Furthermore, the models assume a deterministic demand, referring to a single-product, and having a single objective. Based on these models, it is possible to modify them and create extensions so as to represent the different previously mentioned factors that constraint the models, and better portrait the richness of the real world.

Following Daskin's breakdown of discrete models, the first category is called **covering-based models.** These models are related to the notion of coverage – associated with each demand node, there needs to be a facility within a specified distance which can serve (or cover) the demand. Within covering-based problems, it is considered that demand points must be located within a certain distance/time (denominated "coverage distance") from the facilities which serve them, in order to be covered by the service, or satisfactorily served (Daskin, 2008). We may divide this class of problems into three sub-categories: set covering, maximal covering, and p-center location problems.

Set covering location problem

In these problems, the goal is to minimize the cost of establishing a set of facilities from among a finite set of candidates, while guaranteeing that all the demand is covered by at least one facility (Daskin, 1995). Within this model, if all facility installation costs are equal, then the goal is equivalent to minimizing the number of established facilities, given that demand is covered (Owen & Daskin, 1998). In a set covering problem, the number and location of the set of facilities are determined, such that all demand points are covered, in other words, such that all demand points are within a specified travel distance (or time) of the facilities that are allocated to them (Ahmadi-Javid et al., 2017).

Nonetheless, given the characteristics of the model, one of the main setbacks associated with the latter is that, frequently, the number of facilities proposed to meet all demand points is significantly large, and it becomes frequently infeasible in real-world operations (for monetary, space or other reasons) (Daskin, 1995). With these concerns in mind, we are either led to pre-determine the number of facilities to be located, or to relax the coverage distance, which leads us to the models presented below (maximal covering and p-center location problem, respectively).

Maximal covering location problem

In maximal covering location problems (MCLPs) we determine the location of p facilities, in order to maximize the demand covered within a specified maximum coverage distance (or time). In comparison to the set covering model presented above, the MCLP takes into account the level of demand at each node, hence, differentiating between large and small demand nodes (Ahmadi-Javid et al., 2017).

P-center location problem

The p-center model is the third model within the covering-based models' category. It aims to minimize the coverage distance while requiring that all demand is met; in other words, the p-center problem is a type of minimax problem, in which the goal is to minimize the maximum travel distance (or time) between any demand and its allocated facility (Owen & Daskin, 1998). In this way, the coverage distance associated with locating p facilities is endogenously determined by the model (one of the model's output) and it takes into consideration the demand quantity, thus being a demand-weighted distance (Owen & Daskin, 1998). When the facilities are uncapacitated, meaning they do not have a limited capacity, the demand points will be assigned to the nearest open facility. These type of problems may also be referred to as location-allocation problems, as they involve simultaneously the location of the facilities and the allocation of demand nodes to the open facilities (Ahmadi-Javid et al., 2017).

The relation between the above-described models can be observed in a schematic way in Figure 15.

Figure 15 - Relationships among the set covering, maximal covering and p-center location problems. Source: Adapted from Networks and Discrete Location: Models, Algorithms and Applications (p. 155), by M.S. Daskin, 1995, New York, NY: John Wiley & Sons. Copyright 1995 by John Wiley & Sons, Inc.

Daskin's second category for discrete location problems is called **median-based problem** (Figure 14). As noted by Church & ReVelle (1976), one significant way to measure the success or effectiveness of a facility location is to determine the average distance traveled by its customers. An increase in the average travel distance results in a decrease of the facility accessibility and location's effectiveness (Owen & Daskin, 1998).

Median-based models determine the location of the candidate facilities in order to minimize the average demand-weighted distance (weighted distance according to the quantity of demand at each point) between the demand points and the facilities to which they are allocated to. This category of problems may also be denoted as location-allocation problems, as, similarly to the p-center problem, these models present both location and allocation decisions (Ahmadi-Javid et al., 2017). We will detail two of the most important problems within this class: the p-median and the fixed charge location problems.

P-median location problems

The p-median problem's goal is to minimize the total demand-weighted travel distance (or time) between demand points and facilities, when locating p facilities. These problems are among the most popular in facility location problems (Ahmadi-Javid et al., 2017).

Fixed charge location problems

The fixed charge location problem (FCLP) is closely related to the previous presented problem (p-median problem), with the particularity that, in the FCLPs the cost differences of positioning facilities at different candidate locations are taken into account, and there is no pre-determined number of facilities to locate (Ahmadi-Javid et al., 2017). Hence, FCLPs determine endogenously the number of facilities to locate and positions them so as to minimize the total cost (which comprises both the cost of facilities' installation and transportation cost) (Owen & Daskin, 1998). It is common to find these models within distribution planning contexts in which it is critical to minimize the total outbound or inbound transportation cost (Daskin, 2008).

Other problems

Lastly, the problems which are not included in the two broad categories above described (covering-based and median-based problems) are within the last category. An example of these problems is the **p-dispersion problem,** whose goal is to maximize the minimum distance between any pair of open facilities when locating p facilities (Daskin, 2008). This model is usually applied when dealing with facilities that threaten each other, for example, two supermarkets that compete with each other, and thus it is intended to create the largest separation possible between facilities (Ahmadi-Javid et al., 2017).

Within this category, several more formulations may be added by altering and creating extensions for the basic models (e.g., capacitated facility problems, location of undesirable facilities, etc.).

3.4 Models' Applications in the Public Service Sector

In this section, we present different applications of location models in the public service sector. These models are mainly extensions created from the basic location models presented, inserting alterations and building on top of other models already developed in the field of location problems.

To our knowledge, only one article relating specifically to the location of citizen service centers has been published (Fredriksson, 2017), which will be further detailed below. Thereby, we have decided to explore diverse applications within the public service sector. Our research targeted papers with key words related to location models, which aim at positioning desirable facilities and offering public services, such as health care, fire protection, schools, among others. The papers retrieved were then selected based on their potential contribution to this dissertation and summarized in Table 13, in Appendix 1. The articles were classified using some of the adapted categories from Daskin's (1995) taxonomy (presented in section 3.2), as well as the solution method used (either exact method or non-exact method – heuristics, metaheuristics, etc.). Additionally, some of the articles have been further detailed, namely the ones that we found could contribute the most and support the development and formulation of the model, as well as the ones which introduce to some extent a novelty that may be interesting to the problem being studied.

Besides the criteria above-mentioned, throughout our research, we have privileged, as much as possible, recent applications, thus ordering the papers in a descending order according to their year of publishing; moreover, we have also chosen according to the number of citations (prioritizing papers with a higher number of citations when comparing papers published in the same year).

Through the analysis of the synthesis table of the reviewed papers (Table 13) found in Appendix 1 it is possible to conclude that of the 15 analyzed papers, in general, the articles do not incorporate all the features associated with real-world operations. This may be related to the fact that, as previously mentioned, when choosing a model that reflects all the details involved in the real-world operations, this can generate extremely complex models, which not always provide the best results. By analyzing Figure 16, we may observe that in the reviewed papers, there is a higher percentage of static models than dynamic ones; similarly, the majority uses single-objective models rather than incorporating multiple objectives; and the models used are generally single-level rather than hierarchical models. However, two categories are exceptions as 53,3% of the analyzed papers use a stochastic model and, thus, incorporate uncertainty, and furthermore, the majority of the papers uses capacitated models.

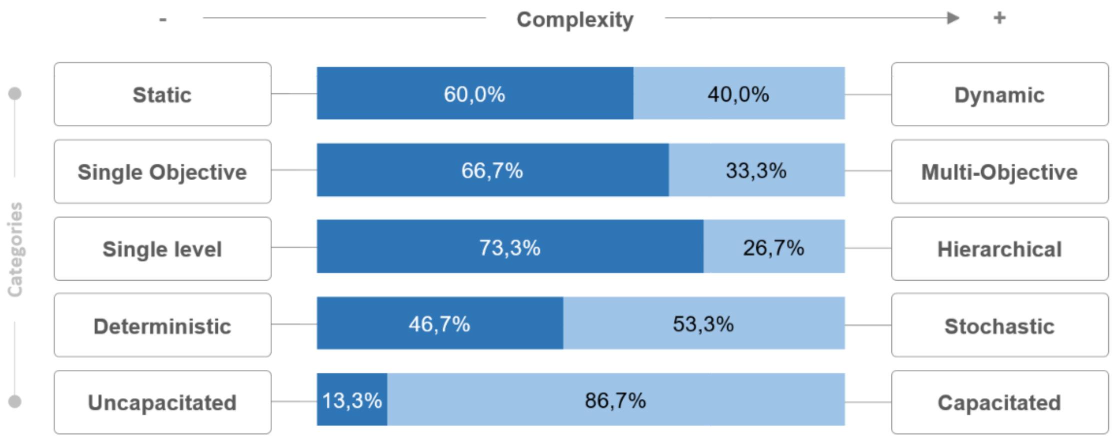


Figure 16 - Analysis of the synthesis table of the reviewed papers found in Appendix 1

Although the papers' sample size may not be representative of all the existing papers in the field, we may deduce that the majority of the papers still fail to capture some of the key features of the real-world operations, such as the temporal aspect (and the related variation of internal and external factors throughout time), the generally intrinsic hierarchy associated, the uncertainty of the parameters and the conflicting objectives that dominate real-world problems. Regarding this matter, it is important to note that only one article used a dynamic, multi-objective, hierarchical, stochastic model, incorporating all of these real-world key factors.

From the table it is also possible to conclude that regarding the solution method used, 80,0% of the papers use an exact method to solve the problem, while 20,0% use a non-exact method such as a heuristic or metaheuristic, for example.

Below we present the applications explored to further detail, which have been selected according to the previously mentioned criteria. These articles are divided into three sections, the first being related to the citizen service centers context, and then, the second and third, related to the fire protection and health care contexts, respectively.

Citizen Service Centers Context

The first paper presented refers to the aforementioned application of location models to locate citizen service centers. Fredriksson (2017) explores a p-median model to determine the optimal spatial location and allocation of citizen service centers in São Paulo, Brazil and in Sweden. The author used an exact method to solve the problem, specifically using a Branch and Bound algorithm through CPLEX software. Besides presenting the model, the author argues that location-allocation analysis can also be used as a tool to increase transparency in the allocation decisions; the author claims that using publicly available data to perform the optimization increases the transparency, as the analysis may be replicated by anyone who intends to. Furthermore, the author introduces different public services misallocation metrics; these misallocation metrics are defined as the difference between the actual distance to the public service, and the distance if the optimal solution were implemented. Moreover, the misallocation metrics can be defined at different levels of aggregation and, thus, allow us to compare the access to public services among different countries, regions, municipalities, etc. These misallocation metrics may also be related to socioeconomic outcomes, and to other potential explanatory factors of misallocation, such as political factors, and, thus, may be a useful tool in analyses of public sector performance (Fredriksson, 2017).

Fire Protection Context

Regarding the problem of fire protection facility siting, several approaches have been developed and, consequently, significant practical and theoretical work has been matured. One of these works is the research by van den Berg et al. (2017) in which the authors developed a mathematical programming model to determine the optimal locations of the vehicle base stations for a city's fire department in the Netherlands, and to optimally distribute the different firefighter vehicle types over the base stations. The authors use a maximal covering model, driven by practical considerations, such as the existence of base locations that cannot be relocated (e.g., for historical reasons), the inclusion of multiple vehicle types, as well as a set of firefighters that include a mixture of both professional and volunteer firefighters. The model's objective is to maximize the coverage provided by all the different vehicle types, considering that a demand point is said to be covered if the closest vehicle of the appropriate type is within the given target response-time (each type of vehicle has its own response-time target). The model also introduces weights to the demand points based on the expected number of calls, to account for the variability in the call intensity throughout a region.

The model was formulated as an integer linear programming (ILP) problem and solved through an exact method using CPLEX. The results of the model's application show a great potential for reducing the number of the vehicle's late arrivals, with a small investment in relocating a minor number of stations.

Still within the same context, Murray (2013) explores the strategic planning goals in fire protection and response, and details modeling approaches to support fire station siting. The spatial optimization models are used to support the decision making of fire stations' location, which is driven by the aim to achieve specific service performance standards. In particular, the paper focuses on the situation where fire stations are to be located intending to best achieve an S minute target response-time for ψ percent of calls in urban areas (in other words, intending to respond to ψ percent of the calls under S minutes). The author begins by explaining the maximal covering location problem (MCLP), and by pointing out that in order to answer to this particular problem, the MCLP has to be solved several times to determine the minimum number of facilities which must be located to suitably cover more than ψ of the demand. The author then presents an alternative to this iterative trial-and-error process, which is the threshold coverage model. This model only needs to be solved once, since the output of the model gives us the minimum number of stations to be positioned and their respective location in order to offer suitable coverage to at least ψ of the total expected demand. Moreover, the author explores additional extensions of these models used to cope with different restrictions such as spatial representation, server availability and existing stations. In this paper, the diverse models are used to solve a case study which examines a fire service system for a city in California, in order to demonstrate the importance of strategic planning and system re-evaluation when expanding services. The models were implemented in Python, incorporating data from geographic information systems (GIS), and solved using an exact method through the optimization software Gurobi.

Health Care Context

In the health care context, Cardoso et al. (2016) built a model to support planning decisions in the Long-Term Care (LTC) sector, proposing a multi-objective and multi-period mathematical programming model with the aim to move towards an equitable provision of care. Specifically, the model aids planning decisions in the medium-term, regarding location and capacity planning, and it incorporates a time component, which allows for the adjustment of LTC provision over time (when and where to locate the different LTC services).

One of this model's particularity is the fact that it incorporates three equity-related objectives and measures: equity of access, geographical equity, and socio-economic equity. The authors explain that equity represents one of the key objectives when planning the delivery of public health care and refer that there is no unique definition for the concept of equity, existing several ways to divide, organize and measure this concept. In face of this, the authors chose to divide it in terms of geographical equity and socioeconomic equity. Even though these types of equity have been recognized as two of the most important equity issues in health care, to our knowledge, this is one of the first approaches in the health care context to combine the search for both types of objectives.

Table 3 presents the three equity goals of the model (one of them encapsulates 2 objectives) and the selected measures to operationalize each one of them.

Table 3 – Cardoso et al. (2016) equity goals of the model and selected measures for operationalization

Model's goals	Description	Measures for operationalization
Equity of Access	(i) to ensure full coverage of LTC demand and (ii) the promotion of equal access to health care for all citizens	Minimization of the total travel time, while ensuring that services will be provided to as many patients as possible
Geographical Access	(iii) the promotion of equity in geographical distribution and utilization of services	Minimization of unmet demand in the geographical area with the highest level of unmet demand
Socioeconomic equity	(iv) the reduction in health socioeconomic inequalities (difference in the services utilization by the socioeconomic groups)	Minimization of unmet demand for the lower income groups

Besides the equity related objectives mentioned, the model also takes into consideration the associated costs. The multiple objectives included in the model are scaled into a common unit through weights, which are defined in a transparent way with the decision-makers. To conclude, the model is then applied to a case study in the Lisbon area, Portugal, having been implemented in the General Algebraic Modeling System (GAMS), and solved using an exact method through CPLEX.

Also within the health care sector, Zhang et al. (2016) develop a location-allocation model to help plan the siting of new health-care facilities in the city of Hong Kong for 2020. The multi-objective (MO) model aims to "improve the equity of accessibility, raise the total accessibility for the entire population, reduce the population that falls outside the coverage range, and decrease the cost of building new facilities".

Their research differs from others in the field as they use Pareto solutions[4] as part of their methodology to find a solution. When dealing with MO problems, the existence of conflicting objectives is recurrent, and there is usually no all-best solution at every objective. As so, to deal with this issue, most studies with a MO problem within the health care facility location context use a sum weighting approach to combine objectives, which gives us a single optimal solution. Nonetheless, these models fail to take into consideration tradeoffs between objectives. Within this context, the Pareto solutions have been proposed to cope with the MO problems in different fields, as rather than presenting a single solution, using Pareto solutions, we can present a set of different solutions from which the decision-makers can select their preferred option.

This research uses a genetic algorithm based multi-objective optimization (non-exact method) to find Pareto solutions, which can then be used by the decision-makers to identify and analyze the tradeoffs between objectives, to compare the spatial distribution of facilities and the values of each objective and to select the solution that best supports their further decisions. The proposed approach is then validated using Hong Kong's described case study.

The third paper within the health care sector is the paper of Mestre, Oliveira, & Barbosa-Póvoa (2015). The authors propose two stochastic location-allocation models for handling uncertainty in the strategic planning of hospital networks, to improve geographical access while minimizing costs. The models have a general framework within the stochastic approach but differ in their assumptions regarding the decisions that have to be made when full information on the uncertain parameters is not available, thus capturing diverse key aspects of hospital network planning. Their aim is to assist in the structuring of the hospital network while accounting for several of the features of real-world applications, such as a hierarchical structure, the provision of multiple services, the flows of patients, the facilities capacities, the planning horizon, and a bi-objective approach to deal with tradeoffs between access and cost.

Concerning the uncertainty, in this article, the authors focus on the uncertainty related to the demand and supply of the services, particularly, on the impact of demand changes related with population trends in developed countries (aging of the population, and increasing life expectancy), and the changes in hospital supply related to the future advances in technology. The demand uncertainty is modelled through a set of discrete scenarios that demonstrate future possible states. In the first model location decisions are considered as first-stage decisions[5], while the allocation decisions are made after the uncertainty is disclosed (scenario dependent allocation); on the other hand, in the second model, both location and allocation are considered first-stage decisions and, thus, the allocation decisions must be

[4] The Pareto solutions are nondominated solutions which imply that an improvement in one objective is only possible with the deterioration of at least one of the other objectives.

[5] In stochastic planning, first-stage decisions are the decisions that need to be made without full information on the uncertainty parameters, while second-stage decisions are the ones that are taken once uncertainty is disclosed, and which are also known as corrective actions.

made before the uncertainty is disclosed. Consequently, in the latter model, unsatisfied demand and extra capacity were modeled and incorporated in the model's formulation.

Both models have the same general objectives (with minor variations) to minimize the expected demand-weighted travel time to the hospital, and simultaneously, to minimize the expected cost, which comprises both the operating costs and the capital costs (related with the opening and closure of facilities). On the first model, it is required that all demand is met by one of the facilities in either hierarchical level; however, on the second model, this constraint is not valid, and as aforementioned, penalties for unsatisfied demand and extra capacity are added, since the demand varies in each scenario and there is a minimum capacity requirement. In the paper, the tradeoffs between an increase in access and cost are addressed using the ϵ-constraint method, giving the DM different alternative solutions from which to choose.

To finalize, both models are applied to a case study in the South Region of Portugal. The results were obtained through an exact algorithm using GAMS with CPLEX, and further demonstrated how these models can assist health care planners, the information that can be obtained through each model, the impact of different assumptions regarding allocation decisions (first-stage versus second-stage allocation decisions), the effect of demand uncertainty, and which were the best performing location–allocation decisions for the designed scenarios.

3.5 Chapter Conclusions

In this chapter, we analyzed and summarized the main location models reviewed in the literature, in order to gain a more comprehensive understanding of the subject and, consequently, support the development of the mathematical model required for the problem.

We started by defining the objectives and core concepts of the location models. From this description we concluded that facility location decisions are crucial strategic decisions in the design of systems for both private and public companies. They aim to choose the best location for the facilities, so that they can meet the customers demand in the best way possible while considering the trade-offs between costs and customer satisfaction. Thereby, these decisions have a significant contribution to the competitiveness of the organization. Furthermore, facility location decisions are long-term investments whose structure has to be adapted to the system's current state, but also ensure that their performance remains lucrative during their lifetime, and that they are prepared to deal with changes in internal and external factors such as market demand, populations shifts, environmental changes, among others.

Then, a taxonomy of the location models was presented, and along with it, the primary focus of this dissertation was highlighted. Regarding our problem, from the conducted study, we suggest the use of a discrete location model to locate desirable facilities within the public sector; furthermore, it seems equally appropriate to formulate our model as a multifacility problem, which provide services that have few or no substitutes, thus, having a seemingly inelastic demand. Other characteristics of the model will be defined in the following chapters of the present document, such as the selection of the distance metric to be used, the use of a static or dynamic model, the use of a single or multi-objective model, the use of a single-leveled or hierarchical system, and the use of a deterministic or stochastic model.

Afterward, we focused on discrete location models as these are especially important to the present study, and each basic discrete location model was briefly explained. Finally, several applications in the public service sector were reviewed and analyzed with regard to some of the elements of the presented taxonomy, of which, some papers were presented and analyzed to greater detail as they were found to be especially relevant to support the development of our model. In our review, we found only one paper dealing with a problem similar to ours (the positioning of citizen service centers), and, thus, we conducted a broader analysis, reviewing papers that also address problems in the public sector, such as the siting of fire protection services and different facilities within the health care context.

From the analysis of the sample of papers which are presented in Appendix 1, although the papers' sample size may not be representative of the all the existing papers in the field, we may deduce that several papers still struggle to incorporate all the key features of the real-world operations, such as the temporal aspect, the uncertainty of the parameters and the conflicting objectives.

From the analysis of such papers, we can conclude that there is no consensus regarding the choice of a type of model, nor regarding the choice of the solution method, however, we were able to conclude that when addressing problems in the public sector, some of the key concerns besides the minimization of costs are the attainment of equity, the universality of service and efficiency.

Chapter 4 MATHEMATICAL MODEL DEFINITION

The current chapter presents the model conceptually along with its mathematical formulation. In section 4.1 a summary of the problem statement is provided. Section 4.2 provides the model's characterization, describing the model's framework, clarifying and explaining the inputs and outputs of the model, and its underlying assumptions. Finally, in section 4.3 the model's mathematical formulation is presented, detailing the respective objective functions and the constraints, and in section 4.4 the main chapter conclusions are presented.

4.1 Problem Statement

In order to better address the further steps that are necessary in tackling the problem presented by AMA (see section 2.4) it becomes necessary to fully recall it. Hence, a succinct review of the problem is presented.

As previously observed, there are currently 51 citizen shops (CSs) located in Portugal which provide a variety of public services to citizens. However, the current network of citizen shops is not evenly distributed throughout Portugal: some districts have as many as 8 CSs while some only have 1. Analyzing the data, namely the number of CSs and citizens per district, we can observe that there is an inequity of access between the citizens, meaning that the average travel time to reach a citizen shop varies significantly among the inhabitants. This dissertation arises to respond to one of the challenges and objectives for the future of the Portuguese public services, in line with the *Grandes Opções do Plano,* outlined by the 21st Government, to expand the physical channel of the citizen assistance network. The aim of this dissertation is thus to facilitate the decision of the DMs, with the aim of selecting a robust set of long-term physical locations for the citizen shops and kiosks that make up the physical assistance network, so as to maximize the accessibility to all citizens, improve the distribution quality of the public services, and increase the proximity to the citizen thus, improving the equity in the provision of such services to all citizens.

In light of this, it is easily understood that ideally establishing a CS or kiosk at each location would be the optimal network in terms of equity of access, nonetheless, we can also easily conclude that this scenario would lead to great costs, and to investments that would have a large pay-off and most likely, could not be afforded due to budget restrictions. Therefore, the analysis of the trade-off between a network that strives for proximity and equity for the client and at the same time is economically sustainable is of great importance.

4.2 Model Characterization

Below the model is conceptually presented in order to better explain the network and its connections. As presented in Figure 17, the model considers that the presential service network operates in a two-level hierarchy: the lower level facilities, the kiosks, and the higher-level facilities, the citizen shops.

Figure 17 - Scheme of the network's structure

The lower level facilities provide a set of less specialized services, that represent a share of the services provided at the CSs, and that do not require human resources; the aim of these facilities is to create a capillary network to be closer to the population. The higher-level facilities, the citizen shops, provide the complete set of services, which include the services offered at the kiosks, as well, as a set of more specialized services, and those services in which a face-to-face interaction is necessary.

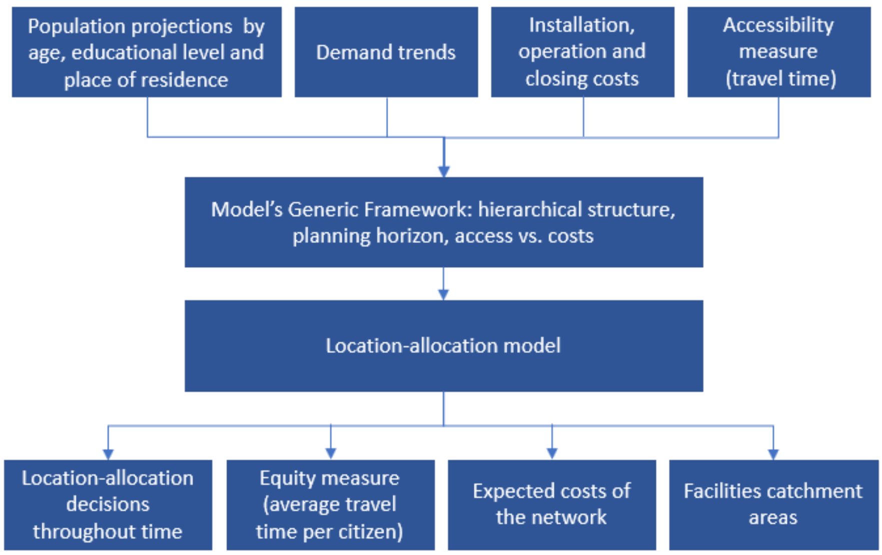


Figure 18 - Generic location-allocation model framework

Figure 18 illustrates the general framework of the model. The model uses as inputs, information on demand (population projections and demand trends), cost and access measures. Additionally, a hierarchical structure is used along with a planning horizon. As previously explained in section 3.2, a hierarchical network means that there is a hierarchy of facilities with potential flows between them. In this case, the model represents a network which is a successively inclusive facility hierarchy, meaning that the services offered in the lower level facilities (the kiosks), are also provided at the higher-level facilities – the citizen shops (Narula, 1986). Furthermore, in this network the citizens may choose the facility they want to visit, not being obligated to start by visiting the lowest level facility. Due to the structure of the network, there is a potential flow from the kiosks to the citizen shops (identified with the dashed arrow in Figure 17), which refers to the share of citizens who cannot see their requirements met at their visit to a kiosk, and, thus, have to travel to a citizen shop to be served. Regarding the planning horizon, the latter can be divided according to the preference of the DMs, into as many time periods (sets of years, for example) as desired. For each of the sets of time, the parameters that vary with time are estimated, such as the population, demand, educational level of the population, among others. For addressing the tradeoffs between improving access and minimizing the costs of expanding and reorganizing the network, a bi-objective location-allocation model is developed, which will be further explained in section 4.3 . As outputs, the model provides the location of the facilities at each period in time, an equity measure, the total expected costs, and the facilities catchment areas (which consists of the demand points which are served by a certain facility).

Regarding the first level of the framework (Figure 18), the population projections by age, educational level and place of residence help us to better understand and predict the evolution of the population within each age group and educational level group, in order to capture its effect on the demand, since these are two of the main factors that impact the demand of the physical network under study (see section 2.4).

Concerning the projections of the demand, which refers to the number of visits to be made to the facilities, the total demand of each demand point i and time t, D_i^t, is divided into two parts: the kiosks' demand, DQ_i^t , and the citizen shops' demand, DL_i^t. In other words, the sum of these two partial demands make up the total demand of a location i for time t ($DQ_i^t + DL_i^t = D_i^t$). The kiosk demand is calculated through the equation $DQ_i^t = \alpha_i^t D_i^t$, being α_i^t the proportion of the population from demand point i that will be served at a kiosk in time t. Thus, the demand of a kiosk in a certain location is a percentage of the total demand for the same location. On the other hand, the citizen shop demand in location i and time t for citizen shop j, is calculated through the formula $DL_i^t = (1 - \alpha_i^t) D_i^t$, translating that the population that is not served at a kiosk will be served at a citizen shop, $(1 - \alpha_i^t) D_i^t$.

The parameter α_i^t is estimated based on the age and educational level of the population as it was previously demonstrated that the use of the presential channel instead of the online channel (for example) is mainly related to the latter reasons. The estimation of the parameter is also based on the expected percentage of services that may be completed in the kiosk (as the kiosk will not provide the complete set of services that are offered at a CS). With this in mind, the kiosks' demand of a certain location i depends on the proportion of people with an age below 65 years in that specific demand point (age_i^t), on the proportion of the population with an educational level equal or higher to a primary level of education[6] (edu_i^t), and on the percentage of the full set of services which is offered at kiosks (S).

[6] Concerning the Portuguese educational system, a primary educational level is equivalent to having completed the 9th grade.

As one may conclude, the higher the percentage of people with an age below 65 and with a higher educational level, the higher the number of citizens that will be served at a kiosk. Similarly, the higher the percentage of services that will be offered at a kiosk, the higher the number of citizens that will use them.

In light of this, and in order to help us estimate the parameter α_i^t, a matrix plotting educational level versus age was built (Figure 19). In this matrix we cross the educational level with the age of the population, in order to determine which is the expected preferred facility of each segment of the population. For example, younger population with a higher level of education are more likely to visit a kiosk rather than a CS, on the other hand, people with an advanced age and a lower level of education, are more likely to prefer to visit a CS. Additionally, the population groups that have a higher educational level and an advanced age, and the population groups which have a younger age and a lower education are expected to visit either a kiosk or a CS, with the same probability (50% probability for either option).

Having understood this, we can estimate the parameter, α_i^t through equation (1).

$$\alpha_i^t = \left[age_i^t\ edu_i^t + \frac{age_i^t(1 - \ edu_i^t) + (1 - age_i^t)edu_i^t}{2}\right] * S \tag{1}$$

This equation corresponds to the sum of the population in each quadrant which will use the kiosks (the shadowed area in Figure 19 – 1st quadrant, half of the 2nd, and half of the 4th), multiplied by the parameter S in order to account for the percentage of services offered in the kiosk (comparing to the complete set of services offered at CSs). As one may observe, it is considered that the population on the 2nd and 4th quadrant will opt for visiting a kiosk half of the time and opt for visiting a CS the other half of the time. Furthermore, it is important to note that the sum of the four quadrants is equal to the total demand of a location, at a given period of time.

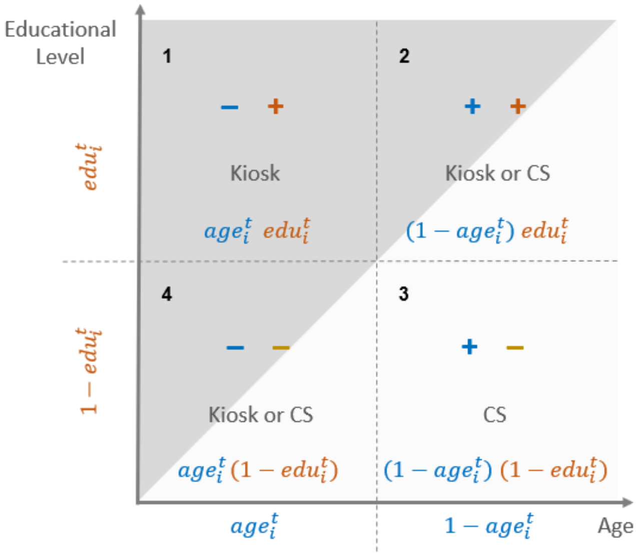


Figure 19 - Age versus Educational Level Matrix

Having explained the first set of inputs of the first level of the framework, still regarding Figure 18, the second set of inputs are the demand trends, which allow us to evaluate the past variation of the demand and to estimate the expected increase or decrease of visits to the network.

With regards to the costs, the model considers the costs related to the capital costs associated with the investment of opening new facilities and closing exiting ones, fixed annual operational costs, and variable operational costs. The historical information of investment costs involves the cost of buying an infrastructure, or remodeling an existing one, as well as the cost of buying new equipment, or the cost of transporting used one. Relatively to the operational costs, these refer, on the one hand, to the fixed costs of owning an infrastructure such as the building's amortization, equipment depreciation, maintenance, electricity, water, cleaning and management cost, among others; and, on the other hand, refer to the variable operation costs, such as labor costs, that result from the daily activity, concerning the use of necessary resources to deliver the services to the customers, and which are proportional to the number of citizens served at each facility. Finally, concerning the closing costs, these may involve different factors, such as the costs that arise from firing employees, cleaning out the facility space, the cost of transporting the equipment, liquidation of assets, accounting costs, among others (Swan, 2010).

The last set of inputs of the first level of the framework (Figure 18) is the accessibility measure. The initial state is characterized by the existing network in 2018. The network is made of a set of demand points, citizen shops, and kiosks, and the model considers the connections that link these entities (demand points and citizens shops, demand points and kiosks, and citizen shops and kiosks). Connections are measured in terms of travel time between the entities, which the citizens need to incur in order to reach one of the facilities (CS or kiosk). These are characterized by their geographical location and relate to each other by the travel time between each one of them. It was decided along with the DMs that the locations of the entities would be defined at a municipality level, as according to the Decree-Law no. 105/2017 of August 29th, 2017, the installation of new citizen shops will be made through the initiative of the municipalities in articulation with AMA. Thus, this provides a sufficient level of detail, and allows us, for example, to aggregate the citizens and have better forecasts of the future population. In this dissertation, the geographical location of each entity is, hence, considered to be the capital of each municipality. As such, concerning the population, the model assumes that all the population of a municipality is geographically located in its capital.

The model's objective is to define which lower and higher-level facilities to locate and when (during the planning horizon), in order to maximize the equity of access of the population while minimizing the expected costs of the network's alterations. The proposed model is based on the classical p-median problem in which the user-facility travel time (or distance) is minimized while simultaneously minimizing the total expected costs, however, in the developed model, the number of facilities to locate is determined endogenously.

The model is based on the assumption that all demand which is calculated *a priori* for each time interval must be mandatorily satisfied in that time set. Regarding the capacity of the facilities, a capacity threshold is not imposed as a constraint, as doing so might possibly lead to the demand from a single location to be split between facilities, in order to respect the maximum capacity constraint. This would lead to a scenario where neighboring populations incur in distinct levels of travelling times, which is rarely accepted in public facility location, as in this context it can be politically unacceptable that citizens from neighboring areas have different levels of geographic access (Mestre et al., 2015). As such, there is no maximum capacity restrictions, and alternatively, once the model provides the results, these are analyzed, and in those facilities where the capacity is excessive, the possibility of opening two facilities in that same municipality is studied. This is done in order to limit the scale of the facilities, which prevents them from operating under diseconomies of scale.

As an output, the model provides the information about when and where to locate the facilities throughout the planning horizon. Moreover, it provides an equity measure which gives us the information about the average time a citizen must travel to access a facility to be served. It is calculated through the weighted sum of the travel times incurred by each citizen that visits a facility, divided by the total demand of the network. As a third output, the model presents the expected costs of expansion of the network, and finally, the last output is the facilities' catchment areas, providing the information of which demand points are served by a facility.

The problem under study may be summarized in the following way:

Given:

- The network of potential locations for the facilities (both citizen shops and kiosks);
- The planning horizon;
- The location of the citizens;
- The travel time between each pair of entities;
- The demand of each location in each time period;
- The investment cost of a citizen shop and of a kiosk in each location and time period;
- The unit operational cost of serving a citizen;
- The annual fixed cost of maintaining a facility;
- The cost of closing an existing citizen shop and kiosk in each location and time period.

Determine:

- The network structure at each time period, specifying when and where to locate each new citizen shop and kiosk, and which facilities to close;
- The flow from each demand point to the citizen shops and kiosks at each time period;
- The total expected costs derived from the expansion and reorganization of the network;
- The value of the equity measure.

In order to maximize the equity of the citizens in accessing these services and at the same time, to minimize the total expected costs of the changes made to the network.

4.3 Mathematical Formulation of the Model

4.3.1 Notation

The model notation is organized into the sets, parameters and variables described below.

Sets

$t \epsilon T$ Set of time periods in which the planning horizon is divided

$i \epsilon I$ Set of demand points

$j \in J$ Set of potential locations for citizen shops

$J_0 \subseteq J$ Set of citizen shops initially existing

$J_c \subseteq J$ Set of citizen shops that are not opened at the initial period

$J_m \subseteq J$ Set of citizen shops initially existing and that must be kept open

$k \in K$ Set of potential locations for kiosks

$K_0 \subseteq K$ Set of kiosks initially existing

$K_c \subseteq K$ Set of kiosks that are not opened at the initial period

$K_m \subseteq K$ Set of kiosks initially existing and that must be kept open

Parameters

dis_{ij}^1 dis_{ik}^2 Average travel time from demand point i to citizen shop j / to kiosk k

dis_{kj}^3 Average travel time from kiosk k to citizen shop j

age_i^t Proportion of the population with an age below 65 years in demand point i and time t

edu_i^t Proportion of the population with an educational level equal or higher to primary education in demand point i and time t

D_i^t Total demand in location i and time t

S Percentage of the full set of services which is offered at kiosks

α_i^t Proportion of the population from demand point i that will be served at a kiosk in time t

$$\alpha_i^t = \left[age_i^t\ edu_i^t + \frac{age_i^t(1-edu_i^t)+(1-age_i^t)edu_i^t}{2}\right] * S$$

DL_i^t DQ_i^t Demand in location i and time t for citizen shop j / for kiosk k

$$DQ_i^t = \alpha_i^t\ D_i^t$$

$$DL_i^t = (1-\alpha_i^t)\ D_i^t$$

$year^t$ Number of years of time period t

γ^t Share of citizens who cannot solve their problem in their visit to a kiosk, and have to travel to a citizen shop, in time period t

ICL_j^t ICQ_k^t Investment cost in a new citizen shop ($j \in J_c$) / kiosk ($k \in K_c$) in time t

$fOCL_j^t$ $fOCQ_k^t$ Annual fixed operational cost for providing service in citizen shop j / kiosk k in time t

$vOCL_j^t$ $vOCQ_k^t$ Variable operational cost (unit cost) for providing service to one citizen in citizen shop j / kiosk k in time t

CCL_j^t CCQ_k^t Cost of closing an existing citizen shop ($j \in J_o$) / kiosk ($k \in K_0$) in time t

Variables

Binary Variables

XL_j^t XQ_k^t Equal to 1 if citizen shop/kiosk is located at site j/k in time t; 0 otherwise

Positive Variables

FL_{ij}^t FQ_{ik}^t Flow from demand point i to citizen shop j / kiosk k in time t

FQL_{kj}^t Flow from kiosk k to citizen shop j in time t

As the model departs from the current status of the network, decisions regarding the opening or closing of facilities are not allowed at the beginning of the planning horizon and the variables associated with these decisions are initialized in the first time period ($t = 1$). Facilities that are not initially operating are declared as closed $\left(XL_j^1 = 0 \quad \forall\, j \in J_c \wedge XQ_k^1 = 0 \quad \forall\, k \in K_c\right)$. On the other hand, facilities that are initially operating are declared as opened $\left(XL_j^1 = 1 \quad \forall\, j \in J_o \wedge XQ_k^1 = 1 \quad \forall\, k \in K_o\right)$. Furthermore, the model also considers that there is a set of initially existing facilities that must be kept opened during the planning horizon $\left(XL_j^t = 1 \quad \forall\, j \in J_m \wedge XQ_k^t = 1 \quad \forall\, k \in K_m,\ t \in T\right)$.

The mathematical programming formulation of the model is defined by the objective functions (2) and (3) and equations (4) – (17) that will be further explained in the next sub-sections.

4.3.2 Objective Functions

The model considers two objective functions related to equity of access and cost.

Objective 1: minimize the expected travel time to reach a citizen shop and a kiosk, respectively, weighted by demand, in order to maximize the population's equity of access.

This objective can be written as

$$\text{Min} \sum_{i \in I} \sum_{t \in T} \left(\sum_{j \in J} dis_{ij}^1\, FL_{ij}^t + \sum_{k \in K} dis_{ik}^2\, FQ_{ik}^t \right) + \sum_{k \in K} \sum_{j \in J} \sum_{t \in T} dis_{kj}^3\, FQL_{kj}^t \tag{2}$$

The objective function (2) translates the sum of the distances weighted by the flows between the demand points and citizen shops, between demand points and kiosks, and lastly between kiosk and citizen shops. The latter, represents the situations where a citizen is unable to solve his/her problem in a first to the kiosk and must be redirected to a CS to solve it.

Objective 2: minimize the total expected costs of expanding and altering the network

$$\begin{aligned} \text{Min} \sum_{t \in T} year^{t} \left(\sum_{j \in J} fOCL_j^t \, XL_j^t + \sum_{k \in K} fOCQ_k^t \, XQ_k^t \right) \\ + \sum_{t \in T} year^{t} \left\{ \sum_{j \in J} vOCL_j^t \left(\sum_{i \in I} FL_{ij}^t + \sum_{k \in K} FQL_{kj}^t \right) + \sum_{i \in I} \sum_{k \in K} vOCQ_k^t \, FQ_{ik}^t \right\} \\ + \sum_{t \in T \setminus \{1\}} \left(\sum_{j \in J_c} \left(XL_j^t - XL_j^{t-1} \right) ICL_j^t + \sum_{k \in K_c} \left(XQ_k^t - XQ_k^{t-1} \right) ICQ_j^t \right) \\ + \sum_{t \in T \setminus \{1\}} \left(\sum_{j \in J_o} \left(XL_j^{t-1} - XL_j^t \right) CCL_j^t + \sum_{k \in K_o} \left(XQ_k^{t-1} - XQ_k^t \right) CCQ_k^t \right) \end{aligned} \tag{3}$$

The first element concerns the expected fixed annual operation costs that result from owning an infrastructure, such as the depreciation of the building and equipment, labor, among others. These costs are fixed and are independent of the number of people that are served by the facility. On the other hand, the second element relates to the variable operation costs that result from the daily activities concerning the use of resources to deliver the services and which are proportional to the number of citizens served at each facility (flow that arrives at each shop and kiosk). The third element computes the capital costs associated with the investment of opening a new facility (CS and kiosk, respectively) and finally, the fourth element accounts for the costs related to the closing of an existing facility.

When pursuing the two objectives, as these are conflicting objectives, a key matter is the impossibility of finding an optimal solution in which all the objectives reach their individual optima (T. Cardoso et al., 2016). In other words, as the objectives conflict, it is not possible to improve one objective without compromising the value of the second objective. As an example, departing from the current network, it's not possible to decrease the distance of the citizens to the facilities without investing in new facilities, and thus increasing the cost (declination of the cost objective). On the other hand, it is not possible to reduce the costs, without increasing the distance that separate the citizens and the facilities.

4.3.3 Constraints

After defining the objective functions, several constraints need to be defined. These constraints are grouped in different categories: (i) demand satisfaction and flow conservation, (ii) assignment, (iii) opening and closure of facilities, (iv) auxiliary constraints, (v) integrality constraints.

Demand Satisfaction and Flow Conservation

$$\sum_{j \in J} FL_{ij}^{t} = DL_{i}^{t} \quad \forall\, i \in I, t \in T \tag{4}$$

$$\sum_{k \in K} FQ_{ik}^{t} = DQ_{i}^{t} \quad \forall\, i \in I, t \in T \tag{5}$$

$$\sum_{j \in J} FQL_{kj}^{t} = \gamma \sum_{i \in I} FQ_{ik}^{t} \quad \forall\, k \in K, t \in T \tag{6}$$

Constraints (4) and (5) ensure demand satisfaction and flow conservation, meaning that, in each time period, all demand must be considered – as satisfied by a citizen shop, (4), or by a kiosk, (5). Constraints (6) establishes the ascendant flow from kiosk k to citizen shop j, as a share of the total flow that arrives at kiosk k, in each time period.

Assignment

Furthermore, it is important to ensure that the flow from a demand point to a facility only exists when the facility is located, which is translated by constraints (7) and (8), and similarly, that a flow between two facilities also only exists if both the facilities are located, constraints (9) and (10).

$$\sum_{i \in I} FL_{ij}^{t} \leq XL_{j}^{t}\ M1 \quad \forall\ j \in J, t \in T \tag{7}$$

$$\sum_{i \in I} FQ_{ik}^{t} \leq XQ_{j}^{t}\ M2 \quad \forall\ k \in K, t \in T \tag{8}$$

$$\sum_{k \in K} FQL_{kj}^{t} \leq XL_{j}^{t}\ M3 \quad \forall\ j \in J, t \in T \tag{9}$$

$$\sum_{j \in J} FQL_{kj}^{t} \leq XQ_{j}^{t}\ M4 \quad \forall\ k \in K, t \in T \tag{10}$$

It is important to note that M1, M2, M3 and M4 are sufficiently large positive numbers so that the constraints are always satisfied. The value of M1, M2, M3, M4 depends on the constraint and must be defined for each one of them, in this case, each value should be larger than the upper bound of the left-hand side.

Opening and closure of facilities

Constraints (11) and (12) concern the location of new facilities that may open during the planning horizon ($j \in J_c$ and $k \in K_c$). They state that new facilities may open, but once opened, they must remain opened until the end of the planning horizon (respectively for CSs and kiosks).

$$XL_{j}^{t-1} \leq XL_{j}^{t} \quad \forall\, j \in J_c, t \in T \setminus \{1\} \tag{11}$$

$$XQ_{k}^{t-1} \leq XQ_{k}^{t} \quad \forall\, k \in K_c, t \in T \setminus \{1\} \tag{12}$$

Constraints (13) and (14) relate to the location of initially existing facilities ($j \in J_o$ and $k \in K_o$), and state that these may close, yet once closed, they cannot be reopened (respectively for CSs and kiosks).

$$XL_j^{t-1} \geq XL_j^t \quad \forall\, j \in J_o, t \in T \setminus \{1\} \tag{13}$$

$$XQ_k^{t-1} \geq XQ_k^t \quad \forall\, k \in K_o, t \in T \setminus \{1\} \tag{14}$$

<u>Auxiliary constraints</u>

Constraints (15) and (16) are auxiliary constraints which ensure that when a facility is located, there is necessarily a flow that arrives at this location.

$$XL_j^t \leq \sum_{i \in I} FL_{ij}^t \quad \forall\, j \in J, t \in T \tag{15}$$

$$XQ_k^t \leq \sum_{i \in I} FQ_{ik}^t \quad \forall\, k \in K, t \in T \tag{16}$$

<u>Integrality and non-negativity constraints</u>

Constraints (17) contains the standard integrality and non-negativity constraints.

$$XL_j^t\ XQ_k^t \in \{0,1\},\ \ FL_{ij}^t\ FQ_{ik}^t\ FQL_{kj}^t, M1, M2, M3, M4 \geq 0 \quad \forall\, i \in I, j \in J, k \in K, t \in T \tag{17}$$

The model made up of the objective functions (2) and (3) and constraints (4) to (17) is a mixed integer linear programming (MILP) model which models a generic location-allocation problem for the planning of a public services network formed by a set of citizen service centers, kiosks, and citizens. The citizen service centers, and the kiosks are established to serve a determined number of citizens, in order to improve the current equity of the network, while minimizing the total expected costs.

The model was developed and implemented in the generic programming language, GAMS 25.0.3 and solved through CPLEX on a computer with an Intel® Core™ i5 CPU, M540, 2.53 GHz.

4.4 Chapter Conclusions

In this chapter the model was presented conceptually along with its mathematical formulation. Firstly, we provided a recall of the problem being tackled in this dissertation in order to better address the further steps necessary. Following the review of the problem, the model was characterized, and a description of the model's framework was provided, along with the underlying assumptions that were taken into consideration when developing the model. The model was presented as having a hierarchical structure with lower-level facilities, the kiosks, and higher-level facilities, the citizens shops. The demand points may be served in either facilities, and there is a potential ascending flow from the lower to the higher-level facilities.

The framework of the model was also described in order to better explain the model conceptually. The model is composed of three sets of entities: the above-mentioned citizen shops and kiosks, and a set of demand points. These entities are characterized by their geographical location and relate to each other by the travel time between each one of them. The locations were defined at a municipal level since this assumption is in accordance with the current strategy for the location of CSs (Decree-Law no. 105/2017 of August 29th, 2017), and it provides a sufficient level of detail for the analysis. The first level of the framework was described, which corresponds to the set of inputs necessary for the model; these include the population projections by age, educational level and place of residence, the demand trends of the network, the cost associated with the network (installation, operational and closing costs of the facilities), and an accessibility measure (travel time between the entities). After that, the model's objective was detailed, which was to define which lower and higher-level facilities to locate and when (during the planning horizon), in order to maximize the equity of access of the population while minimizing the expected costs of the network's alterations. Finally, the outputs of the models were also explained, which are the information about when and where to locate the facilities throughout the planning horizon, an equity measure which gives us the information about the average time per citizen to reach a facility, the expected costs of reorganizing and expanding the network, and finally, the facilities' catchment areas, providing the information of which demand points are served by a facility.

Following the model characterization, the mathematical formulation of the model was presented, defining the sets, parameters and variables of the model, and then, further describing the objective functions and the constraints of the model, and the respective assumptions that lie in the origin of each function and constraint.

Chapter 5 CASE STUDY RESOLUTION

This chapter describes the application of the model presented on the previous chapter to AMA's problem. Thereby, section 5.1 presents the adopted strategies to deal with complexity, namely aggregation strategies and assumptions considered. In section 5.2 the data treatment of the model's input data is described along with its underlying assumptions. In section 5.3 the model's results are presented and analyzed, and in section 5.4 a sensitivity analysis is presented. Finally, in section 5.5 the main chapter conclusions are presented.

5.1 Adopted Strategies to Deal with Complexity

When dealing with real-world context problems, there is, generally, a high complexity embedded. As such, the number of constraints, and variables is very high, increasing the computational time of the model. In order for the model to be computationally feasible it becomes necessary to adopt a number of strategies to deal with the accrued complexity, and in order to reduce the dimension of the problem. The choice of these strategies attempts to minimize the impact they have in the representativeness of the model, so as to allow that the results continue to correctly inform the DMs.

Demand Points Aggregation

There is a high number of demand points and potential locations for both the CSs and kiosks, which would render the resolution of the model computationally difficult. Thereby, an aggregation of the demand points was made to a municipal level. The demand considered for each municipality corresponds to the sum of the demand that results from the population that lives in each municipality and has been allocated to the capital of the municipality. The distance/travel time between the locations was considered to be the distance/travel time between the capitals of the municipalities.

Means of Transport

Concerning the means of transport, there are several means of traveling between two places, and these differ from location to location. Whilst in a city there are more efficient public transportation options, other areas have harder access and fewer availability of public transportation. The consideration of all these different means of transport in the model would introduce an elevated computational complexity to the model. Thereby, to deal with such complexity, a sole means of transport was adopted, the car, and the travel times by car were estimated between the pairs of entities. Further information on the estimation of travel time will be provided in the next section.

Temporal Aggregation

This model was developed under the scope of a project being developed by AMA in partnership with Kaizen Institute. The initial aim of this model was to assist in the strategic decision of the location of CSs and kiosks for the long-term, throughout 20 years. However, at the time of the publication of this master's dissertation, the project was still in development, and some parts of the project, necessary as inputs for the model, were still not completed. As an example, one of the project's components needed was the concrete vision definition for the future citizen shops, regarding the type of materials and energy sources which shall be used, and the estimations of their cost in the future; these parameters influence in turn the investment and operational costs, for example, which are necessary as inputs for the model. Consequently, due to the scarce availability of data, and the lack of information on certain parameters necessary to implement the model for a 20-year planning horizon, in order to reduce the dimension of the problem, it was decided to optimize the network for the next 5 years, for the purpose of this master's dissertation. The optimization of the network for the 20-year planning horizon, will, thus, be done in the future, when the necessary information is available.

Regarding the demand variation of the services offered at the citizen shops, there is a considerable variation throughout the weeks and months of the year. Nonetheless, the computational capacity does not allow to consider weekly or monthly time periods. Furthermore, since this model aims to assist in a strategic/tactical decision for the medium-long-term, yearly time periods are considered.

5.2 Data Analysis and Underlying Assumptions

Considering the above-mentioned strategies adopted to reduce complexity, in this section, we present the data and underlying assumptions used in the resolution of the case study. For confidentiality purposes, the ensuing data was multiplied by a distortion coefficient.

Demand Points and Candidate Locations

As previously mentioned, the demand points and candidate locations for CSs and kiosks were defined as the capitals of each municipality, having resulted in 278 demand points, 228 candidate locations for the CSs (excluding the 50 locations where there is already a CS currently), and 278 candidate locations for the kiosks. The decision of defining the locations at a municipal level was supported by the Decree-Law no. 105/2017 of August 29th, 2017, in which it is defined that the installation of new CS will be initialized through the initiative of the municipalities, and completed in articulation with AMA.

Planning Horizon

As previously mentioned, the planning horizon considered was of 5 years, having been disaggregated into 5 yearly time periods, in which the demand must be satisfied. The model seeks to optimize the location of the CSs and kiosks throughout the next 5 years.

Travel Time

The developed model takes into consideration the maximization of equity in access for the citizens, thus it is crucial to have the most accurate estimation possible of the distance/time between the nodes of the network (i.e. entities of the network), in this case, the distance/time between the municipalities' capitals.

To estimate this parameter, we have opted for estimating the travel time, so we can capture not only the geographical distance but also the characteristics and constraints of the roads' network in each location. The use of travel times is of greater importance in regions such as *Alentejo* in which even short distances translate into long travel times. The travel times were estimated resorting to the website *Distâncias entre Cidades* which provides satisfactory estimates for the travel times at a municipal level ("Distâncias entre cidades," n.d.). We opted for a website where the traffic was not taken into account, so that travel times could be compared and so that they would not depend on the hour of the day in which they were retrieved, for example.

As previously mentioned, regarding the locations, for simplification purposes the model considers that all the demand of a certain municipality is located at its capital. In order to minimize the error associated with this assumption of considering the municipalities' capitals instead of the exact location of the citizens, a margin of 12 minutes was added to each travel time between the municipalities, so as to account for an internal travel time within the municipalities, reducing the error of considering that the distance between the population of a municipality and the CS or kiosk located at the same municipality is zero minutes. This value was calculated based on the average area per municipality (Table 4).

Table 4 - Calculation of the average area per municipality

Description	Value
Total area of mainland Portugal (km^2)	89 102,14 km^2
Number of municipalities in mainland Portugal	278
Average area per municipality	320,51 km^2

Considering the municipalities as circles, having an average area of 320,51 km^2, the average radius of a municipality is 10 km. Considering that the citizens use the car as the mean of transport and travel at 50 km/h, it results in an average travel time of 12 minutes from the outskirts to the municipality's capital.

It is important to note that for this type of model, in order to have a more accurate measure of equity, the time parameter should account, not only for the travel time, but should also include the waiting time at a facility, especially if this value varied according to the facility visited. Nevertheless, currently there is no data available for this parameter, and therefore, it was not possible to perform this analysis. Thus, it is recommended for future work.

Age Groups

The proportion of people with an age below 65 years old in a specific demand point and time period (age_i^t) was retrieved from INE's database, based on the available projections of the resident population by age group and place of residence from 2018 to 2023. Relatively to the place of residence, the population projections are discriminated only for the 5 NUTS II[7] regions of mainland Portugal. Thus, for each municipality within each NUTS II region, the parameter age_i^t was considered to be the same.

[7] NUTS is an acronym that stands for "Nomenclature of territorial units for statistical purposes", a hierarchical system that divides the territory into regions.
The nomenclature is subdivided into 3 levels (NUTS I, NUTS II, NUTS III), defined according to population, administrative and geographical criteria. The 278 municipalities in mainland Portugal are grouped into 23 NUTS III, 5 NUTS II and 1 NUTS I. For more information, please see: https://www.pordata.pt/en/What+are+NUTS

Educational Level

Regarding the parameter edu_i^t which refers to the proportion of the population with an educational level equal or higher to a primary level of education (i.e. equal or higher to the 9th grade in the Portuguese educational system), since there are no available projections of the educational level of the population, it was only possible to retrieve the most recent information regarding this parameter, which is from the Census of 2011. The information available from INE depicts the educational level per municipality for 2011, and hence, the values for each municipality are assumed to remain constant up to 2023.

Demand

The demand of a CS is an intricate parameter since it depends on several different constraints, such as the opening of neighboring shops, the propensity that a citizen has to visit the shops (which in turn is related to the age group and educational level of the citizen), the existing laws (for example, if there is a law that obliges all citizens to visit a CS in a given year, such as the obligation of having an identity card, *Cartão de Cidadão*), the amount of entities represented at the CS, the integration of other surrounding public services (for example, the closing of a an Social Security infrastructure, with the passage of this service to a neighboring CS), and finally, it also depends on political decisions.

In light of this information, some simplifications and assumptions had to be implemented, as the accurate determination of demand would lead to an excessive time of data processing, and it is believed that the benefits that would come from it would not lead to significant changes in the results. However, this is identified as an opportunity for future work and analysis.

With this assumption in mind, the demand was estimated per municipality and per year. Given the demand data of the CSs provided by AMA, we could observe that the demand has been growing for the past three consecutive years, having had increments (relatively to the previous year) of 0,11%, 0,15% and 2,05% in 2015, 2016 and 2017, respectively. Besides the observed increase trend over the last three years, it has already been outlined that there is a movement towards the integration of all public services in the CSs, which is further confirmed by the Decree-Law no. 105/2017 of August 29th, 2017, in which it is stated that when opening a new CS it is mandatory to locate at least 2 out of the 4 core services (see section 2.3.3). Thereby, based on these facts, we can expect the demand to increase over the next years. Knowing the CSs' strategy will not be altered in the next 5 years, combined with the insights received from the DMs about the demand trends, we conclude that the demand will continue to grow, and will have an estimated increase of 2% per year.

Regarding the estimation of demand per municipality, since there is no data relative to the provenience of the customers that visit the CSs, we defined a rationale to estimate the demand of each demand point/municipality. First, we ran the model with the following inputs: the 2017 demand, and the 50 municipalities which currently have a CS. The aim was to determine which are the municipalities that are served by certain CS, in other words, the aim was to determine the citizen shops' catchment areas for the current network. Then, with this information, we divided the total demand of a CS by the municipalities it serves, in proportion to the population of the demand point/municipality. This rationale can be summarized by equation (18), in which we want to determine the $Demand\ of\ location\ i$.

$$\frac{Demand\ of\ CS\ j}{Total\ Population\ of\ its\ Demand\ Points} = \frac{Demand\ of\ location\ i}{Population\ of\ Demand\ Point\ i} \tag{18}$$

For example, in the current network, in 2017, the CS of *Águeda* had a demand of 4 030, and it served the demand points of *Águeda*, *Albergaria-a-velha*, and *Sever do Vouga*. The populations of these municipalities in 2017 were, respectively, 46 333, 24 260, and 11 544. Thereby, for instance, Albergaria-a-velha's demand can be calculated through equation (18.1).

$$\frac{Demand\ of\ CS\ Águeda}{Total\ Population\ of\ its\ Demand\ Points} = \frac{Demand\ of\ Albergaria - a - Velha}{Population\ of\ Albergaria - a - Velha} \tag{18.1}$$

$$\Leftrightarrow \frac{4\ 030}{46\ 333 + 24\ 260 + 11\ 544} = \frac{Demand\ of\ Albergaria - a - Velha}{24\ 260}$$

$$\Leftrightarrow\ Demand\ of\ Albergaria - a - Velha\ = 1190$$

As a particularity, it is important to note that concerning the demand of Lisbon, given the previously described assumption that the location of the demand and of the facilities is at the municipality's capital, we had to combine the demand of the two CSs located in Lisbon. As such, we summed the demand of both CSs (CS of *Laranjeiras* and of *Marvila)* and considered it to be one single demand located in the capital of Lisbon's municipality (Demand of Lisbon = Demand of CS Laranjeiras + Demand of CS Marvila). Below in Table 5 an example of the demands considered in the district of Aveiro is presented.

Table 5 - Total estimated demand for the municipalities of the district of Aveiro per year of the planning horizon

District	Municipality	2018	2019	2020	2021	2022	2023
Aveiro	Águeda	2273	2319	2366	2414	2463	2513
Aveiro	Albergaria-a-Velha	1190	1214	1239	1264	1290	1316
Aveiro	Anadia	29996	30608	31233	31870	32520	33184
Aveiro	Arouca	8649	8826	9006	9190	9378	9569
Aveiro	Aveiro	283855	289648	295559	301591	307746	314027
Aveiro	Castelo de Paiva	5310	5418	5529	5642	5757	5874
Aveiro	Espinho	32063	32717	33385	34066	34761	35470
Aveiro	Estarreja	14361	14654	14953	15258	15569	15887
Aveiro	Ílhavo	140604	143473	146401	149389	152438	155549
Aveiro	Mealhada	21754	22198	22651	23113	23585	24066
Aveiro	Murtosa	5677	5793	5911	6032	6155	6281
Aveiro	Oliveira de Azeméis	27237	27793	28360	28939	29530	30133
Aveiro	Oliveira do Bairro	25940	26469	27009	27560	28122	28696
Aveiro	Ovar	29917	30528	31151	31787	32436	33098
Aveiro	Santa Maria da Feira	56980	58143	59330	60541	61777	63038
Aveiro	São João da Madeira	8871	9052	9237	9426	9618	9814
Aveiro	Sever do Vouga	566	578	590	602	614	627
Aveiro	Vagos	83197	84895	86628	88396	90200	92041
Aveiro	Vale de Cambra	8848	9029	9213	9401	9593	9789

After estimating the total demand for each municipality, the demand was divided between CS's demand and kiosk's demand using the parameter α_i^t, and following the previously described approach (see section 4.2). It is important to note that there are no established kiosks at the initial state ($t = 1$), and, consequently, the demand for kiosks in the first time period, is also non-existent ($DQ_i^1 = 0 \quad \forall\, i \in I$), and the demand for the CSs is equal to the total demand ($DL_i^1 = D_i^1 \quad \forall\, i \in I$).

Investment Cost

As previously mentioned the installation of a new CS or kiosk is associated with diverse costs, such as the cost of buying or remodeling an infrastructure, and the cost of buying new equipment or transporting used one.

Concerning the CSs, due to the lack of data provided by AMA, a research was conducted in order to estimate the capital costs necessary to open a new citizen shop. The recent trend dictated by the Decree-Law no. 74/2014 of May 13th, 2014, is towards a streamlining of costs, through the utilization of State infrastructures and equipment, and towards a more flexible and decentralized management of the CSs' network, furthermore, there is the possibility of transferring the management responsibility to the municipalities (Decree-Law no. 105/2017 of August 29th, 2017).

Given the described framework, we conducted a research to determine the capital investments made in 2016, 2017 and 2018 in CSs, as these values are considered to be the most representative of the law alterations made in the near past, representing the best benchmark to estimate the installation of a new CS in the near future. As a result of the research, we were able to collect the investment information of 8 different CSs spread throughout the country (Center and North), which are summarized in Table 6 below.

Table 6 - Investment cost per citizen shop

Year of Opening	Municipality of the CS	Investment (k €)	Source
2016	Arruda dos Vinhos	410	(Município Arruda dos Vinhos, 2016)
2016	Belmonte	549	(Agência Lusa, 2016)
2016	Sardoal	400	(Município de Sardoal, 2018)
2016	Sintra (Cacém)	600	(Câmara Municipal de Sintra, 2016)
2017	Batalha	600	(Município da Batalha, 2017)
2017	Nelas	360	(Agência Lusa, 2018b)
2017	Torres Vedras	370	(Agência Lusa, 2017)
2018	Valpaços	650	(Agência Lusa, 2018a)

Through our research and analyzing the previous table, we concluded that the average cost of a CS is 500 000 €. The latter value was then validated by the DMs. One might note, that another interesting option would be to define the cost of each CS to be located according to the expected flow of citizens to the shop, or according to the expected area, as such, this analysis is suggested for future work.

Regarding the kiosks, similarly to the CSs, due to the lack of data provided by AMA, it was decided to perform a benchmark analysis based on several sources to estimate the kiosks' investment cost. One of the sources considered was the installation of a Citizen Spot (see section 2.2.3), which is similar to kiosks as it also involves the installation of technological equipment. According to the newspaper article published by *Público*, each Citizen Spot has an estimated cost between 6 000 and 7 000 euros (Lopes, 2014). Moreover, concerning the airline business, a self check-in airport kiosk in 2004 cost between $6 000 and $10 000 (Drennen, 2011). Furthermore, according to Morris & Perry, 2003, in a study conducted by the authors in different industries (music, manufacturing, and airport industries) the average cost of a standard IBM kiosk discussed in their study was approximately $6 700 each, including software and installation costs.

The cost of a kiosk is highly variable depending on the number and complexity of services to be integrated. With this in mind, knowing that the initial kiosks will not have an extreme complexity due to the learning curve of the citizens, based on the conducted benchmark analysis, the installation cost of a new kiosk is considered to be 6 500 €.

Closing Cost

The closing cost of a facility is another intricate parameter, as it is also dependent on several variables. In the event of the closure of a facility, one of the largest costs could be the cost of firing the personnel. However, this cost may not exist, as it is possible to reallocate the human resources to another facility or function, for example. Notwithstanding, a cost that is almost certain is the cost of emptying and cleaning the facility, as the equipment is either going to be disposed of or transferred to another location (which in turn has transportation costs involved). As it can be observed, the cost of closing a facility is highly dependent on the context. As such, it was decided along with the DMs that the closing cost should be defined as a percentage of the investment cost, and the value which was agreed upon was 10% of the initial investment, which, in this case, translates to 50 000 €.

Regarding our case study, the closure of kiosks is not considered because there are no initially existing kiosks in the network ($K_o = \{\ \}$), and thus, as restricted by constraints (12), new kiosks may open, but once opened, they cannot be closed until the end of the planning horizon. Hence, since the closure of kiosks is not allowed, their closing costs have not been estimated.

Operational Costs

As described in Chapter 4, the operational costs were divided into fixed and variable costs.

Concerning the fixed operational costs of a CS, AMA could only provide an average annual operational cost per square meter of 250 €. This average value included the costs (when applicable) of water, communications, electricity, cleaning, security, rent and condominium fees, maintenance and the management fee. In order to estimate the average operational fixed costs per CS we had to determine the average area per CS, which is 400 m^2. Thereby, we calculated the average annual operational fixed cost per CS multiplying the average cost per square meter by the average area per CS, resulting in the value of 100 000 € per shop per year.

Relatively to the variable operational costs of the CS, the sole cost component considered was the cost of personnel. AMA did not provide substantial data for this component, having only provided information regarding: the number of counters in the CS of *Laranjeiras*, the number of shifts worked per counter, and the cost of each shift. Given the information provided, it was decided to use the CS of *Laranjeiras* as a benchmark to estimate the variable operational cost of a CS. The reasoning developed can be observed in Table 7 and Table 8.

Table 7 - Calculation of the annual cost per counter of the CS of Laranjeiras

Calculation of the annual cost per counter	
Number of shifts per counter	3
Monthly cost per shift	600 €
Monthly cost per counter	1 800 €
Annual cost per counter	25 200 €

Each counter of the CS works with 3 shifts, which cost each 600 € per month, resulting in a monthly cost per counter of 1 800 € and in an annual cost of 25 200 € per counter (1800 €/month x 14 months).

Table 8 - Calculation of the price per transaction for the face-to-face channel

Calculation of the price per transaction	
Annual cost per counter	25 200 €
Number of counters	150
Annual personnel cost	3 780 000 €
Number of visits to the CS	1 200 000
Price per transaction	3,15 €

Knowing the annual cost per counter and knowing that in the CS of *Laranjeiras* there are approximately 150 counters, we calculated the annual personnel cost of 3 780 000 € (2 5200 €/counter x 150 counters). Following this, knowing that the CS had approximately 1 200 000 visits in 2017, we can estimate the price per transaction on the face-to-face channel, dividing the annual personnel cost by the number of visits of the CS, which results in the value of 3,15 € per transaction.

In relation to the kiosks as these facilities do not exist in the current network, there is no data regarding their operational costs. As such, we resorted to benchmark analyses in order to estimate their values. Concerning the variable operational costs for a kiosk, when comparing the costs per transaction of a self-service kiosk to the cost per transaction of a face-to-face service, in segments like the airline industry, the former can cost up to 20 times less than the latter (Castro, Atkinson, & Ezell, 2010; Drennen, 2011). In the authors' report, Castro et al. (2010), point out that the cost of checking in a passenger with an airline agent is approximately $3, while the cost of doing it at a kiosk is only $0,14. In general, self-service kiosks offer a much cheaper price per transaction, mainly due to the staff cost decrease.

The kiosks allow for less use of space which can lead to a decrease in customer congestion and an increase in the efficiency of other processes by using the liberated space for different purposes (Drennen, 2011). Concerning the staff costs, kiosks can replace the work of human resources, as an example, within the airline business, a self-service kiosk can replace 2,5 ticket agents (Drennen, 2011). Nonetheless, it is important to note that the decrease in staff cost may not necessary lead to staff cutting, in fact, the impact on employees should be minimal as they will be, most likely, redeployed to other functions, or even to assist the customers in using the kiosks (Caterinicchia, 2007).

Analyzing the benchmark, the cost per transaction in a kiosk could be up to 20 times less than the cost per transaction in the face-to-face channel, nonetheless we opted for a conservative approach and considered the cost per citizen served in a kiosk to be 10 times less than in a CS, in other words, the cost per transaction in a kiosk is 1/10 of the cost per transaction in a CS, which results in the value of 0,32 € per transaction (3,15 € /10).

Although the kiosks present much lower prices per transaction, representing a more attractive investment than the CSs, the investment must be analyzed carefully as there is a large initial investment needed, related to the development of software, and customization of the latter. These costs vary with the complexity and level of customization desired, as such, some examples are provided: in 2009, Newark Liberty International Airport installed six trial Self-Service Kiosks (SSK), with connection to ticketing systems in four international airlines, which had an initial cost of $200 000 (Drennen, 2011); another application of SSKs by a health company in the United States reported that the customer's registration times decreased from nearly 10 minutes, to only 2 minutes after one year since they began using SSKs. The company had to invest $750 000 over four years in order to make the application viable, but was pleased with the return on investment (Caterinicchia, 2007).

Besides the software investment cost, there are also costs related to the maintenance of these devices, which must be taken into consideration. Self-service kiosks are connected to networks which can experience system failures and service outages, and therefore companies must have systems in place that allow strategic planning for humans, financial and equipment resource planning (Weiss, 2006). Thereby, a team of human resources is usually necessary to maintain and be available throughout most part of the day in order to deal with possible breakdowns or malfunctions (Weiss, 2006). This is due to the fact that a SSK can only bring benefits if it works properly, otherwise, rather than improving customer experience, it will decrease customer satisfaction, and increase the complaints. Furthermore, it is important to note that when customers are not successful in using the SSK, or in solving their problem, they turn to the other available and more expensive channels (i.e. channels with higher costs per transaction) of the network to solve their problem. Therefore, even though the SSK channel has a low price per transaction, when the customers turn to other channels, the price per transaction becomes much higher, as it becomes the sum of the price per transaction at the kiosk, plus the price per transaction by telephone or face-to-face. Thus, the investment in maintenance and continuous improvement is of great importance, as it is essential to maintain the kiosks' low cost per transaction, and to maintain the customers' satisfaction.

In summary, the annual fixed costs of a kiosk involve the cost of maintenance of the software and hardware, and the investment in continuous improvement of the system, so it can be further optimized to be more effective and efficient in serving the citizen. According to the study performed by Morris & Perry, 2003, this annual fixed cost for a kiosk is around 10-15% of the initial investment.

Using this benchmark, it was necessary to estimate the total initial investment. The latter contemplates the investment in software and training of the staff, and the investment in hardware, which is calculated multiplying the number of kiosks by its unitary cost. The total hardware cost, preferably, should be calculated based on the real number of kiosks opened in a time period. Nonetheless, adding this constraint to the model would increase its computational difficulty, which due to time restrictions was not viable. Notwithstanding, we recognize this as an opportunity to be analyzed, and which could be interesting to perform in the future work. As this approach was not workable, we used a rationale to estimate the annual fixed cost. The line of thought may be followed observing Table 9.

Table 9 – Calculation of the required number of kiosks for a 70% occupation

Description	Value
Estimated total kiosk demand for 2019 (t=2)	2 489 058
Time per visit	15 min
Total time needed to serve the demand	37 335 870
Time availability per kiosk	15h/day x 60min/h x 7 day/week x 52 weeks/year = = 327 600 min/year
Number of kiosks needed	114
Number of kiosks needed for a 70% occupation	140÷0,7 ≈ 160

Knowing the estimated total kiosk demand for 2019 ($t = 2$) is 2 489 058 visits, and that it takes an average of 15 minutes for a citizen to be served at a counter (information provided by AMA), we conclude that it would take a total of 37 335 870 minutes to serve all the demand. The time availability of a kiosk is 327 600 minutes per year, as the strategy defined for the kiosks is for these to be opened in an extended schedule of 15 hours per day (for example from 7h00 to 22h00) and 7 days a week, all year. Thereby, if we divide the total time needed to serve the demand, by the time availability per kiosk, we obtain the number of kiosks needed to satisfy the demand, which, in this case, is approximately 114. It is important to note that if 114 kiosks were located, these would have a theoretical occupation of 100%. Therefore, as the previous scenario is unrealistic, it was decided that the number of kiosks should be dimensioned for a 70% occupation, resulting in approximately 160 kiosks.

Given the assumptions considered, the need to limit the total number of kiosks opened during the planning horizon arose, because given its lower costs, the model will locate kiosks in almost every candidate location as it is a more attractive alternative (due to its low costs) to improve the equity measure. However, when locating a high number of kiosks, their occupation drops significantly, with some of the kiosks reaching levels of 5% of occupation, which is not a feasible solution in real life. Thereby, for the reasons stated, the number of kiosks to be located was limited to 160 kiosks, so that each located kiosk would have a minimum occupation of 70%. This restriction was added to the model, translated by constraints (19), where NQ is the maximum number of kiosks to be located (160, in this case).

$$\sum_{k \in K} XQ_k^t = NQ \quad \forall\ t\ \in\ T \setminus \{1\} \tag{19}$$

Afterwards, we then had to impute the estimated annual fixed costs to the kiosks following a rationale which can be observed in Table 10.

Table 10 – Calculation of the estimated annual fixed cost per kiosk

Description	Value
Initial cost (software + training)	200 000 €
Initial hardware investment	6 500 € x 160 kiosks = = 1 040 000 €
Annual estimated fixed cost	(200 000 + 1 040 000) x 0,15 = = 186 000 €
Annual estimated fixed cost per kiosk	1 162,5 €

As mentioned, the annual estimated fixed cost was calculated based on the previously described benchmark, in which the cost to operate, upgrade and maintain the kiosk is considered to be a 15% of the total initial investment. As such, first, we had to define the initial cost for deployment of the kiosks network. Analyzing the benchmark analyses, we assumed that this initial cost would be 200 000 €, which includes the initial cost of purchasing the software, the fees paid to the systems integrators, as well as the training cost of training the internal staff (Morris & Perry, 2003). The initial hardware investment is obtained multiplying the kiosk investment cost (previously defined in the investment cost sub-section) by the number of kiosks. Finally, the estimated annual cost is 15% of the sum of the previous costs, thus totaling in 186 000 € per year, which divided by the 160 kiosks, results in an annual fixed cost per kiosk of 1 162,5 €. Following a conservative approach to account for the uncertainty of the values gathered from benchmark, the value used in the model was 1200 € per kiosk.

Success/failure rate (Citizen flow from kiosks to the CSs)

As previously mentioned, there is a percentage of the citizens that will visit the kiosks for a specific service, but who, due to any problem or unforeseen circumstance will not be able to be served according to their expectations or solve their problem at the kiosk and will have to resort to the citizen shop to do so. Due to the lack of information and data, we performed a benchmark analysis. According to McGovern, 2017, the percentage of failure rate is about 40% in the employment of SSKs, in other words, only 60% of the customers that visit a SSK are successfully served, meaning that the other 40% of the customers, will have to be redirected to another channel to complete their action.

Thus, in the case under study, the percentage of failure rate considered was of 40% in the first year, with an estimate 2% decrease each year, due to the learning curve of the citizens, and due to the continuous improvement to be employed.

Share of services offered at a kiosk

As described in section 4.2 , the developed model is a hierarchical model, in which the higher level facilities, the CSs, offer the full set of services, and the lower-level facilities, the kiosks, offer a percentage of those services, which are the less complex services, and those services that do not require human validation for security purposes. When discussing this topic with the DMs, the estimate value agreed upon for the percentage of services that would be offered at a kiosk in comparison to the CSs was 50%, in other words, in the first year, the kiosk will offer the possibility of providing half of the full set of services available at a CS. The estimated value of 50% is related to the fact that the higher the number of services, the higher the investment cost in software. Furthermore, on a continuous improvement perspective, the idea is to launch the kiosk with 50% of the services, in order to test their performance, and in order to better understand what works best for the citizens. Following that, based on the feedback from the citizens, the kiosk will then be improved each year, and more services will be added. The integration of new services in the kiosk is expected to grow 5% each year for the first 5 years, achieving a value of 60,8% at the end of the planning horizon. It is important to note that even in the long-term the share of services offered at a kiosk, most likely, will never reach 100%, as there are some services that due to security reasons will not be able to be offered at a kiosk, without human validation (at least considering the currently existing technology).

5.3 Results

The model previously described was developed as a multi-objective hierarchical model with the aim to build a Pareto curve with the Pareto solutions, in other words, a curve with the nondominated solutions which imply that an improvement in one objective is only possible with the deterioration of at least one of the other objectives. Nevertheless, due to time and computational restrictions this was not feasible, as the model had a large number of variables (1 051 674) and therefore took an extremely long time to identify the Pareto solutions.

As the model could not be ran in order to find the Pareto solutions, there were two possibilities: to minimize the total weighted average travel time, given different budget levels, or to minimize the total costs, given different equity targets. Within the scope of this dissertation, the first approach was chosen with the DMs, as it is the most realistic one, given the context. Furthermore, the second alternative would implicate the need for the definition of equity targets, and since these are not defined by the DMs, the second alternative became less attractive.

Given the above-mentioned restrictions, it was decided to use the model and the data previously described to study different scenarios. Thereby, the analysis of the results stemmed from two different type of analysis carried out:

- **I.** Comparison of the current state of the network, with an optimized state of the current network in terms of equity;
- **II.** Minimization of the total travel time given different budget levels defined.

5.3.1. Comparison of the Current Network with the Optimized Current Network

The first analysis carried out was the comparison between the current network of CSs and the hypothetical optimized current network. In other words, the hypothetical optimized current network is the network that would result from locating CSs in the same number of municipalities (50) but giving the model total freedom to choose these locations with the aim to maximize the equity of access. For this analysis, the costs were not taken into account, as the main objective of the analysis was to compare the networks in terms of equity in order to understand what the potential benefit of having the current network optimized could be.

The first step was to run the model for the current network, not allowing the model to open or close any facilities, in order to analyze the equity measure it presents. Currently, there are 51 shops located through Portugal, distributed throughout 50 different municipalities (the municipality of Lisbon has 2 CSs). In this analysis, the demand of the two CSs located in Lisbon has been grouped due to the simplification reasons explained above. The representation of the current network in the map of Portugal may be observed below in Figure 20-A.

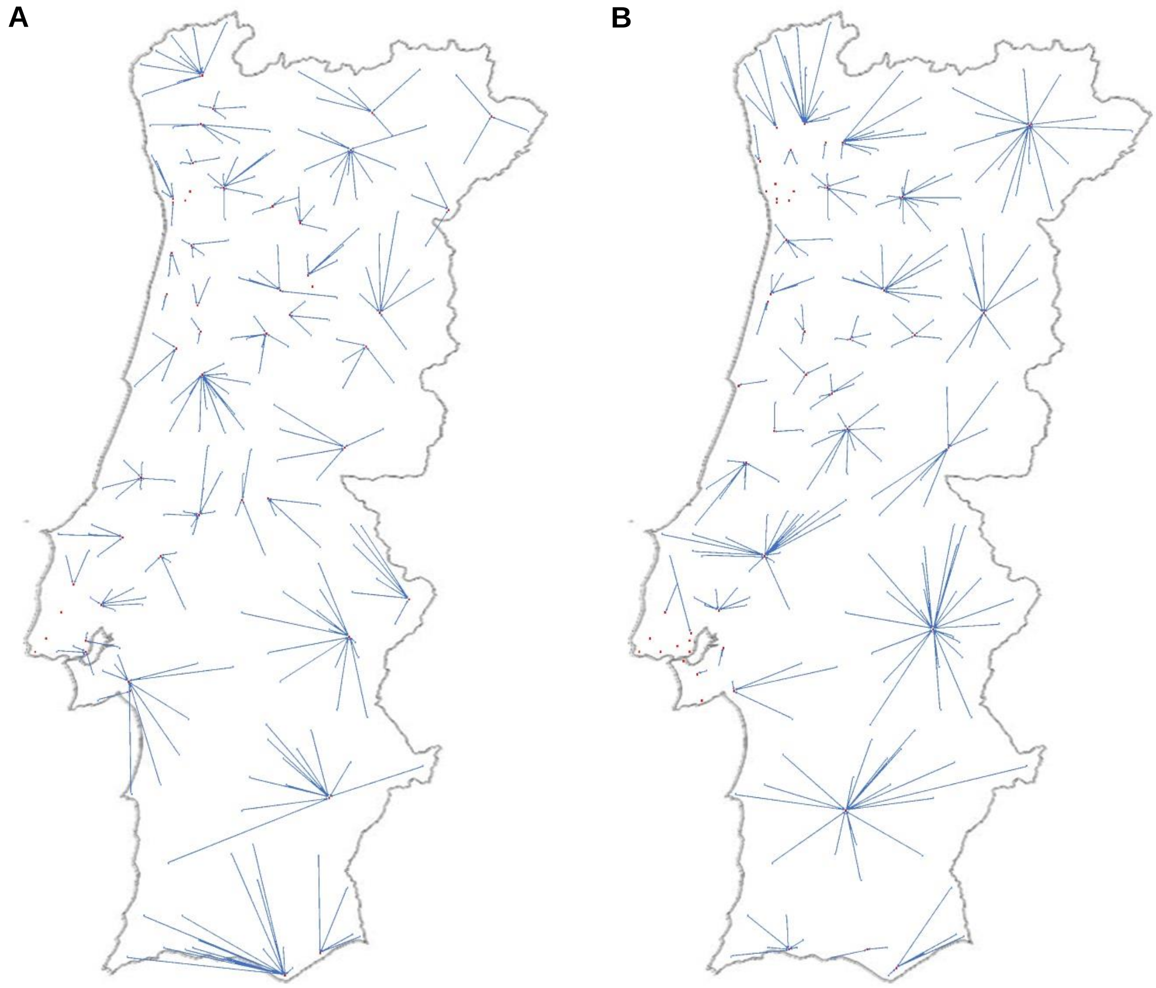
The second step was to run the model to generate the optimized current network, without considering any initial CSs located, in order to give the model the freedom to locate 50 shops while minimizing the total weighted average travel time of the citizens. Additionally, this determined which could be the best value of the equity measure for the location of 50 CSs. The representation of the optimized current network in the map of Portugal may be observed below in Figure 20-B.

Through the observation of the maps, we can see that in the areas of Porto and Lisbon, there are more CSs that only serve their own municipalities than in the rest of the country. Comparing the two maps and the output information of the model for the two situations, we can observe that in the optimized current network, the model creates “star-like” catchment areas for the CSs, which are located, whenever possible, in municipalities with a higher demand. This is due to the reason that the model minimizes the demand weighted average travel time, and thus, prioritizes the municipalities with a higher demand, and penalizes the municipalities with a lower demand.

There are 19 CSs in common between the current network and the optimized network. In Appendix 2 a list of the CSs located in the current network (Table 14) and in the optimized current network (Table 15) can be found.

Weighted average travel time per citizen

In Table 11 the information about the citizens’ travel time, both in the current and optimized networks, is summarized. The table presents four different travel time intervals, the number of citizens who belong to each time interval (and the percentage they represent of the total demand), and the weighted average travel time for the citizens in that travel time interval, for both networks. Furthermore, the table provides information regarding the comparison between the networks.



Legend: Citizen Shop

Demand point

Allocation of a demand point to a CS

Figure 20 - A: Location of the CSs in the current network; B: Location of the CSs in the optimized current network

Table 11 - Distribution of the population and weighted average travel time per travel time interval: comparison between the current network (CN) and the optimized current network (OCN)

Travel time, *min*	No. of citizens (% of the total demand)				Variation OCN vs. CN	Weighted average travel time, *min*		Variation OCN vs. CN
	CN		OCN			CN	OCN	
[12;124]	9 179 798	(100,0 %)	9 179 978	(100,0 %)	- %	21,89	16,29	- 20,10 %
[12; 30]	7 254 549	(79,0 %)	8 298 276	(90,4 %)	14,39 %	16,73	13,63	- 18,35 %
]30; 35]	653 822	(7,1 %)	361 361	(3,9 %)	- 44,73 %	32,80	33,17	1,13 %
]35; 40]	518 066	(5,6 %)	150 433	(1,7 %)	- 70,96 %	38,20	37,91	- 0,76 %
]40; 124]	753 361	(8,2%)	369 728	(4,0 %)	- 50,92 %	50,86	50,64	- 0,43 %

As shown in Table 11, in the current network each citizen must travel, on average, 21,89 minutes to arrive to a citizen shop, whereas in the optimized current network each citizen has to travel a shorter time of 16,29 minutes, on average. This represents a decrease of 20,10% of the weighted average travel time per citizen in relation to the current network.

Regarding the specific travel time interval of [12;30] minutes, the variations in relation to the current network are also positive (please note that negative variations are improvements in this case). In the current network, there are 7 254 549 citizens who travel between 12 and 30 minutes to a shop, and who represent 79,0% of the demand; within this group of citizens, on average, each citizen travels 16,73 minutes to a shop. In the optimized current network there are 8 298 276 citizens who travel between 12 and 30 minutes (inclusive) to a CS, and who represent 90,4% of the demand; within this group of citizens, on average, each citizen travels 13,63 minutes to a shop. As summarized in Table 11, in the optimized current network, there would be an increase of 14,39% of the number of citizens which would be at less than 30 min from a CS, and the weighted average travel time would decrease by 18,35% since the citizens would have an inferior weighted average travel time of 13,63 minutes for this time interval. However, one may also observe that for the travel time interval of]30;35] minutes, there is an increment on the weighted average travel time of 1,13 % when compared to the current network. Nonetheless, if we analyzed the variation in the number of citizens, there was a reduction of 44,73% of citizens who belong to this travel time interval, which means that overall, in spite of the slight increase in the average travelled time, the optimized current network still presents a better equity measure for this time interval. In the two remaining travel time intervals (between 35 and 40, inclusive, and above 40) the variations reveal improvements of 70,96% and 50,92% less citizens in these time intervals, respectively, which is a considerable gain even though the improvements in the weighted average travel time per citizen only decrease 0,76% and 0,43%, respectively.

The highest travel time in the current network is 115 minutes (1h55) which occurs in the municipality of *Odemira* whose demand is 3 993 citizens who must drive to the CS of *Serpa*. In the optimized current network, the highest travel time is 124 minutes (2h04), which occurs in the municipality of *Barrancos* whose demand is 269 citizens who must travel to the CS of *Aljustrel*. The fact that this value (124 minutes) is higher than the one observed in the current network (115 minutes), may be explained by the fact that the model minimizes the demand weighted average travel time, thus, it prioritizes the municipalities with a higher demand, and penalizes the municipalities with a lower demand. Since *Barrancos* is the municipality with the smallest demand of the network, it is, consequently, penalized resulting in a higher travel time.

Weighted average travel time per CS

An analysis of the weighted travel time per CS was also performed.

In the current network, the CS with the highest weighted average travel time is *Serpa*, which serves approximately 20 800 citizens from 12 municipalities (one of which, *Serpa* itself), and who must travel, on average, 55,15 minutes to reach the CS. On the other hand, there are 6 shops that only serve the citizens of their own respective municipality which are *Cascais, Gondomar, Mafra, Penalva do Castelo*, *Sintra* and *Valongo,* and thus the weighted average travel time for these municipalities is the minimum value of 12 minutes (as previously explained, 12 minutes was assumed to be the average travel time for the citizens of a municipality to travel to the CS of the same municipality).

In the optimized current network, the CS with the highest weighted average travel time is *Aljustrel*, which serves approximately 51 619 citizens from 18 municipalities (one of which, *Aljustrel* itself), who must travel, on average, 54,08 minutes to reach the CS. On the other hand, in this network, there are 14 shops that only serve the citizens of their own municipality which are *Almada, Amadora, Cascais, Gondomar, Lisboa, Maia, Matosinhos, Odivelas*, *Oeiras, Porto, Sesimbra, Sintra*, *Valongo* and *Vila Nova de Gaia,* and thus the weighted average travel time for these municipalities is the minimum value of 12 minutes.

In Figure 21 we may observe a histogram of the number of CSs contemplated in different weighted average travel time intervals, for the current network and for the optimized current network. As an example, in the current network there are currently 9 CSs with a weighted average travel time between 12 and 17 min (inclusive), which represent 18% of the total shops. On the other hand, one can conclude that, in the optimized current network, a higher number of CSs, namely 27, present a weighted average travel time between 12 and 17 minutes (inclusive), which correspond to 54% of the number of CSs. In the current network, 36% of the CSs have a weighted average travel time per shop of over 30 minutes, while in the optimized current network, only 12% of the CSs have a weighted average travel time per shop of over 30 minutes.

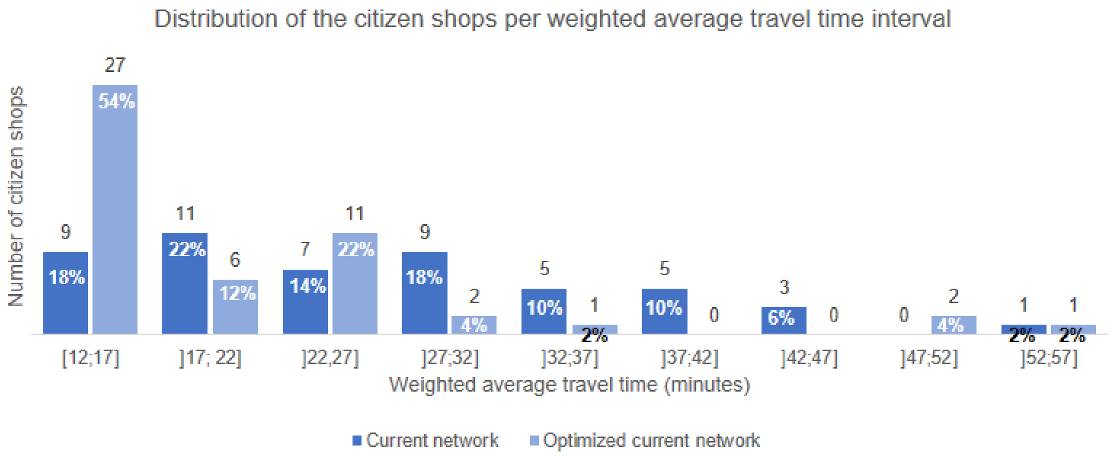


Figure 21 - Distribution of the citizen shops per weighted average travel time interval: comparison between the current network and the optimized current network

Additionally, as previously observed, it was noted that since the model minimizes the demand weighted average travel time, it tends to locate facilities in municipalities with a higher concentration of demand, and to penalize the municipalities with a smaller demand. As a result, some citizens must incur in considerably high travel times to access a facility (such as *Barrancos*). Given this particularity of the model and the analysis of the results, for a future work analysis it is suggested to analyze the results given by the model when a maximum travel time per citizen is imposed, so that no citizen is allowed to be further away from a facility than the value defined.

5.3.2. Model's Solutions considering Different Budget Restrictions

This subsection answers the planning question: how should the current network of CSs and kiosks evolve so that equity is maximized, given different levels of budget?

To define the budget levels to be studied, the model was ran first with no budget restriction, in order to determine the maximum level of equity that could be reached. This solution corresponds to the opening of all the CSs, one in each of the 278 municipalities (since there is no limitation to this number) and the opening of the maximum number of kiosks allowed, 160. It results in a weighted average travel time per citizen of 14,79 minutes and an approximate total cost of 419 million euros. Thereafter, the model was ran minimizing the total cost, resulting in the minimum cost of the network of approximately 167 million euros, which would correspond to the hypothetical situation of closing all the facilities, except for one that would serve all citizens. Both these scenarios, of opening or closing all the facilities are unrealistic, nevertheless, they are important to determine the minimum and maximum values of each variable. It is important to note that for the lowest cost of the network with only one CS located, the weighted average travel time was not determined due to time and computational restrictions, as in order to minimize both the cost and the traveled time, a large amount of time is required. Nonetheless, given the upper and lower bound defined for the cost, the first level of budget defined was of 295 M€, which is the level equally distant from the minimum and maximum cost, which were considered to be 170 and 420M€, respectively. Thereafter, two more budget levels in between the three existing ones were defined, forming four equal cost intervals. Hence, the budget levels defined were 232,5 M€, 295 M€ and 357,5M€.

In order to perform this analysis, it was necessary to add constraint to model the budget restriction. Thus, a constraint that limits the cost objective function (3) was added. If we denominate the cost function as z, and the budget as b, the constraint is written as $z \leq b$.

Running the model with this additional constraint for the defined budgets resulted in the solutions which are mapped in Figure 22. Solution A corresponds to the maximum hypothetical improvement of the equity measure for the network (minimum weighted average travel time). Solutions B, C and D correspond to the solutions for the budgets of 357,5 M€, 295 M€ and 232,5 M€, respectively.

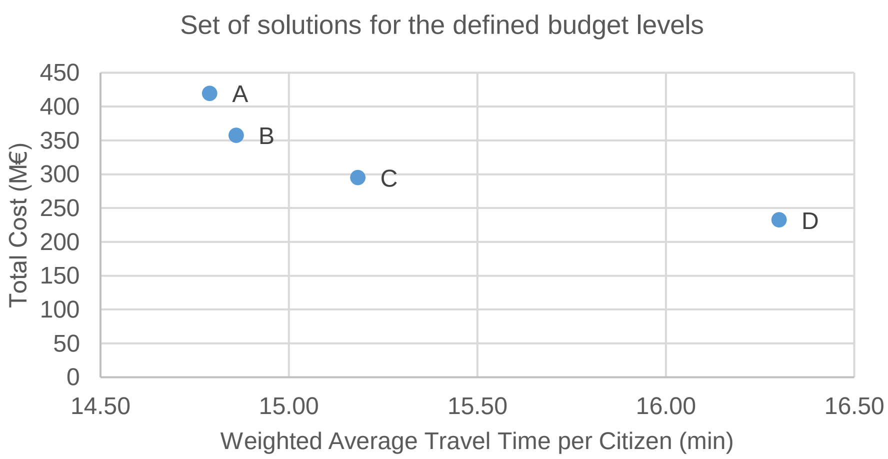


Figure 22 - Set of model's solutions for the defined budget levels

As previously mentioned, the attainment of the Pareto curve was not viable, and thus, the solutions presented in Figure 22 may be dominated solutions. In other words, for example, for a budget of 357,5M€, the weighted average travel time per citizen (TTPC) resulted in 14,86 min; since this solution may be dominated, it means that there might be a solution which reaches the same weighted average TTPC of 14,86 min but with a lower cost. The hypothetical solution that would reach 14,86 min of weighted average TTPC and the minimum cost to do so, would be the non-dominated solution.

Analyzing the graph, we can conclude that an increase of the budget from 232,5 to 295 M€ has a greater impact on the weighted average travel time per citizen, than an increase of the budget from 295 M€ to 357,5M€. This fact may be explained through the definition of marginal benefit. A marginal benefit represents the increase in total benefit when a unit of product is produced or consumed, in this case, the product being monetary units (Zhang et al., 2016). In accordance with the principle of marginal benefit, the marginal benefit decreases as the consumed product increases. As such, when the equity of access of the network is relatively high, there is little benefit in adding a new facility. On the other hand, when the network's equity of access is relatively low, adding a new facility can result in a large benefit (Zhang et al., 2016).

Analyzing Figure 22 we can observe that the budget increment from 232,5 M€ (solution D) to 295 M€ (solution C) results in an improvement from 16,30 min to 15,18 min in the weighted average TTPC, which corresponds to a decrease of 6,86% of the weighted average TTPC. Moreover, the budget increment from 295M€ (solution C) to 357,5 M€ (solution B) results in an improvement from 15,18 min to 14,80 min, which corresponds to a smaller decrease of the weighted TTPC, of 2,13%.

With the lowest budget level defined of 232,5 M€ (solution D) the model locates 47 new CSs and 160 kiosks in the first year (2019) and closes 12 of the existing CSs. In the two following years, one CS is closed per year, resulting in a final number of 83 CSs at the end of the planning horizon. It is important to recall that since there are no initially existing kiosks in the network, the model does not allow for the closure of kiosks, and thus, in all the scenarios analyzed, no kiosk will be closed. For simplification reasons, the closure of kiosks will not be referred to in the following analyses.

With the middle budget level of 295 M€ (solution C) the model locates 108 new CSs and 160 kiosks in the first year and closes 10 of the initially existing CSs, resulting in a final number of 148 CSs at the end of the planning horizon.

With the budget level of 357,5 M€ (solution B), 166 CS and 160 kiosks are located in the first period and 2 CSs are closed, then, on the following year, another CS is opened, resulting in a final number of 215 CSs at the end of the planning horizon.

Given the three budgets defined, it was decided to further analyze one of the solutions. The rationale used was based on the number of CSs to be opened during the planning horizon. Solution D would result in the opening of approximately 9 shops per year if the investment was phased throughout the planning horizon, while solution C would result in the opening of approximately 21/22 CSs per year if the investment was also phased. Initially, the identified solution to be further analyzed was solution D as it was the closest representation of the problem's reality. Nonetheless, when comparing the computational time for solution D to solution C, the former is approximately 2,5 times larger than the latter. As such, due to time restrictions, the chosen solution to be further analyzed was solution C.

In Figure 23 we can observe the network cost structure for solution C (corresponding to a budget of 295M€). Analyzing the graph, we can see that the largest component of the cost structure is the CSs' variable operational costs, which account for 52,5% of the budget. The second and third biggest components of the cost are the CSs' fixed operational costs, and the CSs' investment costs, with a percentage of 26,8 and 18,3% of the budget, respectively. Observing the graph, we may also conclude that the cost related to the kiosks represents a small percentage of the total costs. Summing all the costs for the kiosks, their accumulated percentage only represents 2,2% of the network costs. Within the kiosks' costs, the component with the largest weight is the variable operational costs of the kiosks, similarly to what was observed for the CSs.

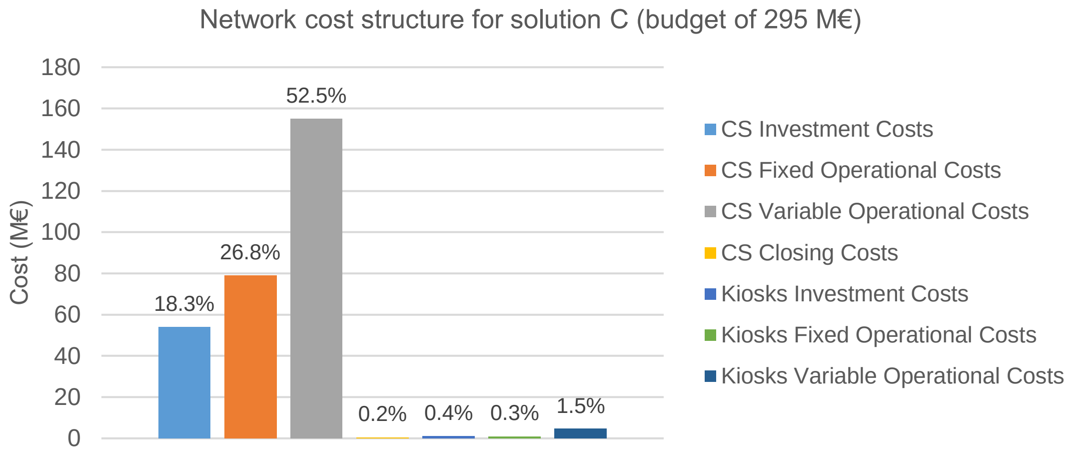


Figure 23 - Network cost structure for solution C (budget of 295 M€)

After having analyzed the graph in Figure 22, we observed that from solution D to solution C, there was a large improvement in the weighted average TTPC due to the higher marginal benefit of networks with lower equities of access. As such, it was decided to introduce and analyze another budget level of 265M€ in between the two budgets mentioned in order to explore an intermediate solution which would still bring considerable improvements on the weighted average TTPC, but with lower costs. In Figure 24 we may observe the solutions previously presented in Figure 22 with the additional solution for the budget of 265 M€ (solution E). In this solution, 79 CSs and 160 kiosks are located in the first time period and 13 CSs are closed, resulting in a final number of 116 CSs at the end of the planning horizon. This solution results in a weighted average TTPC of 15,59 minutes. Furthermore, this solution corresponds to an increase in cost of approximately 32,5 M€ relatively to solution D and corresponds to an improvement of the weighted average TTPC of 4,35% (correspondent to a decrease of the weighted average).

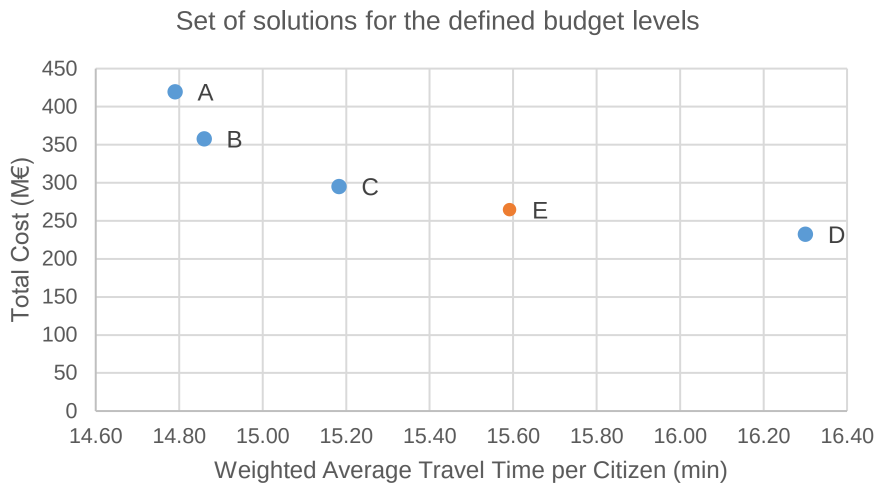


Figure 24 - Set of previously presented model's solutions for the defined budget levels with the additional budget level

Analyzing the graph in Figure 24, we can observe that the marginal benefit of the weighted average TTPC per monetary unit decreases as the budget increases. In other words, this means that the investment of an extra monetary unit in the first budget interval leads to a greater improvement in equity than adding an extra monetary unit in the second budget interval, and so forth. The marginal benefit of the different budget intervals may be observed in Figure 25, and it is observable that the marginal benefit decreases considerably as the budgets increase.

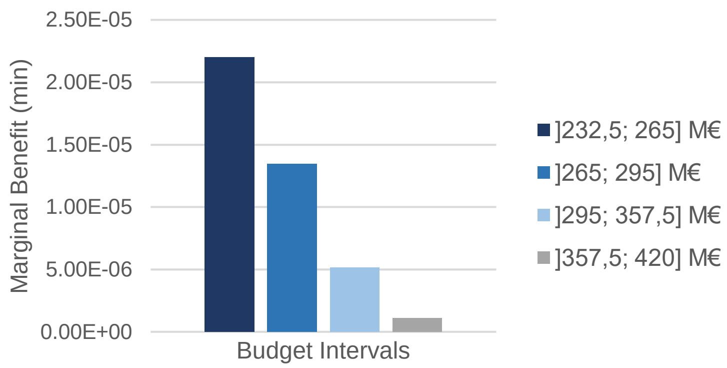


Figure 25 - Marginal benefit per budget interval

Additionally to the analyses performed, for future work, it is suggested to analyze the solutions that would result from running the model with budgets defined per year, instead of a sole budget for the entire planning horizon.

5.4 Sensitivity Analysis

In order to test the impact of the variation of certain parameters in the number and location of the facilities, in the cost structure, and in the recommendations resulting from the model, a sensitivity analysis was performed allowing us to comprehend the greater or less sensitivity of the solutions to the variation of the analyzed parameters.

Due to the reasons of computational time stated above (see section 5.3.2), it was decided to further the analysis of solution C (budget of 295 M€). As such, for consistency and continuity purposes, it was also decided to perform the sensitivity analysis for the same budget level of 295 M€. Thus, from hereafter, this scenario (solution C) will be identified as the base scenario, and thereby, the values henceforth presented are a comparison relatively to the base values used in the base scenario (solution C).

Some of the key input parameters and output values for the base scenario are summarized below in Table 12.

Table 12 – Key input and output values of the base scenario (solution C)

Inputs of the Base Scenario	
Demand (in relation to the estimated demand for 2017)	+2%
CSs investment cost	500 000 €
CSs fixed operational cost	100 000 €/year/CS
CSs variable operational cost	3,15 €/citizen
CSs closing cost	50 000 €/CS
Kiosks investment cost	6 500 €/kiosk
Kiosks fixed operational cost	1 200 €/year/kiosk
Kiosks variable operational cost	0,32 €/citizen

Outputs of the base scenario	
Weighted average travel time per citizen	15,18 min
Total Cost	294 981 €
Number of CSs to locate in the first period	108
Number of kiosks to locate in the first period	160
Number of CSs to close in the first period	10
Number of people served at CSs	43 721 671 + 5 460 136 = 49 181 807
Number of people served at Kiosks	14 244 887

As described in section 5.2 , the parameters were estimated given the historical data (when available) and based on the current defined strategy for the network. Nevertheless, several parameters were estimated based on benchmark analysis due to the lack of data provided and given that the model has a 5-year planning horizon, some of the parameters may vary with time in a different manner than predicted due to factors such as, the evolution of technology, propensity of the population to use the digital channel, political agenda, laws in force, inflation variation, among others. Hence, it is important to analyze how the variation of the key input parameters impact the solutions generated by the model.

The first sensitivity analysis performed is related to the expected increase (or decrease) of the total demand of the network (D_i^t). Additionally, analyzing the network cost structure in Figure 23, we can observe that the most critical component of cost due to its proportion of the total cost is the variable operational cost for the CSs ($vOCL_j^t$). Thereby, we performed a sensitivity analysis for each of the parameters, which are presented below. In each one of the analyses, the remaining input parameters of the base scenario are maintained.

Additionally, it is important to note that the solutions for the sensitivity analysis were determined with a relative gap of 0,01%. Due to time restrictions, given that the computational time function for the program to find the optimal solution is an inverse logarithmical function, the use of a relative gap of 0,01% (instead of 0,00%) largely reduced the computational time, while still providing good enough representative solutions.

Total Demand

As previously referred, the total demand, D_i^t, refers to the number of citizens from location i that need to visit a facility in time t.

As this parameter was estimated not only based on recent years, but also based on the services integration strategy defined for the future, there is some uncertainty related to the predicted increase of the demand of 2%, and therefore, it was considered important to verify the impact that the alteration of this parameter would have on the location and allocation of the facilities, and on the equity measure.

The results of the model were analyzed setting the demand variation to 0% (no increase or decrease of the demand per year compared to estimated demand for 2018), -2%, +4% and +6% per year in relation to the estimated demand for 2018 (Figure 26).

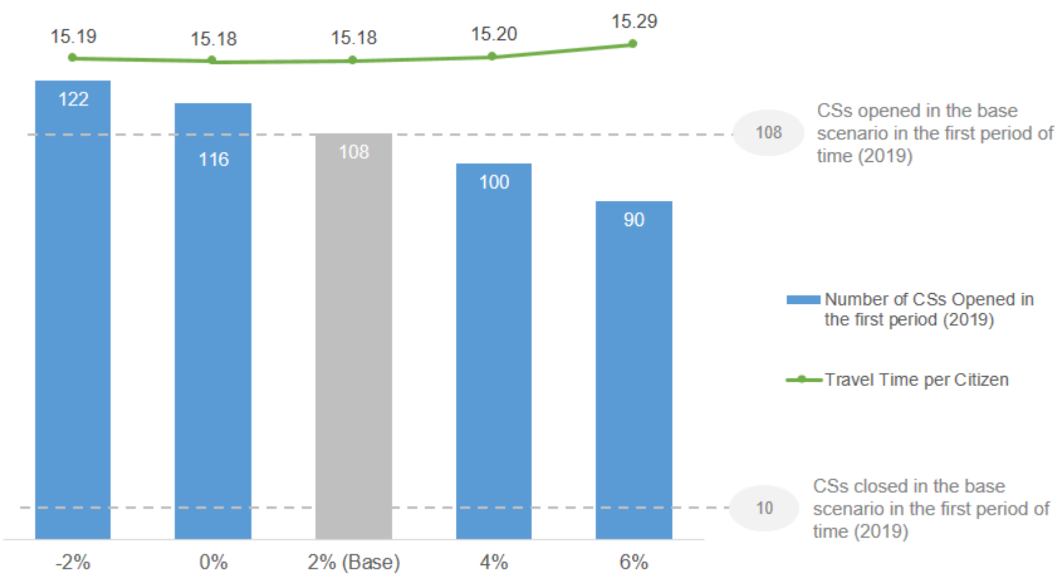


Figure 26 - Sensitivity analysis for the total demand parameter

In Figure 26 we may observe the results from the sensitivity analysis performed to the total demand. In this figure we can see that the lower the demand, the higher the number of CSs opened in the first period. This is due to the fact that the operational cost (unit cost per citizen served) is the most significant portion on the cost structure (see Figure 23), therefore, as the demand decreases, the variable costs portion decreases, and there is a larger portion of the budget which can be invested in the establishment of new CSs. Relatively to the number of kiosks, this number remains constant (160 kiosks opened in the first period) despite the demand variations. This is due the reason that the kiosks represent a more attractive option to increase the equity of access of the citizens, due to their low costs in comparison to the CSs. The value of the weighted average travel time remains approximately constant despite the demand variations, having the maximum increase of 0,71% (relatively to the base scenario) in the scenario where the demand increases 6% per year and in which only 90 CSs are installed, thus, causing the weighted average travel time per citizen to deteriorate slightly. Moreover, only one solution decreased the weighted travel time in 0,03% (namely the scenario where the demand increase is null). The demand variations of 0% and 4% led to variations of the weighted average TTPC of -0,03% and +0,14%, respectively. For demand variations of -2% and 6% it led to an increase of 0,07% and 0,71%, respectively, for the weighted average TTPC.

CSs' Variable Operational Costs

The variable costs of the CSs, $vOCL_j^t$, refer to the unit cost of serving one citizen in CS j in time t.

This parameter was estimated based on the average values provided by AMA and based on a benchmark analysis of one of the CSs. As such, there is some uncertainty related to the value of this parameter, and therefore, it was considered important to verify the impact that the variation of this parameter would have on the location and allocation of the facilities, and on the equity measure.

The variations of the parameter analyzed were of -5%, -2%, +2% and +5% relatively to the base scenario (Figure 27). It is important to note that by varying the operational cost of the citizen shops, the variable cost of the kiosks also varies, since the latter is equivalent to 1/10 of the former.

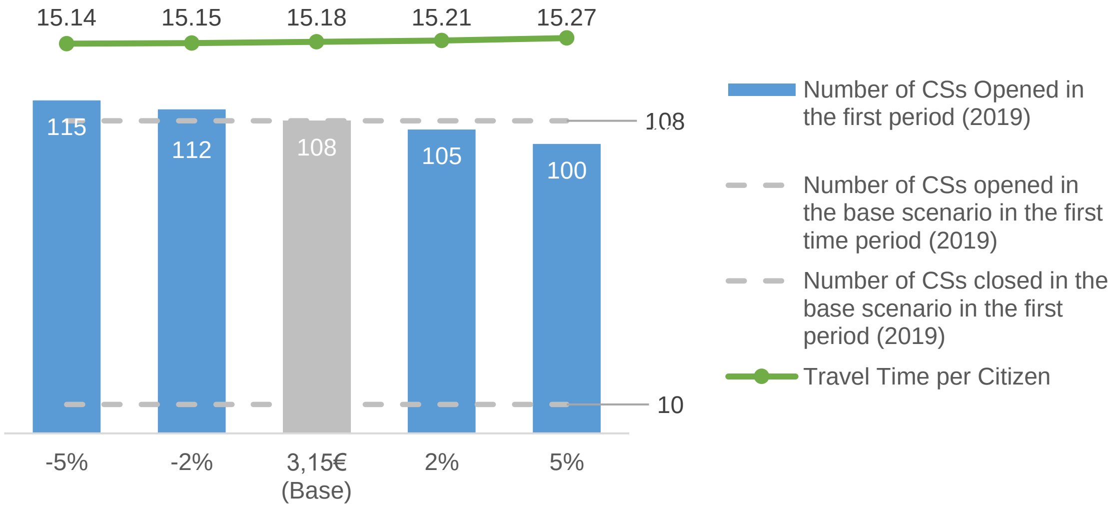


Figure 27 - Sensitivity analysis for the CSs's variable cost parameter

Analyzing Figure 27 we can observe that as the variable costs decrease, the number of CSs opened in the first period increases. This is due to the fact that, since the cost of serving one citizen decreases, a larger portion of the budget is available to invest in the installation of new CSs. Concerning the kiosks, the 160 kiosks are located for each of the scenarios, except for the +5% variation, in which only 158 kiosks are opened. This may be explained through the fact that this increase in the variable costs of the citizen shops and, consequently, of variable costs of the kiosks, leads to a greater use of the budget for operational costs, and a smaller share for investment.

In relation to the weighted average TTPC, this variable is improved as the variable costs are decreased. This fact is in accordance with the previous conclusion because, with lower variable costs, more CSs are located, which in turn, allow for the reduction of the weighted average TTPC. For variations of 2%

of the variable cost, the impact in the weighted average TTPC was of 0,19% for both positive and negative variations. For variations of 5%, the maximum impact was of +0,56% for positive variations (increase of 5% of the variable cost), and of 0,30% for negative variations (decrease of variable cost).

The variation of the predicted demand variation between -2% and 6%, would have a considerable impact on the number of CSs opened, namely causing an increase to 122 (+13%) and a decrease to 90 (-17%), respectively, from the baseline total number of 108.

The variation of the CSs variable operational costs in 5%, both negatively and positively, would also have a considerable impact on the number of CSs opened, namely causing an increase to 115 (+7%) and a decrease to 100 (-7%), respectively, from the baseline total number of 108.

The variation of the CSs variable operational costs have a greater impact on the average weighted TTPC than the variation of the predicted demand variation. Namely, for variations of 2% of the variable cost, the impact in the weighted average TTPC was of 0,19% for both positive and negative variations. For variations of 5%, the maximum impact was of +0,56% on the weighted average TTPC (declination due to the increase of the variable costs), and of -0,30% (improvement due to the decrease of the variable costs). The variation of the value of the weighted average travel time remains approximately constant despite the demand variations, having the maximum increase (declination) of 0,71%.

Given the sensitivity analysis and the observed variations, it is recommended that the estimation of the parameters be analyzed to a fuller extent, since as observed, even small variations of the parameters have a considerable impact in the solution recommended by the model. Furthermore, it is suggested as future work the performance of further sensitivity analyses of other parameters such as the fixed operational costs of CSs, and the investment cost of the CSs, since these also represent a considerable share in the cost structure, and thus, it would be interesting to better understand how these parameters may influence the recommended solutions.

5.5 Chapter Conclusions

In this chapter the application of the model to the case study presented by AMA was described.

As we were dealing with a problem inserted in a real-world context, we were confronted with a high complexity inherent to the problem. Thereby, the first necessary step was the definition of strategies to deal with the complexity of the problem, and therefore, assumptions and simplifications used were described thoroughly. The choice of the strategies was made with the aim of minimizing the impact that they have in the representativeness of the model, so that the results will continue to correctly inform the DMs. The adopted strategies to deal with the complexity of the amount and location accuracy of the demand points were described, as well as the strategies used for the means of transport and temporal aggregation. Besides the strategies mentioned, the data treatment was explained, highlighting the difficulties felt in gathering data, and the need to use several benchmark analyses to cope with this difficulty. Nevertheless, the data analysis and underlying assumptions of the input parameters were described, along with the line of thought that was followed to reach the values of the parameters.

Following the data treatment description, the results of the application of the model to the case study were presented. As such, the two types of analyses carried out were described: a comparison in terms of equity of the current state of the network, with an optimized state of the current network; and the analysis of the solutions obtained from different budget levels defined. Through the first analysis we could conclude that if the location of the CSs in the 50 current municipalities could be optimize, this would bring significant improvements of equity to the network as a whole, as the citizens would benefit from a decreased weighted average travel time to reach a facility. However, it is also important to note that analyzing the model and its results, since it minimizes the demand weighted average travel time, it tends to locate facilities on locations with a higher demand, and to penalize to some extent the demand points with a lower demand.

Concerning the second analysis of the model's solutions for different budget restrictions, we were able to map the different solutions and to observe how they relate to each other. As expected, a key take-way from the analysis, is that through the observation of the mapped solutions, we could see that the marginal benefit of equity decreases as the budget increases. This is due to the fact that for networks with lower equity levels, when investing in a new facility, it could bring great improvements of equity; on the other hand, for a network with a considerably high level of equity, investing in a new facility will only slightly increase the equity of the network.

To conclude, a sensitivity analysis was conducted in order to test the impact of the variation of certain parameters in the number and location of the facilities, in the cost structure, and in the recommendations resulting from the model. The sensitivity analysis allowed us to comprehend the greater or less sensitivity of the solutions to the variation of the analyzed parameters. Furthermore, the sensitivity analysis is important given the lack of provided data, which leads to a considerable uncertainty associated with the values established for the parameters. Moreover, given that we developed a multi-period model with a 5-year planning horizon, some of the parameters may vary with time in a different manner than predicted due to factors such as, the evolution of technology, propensity of the population to use the digital channel, political agenda, laws in force, inflation variation, among others. Hence, it is important to analyze how the variation of the key input parameters impact the solutions generated by the model.

Chapter 6 FINAL REMARKS AND FUTURE WORK

The improvement of the performance of public services in Portugal has been on the political agenda since 1980 and has led to the launch of the Public Administration Reform Program. This program has evolved throughout the years towards a citizen-oriented approach with a concern for service quality.

In this master's dissertation, a characterization and analysis of the problem and its context were presented, allowing us to observe the effort and developments made in order to update the obsolete administrative structures, and to develop an efficient public administration. From this characterization, it was possible to conclude that the public management reform has been a movement, relying on continuity of thinking, and building on previous work, regardless of political changes.

Within this context, the citizen assistance network, first established in 1999, more specifically the citizen shop channel, was studied to further detail. It was identified that one of the objectives for this channel is the expansion of the network in order to improve the distribution quality of the public services, increase the proximity to the citizen through a capillary network, and to improve the quality of the service, enhancing customer experience. Based on these objectives, and on the existing vision for the future, the study has drawn the need to develop a mathematical model in order to support the DMs to make an informed decision relating to the location of the new citizen shops and kiosks (possible new channel being explored).

In order to support the development of a mathematical model, we have conducted a review of the literature regarding facility location problems. From this review we concluded that facility location decisions are crucial strategic decisions for both private and public companies. They aim to choose the best location for the facilities, so that they can meet the customers demand in the best way possible while considering the trade-offs between costs and customer satisfaction. Thereby, these decisions have an important contribution to the success or failure of an organization.

Supported by the literature review, we developed a hierarchical multi-period model with aim to inform the decision of the DMs. The model was presented as having a hierarchical structure with lower-level facilities, the kiosks, and higher-level facilities, the citizen shops. The model was developed with the goal to define which lower and higher-level facilities to locate and when (during the planning horizon), in order to maximize the equity of access of the population while minimizing the expected costs of the network's alterations. The equity of the population was measured through the weighted average travel time per citizen.

The model was also developed to be analyzed as a multi-objective model in order to understand the tradeoffs between equity of access and cost, however, due to time and computational restrictions, this option was not viable. As such, the tradeoffs were addressed by mapping the model's solutions obtained from defining different budget levels, which provides the decision makers alternative solutions for planning, each of which can be further analyzed in the future if wanted. The model integrates a planning horizon allowing for the decisions of reorganization and expansion of the network to be phased throughout time.

This work contributes to the location of public facilities by addressing the planning of citizen service centers in the presence of a hierarchical structure, a planning horizon, and considering several features relevant in many real-world applications. The application of the model to the case study illustrates its applicability to a real-world context problem and demonstrates the nature of the results which can be obtained with the model.

Given the fact that we are dealing with a problem inserted in a real-world context, we were confronted with a high complexity inherent to the problem. Thereby, it was necessary to define several strategies to deal with the complexity of the problem, while minimizing the impact they have in the representativeness of the model, and in the correct recommendations that should arise from its application to inform the DMs. Besides the strategies adopted, the data treatment was also described, highlighting the difficulties felt in gathering data, and the need for using several benchmark analyses to cope with this difficulty. Nevertheless, the data analysis and underlying assumptions of the input parameters was described, along with the line of thought that was followed in order to reach the value for each parameter.

Following this description, the results of the application of the model to the case study were presented. As such, the two types of analyses carried out were described: a comparison in terms of equity of the current state of the network, with an optimized state of the current network; and the analysis of the solutions obtained from different budget levels defined. Through the first analysis we could conclude that if the location of the CSs in the 50 current municipalities could be optimize, this would bring significant improvements of equity to the network as a whole, as the citizens would benefit from a decreased weighted average travel time to reach a facility. However, it is also important to note that analyzing the model and its results, since it minimizes the demand weighted average travel time, it tends to locate facilities on locations with a higher demand, and to penalize to some extent the demand points with a lower demand. Concerning the second analysis of the model's solutions for different budget restrictions, we were able to map the different solutions and to observe how they relate to each other. As expected, a key take-way from the analysis, is that through the observation of the mapped solutions, we could see that the marginal benefit of equity decreases as the budget increases.

To conclude, a sensitivity analysis was conducted in order to test the impact of the variation of certain parameters in the number and location of the facilities, in the cost structure, and in the recommendations resulting from the model. The sensitivity analysis allowed us to comprehend the greater or less sensitivity of the solutions to the variation of the analyzed parameters. Moreover, given that we developed a multi-period model with a 5-year planning horizon, some of the parameters may vary with time in a different manner than predicted due to factors such as, the evolution of technology, propensity of the population to use the digital channel, political agenda, laws in force, inflation variation, among others. Hence, it is important to analyze how the variation of the key input parameters impact the solutions generated by the model.

6.1 Future Work

For the future development of this subject some improvement and analysis opportunities were identified as well as complementary factors that may be taken into consideration:

Firstly, the equity measure defined for the model was the weighted average travel time. In order to have a more accurate measure of equity, the time parameter could account, not only for the travel time, but also include the waiting time at a facility, especially if this value varies accordingly to the facility visited.

Secondly, a more extensive study and estimation of the demand is suggested, as this is an intricate parameter which depends on several different constraints, such as the opening of neighboring shops, the propensity that a citizen has to visit the shops, the laws in force in a given year, the amount of entities represented at the CS, the integration of other surrounding public services, political decisions, among others. Thereby, a further study of this input parameter could lead to more accurate results, or to further understand how the demand impacts the results.

Thirdly, it would be interesting to explore the option of defining the cost of each facility to be located according to the expected flow of citizens, or according to the expected area of the facility, and to analyze how this possibility would impact the results.

Fourthly, the possibility of calculating the fixed costs for the kiosks based on the real number of kiosks opened in a time period should be explored.

Fifthly, given that the model benefits municipalities with a higher demand, and penalizes smaller demand points, it is recommended as future work to analyze the results provided by the model when a maximum travel time per citizen is imposed, so that no citizen is allowed to be further away from a facility than the defined value.

Sixthly, it is suggested to analyze the solutions that would result from running the model with budgets defined per year, instead of a sole budget for the entire planning horizon, in order to understand the impact of this variation in the costs and in the equity measure.

Seventhly, it would be interesting to run the model in order to obtain the curve with the non-dominated Pareto solutions, and to be able to, more accurately, trace the tradeoffs between equity and cost, to better understand the benefit that could be attained with each solution.

6.2 Managerial Insights

As previously mentioned, there was few available data from AMA at the time of the writing of this dissertation. Therefore, it is imperative that a greater gathering of real data is done, in order for the model to provide more accurate and representative solutions.

Once these data is collected, and the model has provided a representative recommendation for the network (for the latter data), it is then suggested, based on the developed work, that AMA performs a more in-depth analysis and estimation of the input parameters for the model, since as observed in the sensitivity analysis, even small variations of these parameters' values have a considerable impact in the recommended solutions.

It is further recommended that AMA invests in the installation of kiosks, since these are an attractive alternative (given their low overall cost) to improve the equity of access of the citizens with lower costs.

References

Agência Lusa. (2016). Governo vai manter programa de expansão das lojas do Cidadão. Retrieved from https://www.tsf.pt/sociedade/interior/governo-vai-manter-programa-de-expansao-das-lojas-do-cidadao-5556868.html

Agência Lusa. (2017). Torres vedras inaugura loja do cidadão na Segunda-feira. Retrieved from https://www.dn.pt/lusa/interior/torres-vedras-inaugura-loja-do-cidadao-na-segunda-feira-8665208.html

Agência Lusa. (2018a). Loja de Cidadão de Valpaços representa investimento de 650 mil euros. Retrieved from https://www.dn.pt/lusa/interior/loja-de-cidadao-de-valpacos-representa-investimento-de-650-mil-euros-9057793.html

Agência Lusa. (2018b). Número de Lojas do Cidadão quase que duplicará em quatro anos. Retrieved from https://www.jornaldenegocios.pt/economia/detalhe/numero-de-lojas-do-cidadao-quase-que-duplicara-em-quatro-anos

Ahmadi-Javid, A., Seyedi, P., & Syam, S. S. (2017). A survey of healthcare facility location. *Computers and Operations Research*, *79*, 223–263. https://doi.org/10.1016/j.cor.2016.05.018

AMA. (2016). AMA - Agência para a Modernização Administrativa. Retrieved April 22, 2018, from https://www.ama.gov.pt/web/agencia-para-a-modernizacao-administrativa/a-ama

AMA. (2018). *Plano de Atividades 2018*. Retrieved from https://www.ama.gov.pt/web/agencia-para-a-modernizacao-administrativa

Antunes, A., & Peeters, D. (2001). On solving complex multi-period location models using simulated annealing. *European Journal of Operational Research*, *130*(1), 190–201. https://doi.org/10.1016/S0377-2217(00)00051-5

Arabani, A. B., & Farahani, R. Z. (2012). Facility location dynamics: An overview of classifications and applications. *Computers and Industrial Engineering*, *62*(1), 408–420. https://doi.org/10.1016/j.cie.2011.09.018

Barbati, M., & Piccolo, C. (2016). Equality measures properties for location problems. *Optimization Letters*, *10*(5), 903–920. https://doi.org/10.1007/s11590-015-0968-2

Câmara Municipal de Sintra. (2016). Nova Loja do Cidadão no Cacém. Retrieved September 15, 2018, from http://www.cm-sintra.pt/nova-loja-do-cidadao-no-cacem

Canel, C., Khumawala, B. M., Law, J., & Loh, A. (2001). An algorithm for the capacitated, multi-commodity multi-period facility location problem. *Computers and Operations Research*, *28*(5), 411–427. https://doi.org/10.1016/S0305-0548(99)00126-4

Cao, W., Çelik, M., Ergun, Ö., Swann, J., & Viljoen, N. (2016). Challenges in service network expansion: An application in donated breastmilk banking in South Africa. *Socio-Economic Planning Sciences*, *53*, 33–48. https://doi.org/10.1016/j.seps.2015.10.006

Cardoso, J. (2012). *Da Reforma Administrativa ao e-government*. Faculdade de Letras da Universidade de Lisboa.

Cardoso, T., Oliveira, M. D., Barbosa-Póvoa, A., & Nickel, S. (2015). An integrated approach for planning a long-term care network with uncertainty, strategic policy and equity considerations. *European Journal of Operational Research*, *247*(1), 321–334. https://doi.org/10.1016/j.ejor.2015.05.074

Cardoso, T., Oliveira, M. D., Barbosa-Póvoa, A., & Nickel, S. (2016). Moving towards an equitable long-term care network: A multi-objective and multi-period planning approach. *Omega*, *58*, 69–85. https://doi.org/10.1016/j.omega.2015.04.005

Castro, D., Atkinson, R., & Ezell, S. (2010). *Embracing the Self-Service Economy*.

Caterinicchia, D. (2007). Self-service Economy Arrives Gradually. *The Washington Post*. Retrieved from http://www.washingtonpost.com/wp-dyn/content/article/2007/08/02/AR2007080201193.html??noredirect=on

Church, R. L., & ReVelle, C. S. (1976). Theoretical and Computational Links between the p-Median, Location Set-covering, and the Maximal Covering Location Problem. *Geographical Analysis*, *8*(4), 406–415. https://doi.org/10.1111/j.1538-4632.1976.tb00547.x

Council of Ministers Resolution no. 87/2008 of May 27th, Pub. L. No. Diário da República, 1.ª série — N.º 101 — 27 de Maio de 2008 (2008). Retrieved from https://dre.pt/application/conteudo/449195

Daskin, M. S. (1995). *Network and Discrete Location: models, algorithms, and applications*. (R. L. Graham, J. K. Lenstra, & R. E. Tarjan, Eds.). New York: John Wiley & Sons.

Daskin, M. S. (2008). What You Should Know About Location Modeling. *Naval Research Logistics*, *55*(4), 283–294. https://doi.org/10.1002/nav.20284

Decree-Law no. 105/2017 of August 29th, Pub. L. No. Diário da República: 1.ª série, N.º 166, 5194 (2017). Portugal.

Decree-Law no. 74/2014 of May 13th, Pub. L. No. Diário da República: 1.ª série, N.º 91, 2765 (2014). Portugal.

Distâncias entre cidades. (n.d.). Retrieved September 5, 2018, from http://www.distanciasentrecidades.com/

Drennen, H. (2011). *Self Service Technology in Airports And the Customer Experience*. Univeristy of Nevada, Las Vegas.

European Comission. (2016). eGovernment Benchmark 2016. https://doi.org/10.2759/002688

European Comission. (2017). eGovernment Benchmark 2017. Retrieved April 28, 2018, from https://www.capgemini.com/wp-content/uploads/2017/11/2017-egovernment-benchmark_background_v7.pdf

Eurostat. (2018). Internet access and use statistics - households and individuals. Retrieved April 29, 2018, from http://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:Internet_access_and_use_statistics_-_households_and_individuals

Fredriksson, A. (2017). Location-allocation of public services – Citizen access, transparency and measurement. A method and evidence from Brazil and Sweden. *Socio-Economic Planning Sciences*, *59*, 1–12. https://doi.org/10.1016/J.SEPS.2016.09.008

Gouveia, L. B. (2004). *Local e-Government: a Governação Digital na Autarquia*. (SPI - Sociedade Portuguesa de Inovação, Ed.). SPI - Principia. Retrieved from https://bdigital.ufp.pt/bitstream/10284/263/1/livro_egov.pdf

Haase, K., & Müller, S. (2013). Management of school locations allowing for free school choice. *Omega*, *41*(5), 847–855. https://doi.org/10.1016/j.omega.2012.10.008

Khodaparasti, S., Maleki, H. R., Bruni, M. E., Jahedi, S., Beraldi, P., & Conforti, D. (2016). Balancing efficiency and equity in location-allocation models with an application to strategic EMS design. *Optimization Letters*, *10*(5), 1053–1070. https://doi.org/10.1007/s11590-015-0929-9

Lopes, M. (2014). Cada Espaço do Cidadão vai custar entre 6000 e 7000 euros. Retrieved from https://www.publico.pt/2014/01/08/politica/noticia/cada-espaco-do-cidadao-vai-custar-entre-6000-e-7000-euros-1618874

Madureira, C., & Ferraz, D. (2010). The Need of a XXI Century Governance Paradigm for Public Administration: The Specific Case of Portugal. *Public Policy and Admnistration*, *31*, 35–48. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=16482603&AN=49010027&h=yQW%2BGR4TAdPxUH5%2FHkmHoe9zw4LUfnJS3rJ6WFfyfW%2F7vYvrb2FCp8WWCRKHyDMQfrsbrmEPFH%2F4efRHyrtfLw%3D%3D&crl=c

Marianov, V., & Serra, D. (2002). Location Problems in the Public Sector. In Z. Drezner & H. Hamacher (Eds.), *Facility Location: Applications and Theory*. Springer, Berlin. https://doi.org/10.1007/978-3-642-56082-8

Marsh, M. T., & Schilling, D. A. (1994). Equity measurement in facility location analysis: A review and framework. *European Journal of Operational Research*, *74*(1), 1–17. https://doi.org/10.1016/0377-2217(94)90200-3

Martins, L. (2009). *A Loja do Cidadão de Aveiro e a Reforma da Administração Pública*. Universidade de Aveiro.

McGovern, G. (2017). Business case for digital self-service. Retrieved September 20, 2018, from https://medium.com/@gerrymcgovern/business-case-for-digital-self-service-72a030cd4772

Melo, M. T., Nickel, S., & Saldanha-da-Gama, F. (2009). Facility location and supply chain management - A review. *European Journal of Operational Research*, *196*(2), 401–412. https://doi.org/10.1016/j.ejor.2008.05.007

Mestre, A. M., Oliveira, M. D., & Barbosa-Póvoa, A. P. (2015). Location-allocation approaches for hospital network planning under uncertainty. *European Journal of Operational Research*, *240*(3), 791–806. https://doi.org/10.1016/j.ejor.2014.07.024

Mitropoulos, P., Mitropoulos, I., Giannikos, I., & Sissouras, A. (2006). A biobjective model for the locational planning of hospitals and health centers. *Health Care Management Science*, *9*(2), 171–179. https://doi.org/10.1007/s10729-006-7664-9

Morris, G., & Perry, R. (2003). *Realizing the Business Benefits of Kiosks*.

Município Arruda dos Vinhos. (2016). Arruda dos Vinhos terá Loja do Cidadão já em 2016. Retrieved September 15, 2018, from http://www.cm-arruda.pt/Arruda-dos-Vinhos-tera-Loja-do-Cidadao-ja-em-2016

Município da Batalha. (2017). Batalha inaugura primeira Loja do Cidadão da região. Retrieved from http://www.cm-batalha.pt/noticias/batalha-inaugura-primeira-loja-do-cidadao-da-regiao

Município de Sardoal. (2018). Loja do Cidadão. Retrieved September 15, 2018, from http://www.cm-sardoal.pt/index.php/viver/loja-do-cidadao

Murray, A. T. (2013). Optimising the spatial location of urban fire stations. *Fire Safety Journal*, *62*(PART A), 64–71. https://doi.org/10.1016/j.firesaf.2013.03.002

Narula, S. C. (1986). Minisum hierarchical location-allocation problems on a network: A survey. *Annals of Operations Research*, *6*(8), 255–272. https://doi.org/10.1007/BF02023745

Neves, P. (n.d.). Agency for the Public Services Reform - The Portuguese Approach. Retrieved May 1, 2018, from http://infoter.eu/attachment/0022/21768_paulo_neves.pdf

Núñez Ares, J., de Vries, H., & Huisman, D. (2016). A column generation approach for locating roadside clinics in Africa based on effectiveness and equity. *European Journal of Operational Research*, *254*(3), 1002–1016. https://doi.org/10.1016/J.EJOR.2016.04.031

OECD. (1996). Putting Citizens First: Portuguese Experience in Public Management Reform No. 13. *Public Management Occasional Papers*. Paris: OECD Publishing. https://doi.org/10.1787/20743718

OECD. (2013a). ICT Access and Usage by Households and Individuals. Retrieved April 30, 2018, from http://stats.oecd.org/Index.aspx?DataSetCode=ICT_HH2

OECD. (2013b). Portugal: Reforming the State to Promote Growth. Paris: OECD Publishing. https://doi.org/10.1787/9789264207981-en

OECD. (2018). Working age population (indicator). https://doi.org/10.1787/d339918b-en

Owen, S. H., & Daskin, M. S. (1998). Strategic facility location: A review. *European Journal of Operational Research*, *111*(3), 423–447. https://doi.org/10.1016/S0377-2217(98)00186-6

PRACE. (2006). *Modelo de Reestruturação da Administração Central do Estado*. Retrieved from http://asficpj.pt/images/documentos/estudos/Modelo_PRACE.pdf

Proposta de Lei n.º 99/XIII, Pub. L. No. Proposta de Lei n.º 99/XIII (2018). Portugal. Retrieved from http://app.parlamento.pt/webutils/docs/doc.pdf?path=6148523063446f764c324679595842774f6a63334e7a637664326c756157357059326c6864476c3259584d7657456c4a535339305a58683062334d76634842734f546b7457456c4a5353356b62324d3d&fich=ppl99-XIII.doc&Inline=true

ReVelle, C. S., & Eiselt, H. . (2005). Location analysis: A synthesis and survey. *European Journal of Operational Research*, *165*(1), 1–19. https://doi.org/10.1016/j.ejor.2003.11.032

ReVelle, C. S., Eiselt, H. A., & Daskin, M. S. (2008). A bibliography for some fundamental problem categories in discrete location science. *European Journal of Operational Research*, *184*(3), 817–848. https://doi.org/10.1016/j.ejor.2006.12.044

Serra, D., & Marianov, V. (2004). New Trends in Public Facility Location Modeling. *SSRN Electronic Journal*, 1–48. https://doi.org/10.2139/ssrn.563843

Smith, H. K., Harper, P. R., & Potts, C. N. (2013). Bicriteria efficiency/equity hierarchical location models for public service application. *Journal of the Operational Research Society*, *64*(4), 500–512. https://doi.org/10.1057/jors.2012.68

Sobre o Portal. (2015). Retrieved April 24, 2018, from https://www.portaldocidadao.pt/pt/sobre-o-portal

Swan, W. A. (2010). The Cost of Closing a Business on Short Notice. Retrieved September 19, 2018, from https://www.brighthub.com/office/entrepreneurs/articles/49025.aspx van den Berg, P. L., Legemaate, G. A. G., & van Der Mei, R. D. (2017). Increasing the Responsiveness of Firefighter Services by Relocating Base Stations in Amsterdam. *Interfaces*, *47*(4), 352–361. https://doi.org/10.1287/inte.2017.0897

Wang, J., Liu, H., An, S., & Cui, N. (2016). A new partial coverage locating model for cooperative fire services. *Information Sciences*, *373*, 527–538. https://doi.org/10.1016/j.ins.2016.06.030

Weber, A. (1909). *Uber den Standort der Industrien (Alfred Weber's Theory of the Location of Industries)*. J.C. B. Mohr.

Weiss, D. (2006). Analysis: kiosk uptime, revenue. Retrieved September 15, 2018, from https://www.aviationpros.com/article/10382726/analysis-kiosk-uptime-revenue

What Is Simplex ? (n.d.). Retrieved May 1, 2018, from http://historico.simplex.gov.pt/downloads/whatissimplex.pdf

Yan, S., Lin, J.-R., Chen, Y.-C., & Xie, F.-R. (2017). Rental bike location and allocation under stochastic demands. *Computers & Industrial Engineering*, *107*, 1–11. https://doi.org/10.1016/J.CIE.2017.02.018

Zhang, W., Cao, K., Liu, S., & Huang, B. (2016). A multi-objective optimization approach for health-care facility location-allocation problems in highly developed cities such as Hong Kong. *Computers, Environment and Urban Systems*, *59*, 220–230. https://doi.org/10.1016/j.compenvurbsys.2016.07.001

Appendix 1 – Synthesis of the papers reviewed

Table 13 - Synthesis of the papers reviewed

Authors	Public vs. Private	Static vs. Dynamic	Single vs. Multi-objective	Hierarchical vs. Single-level	Deterministic vs. Stochastic	Capacitated vs. Uncapacitated	Resolution method
Citizen Service Centers							
(Fredriksson, 2017)	Public (Citizen service centers)	Static	Single objective	Single-level	Deterministic	Uncapacitated	Exact Method
Health Care							
(T. Cardoso et al., 2015)	Public (LTC)	Dynamic	Single-objective	Hierarchical	Stochastic	Capacitated	Exact Method
(Mestre et al., 2015)	Public (Hospital)	Dynamic	Multi-objective	Hierarchical	Stochastic	Capacitated	Exact Method
(Khodaparasti et al., 2016)	Public (EMS services)	Static	Multi-objective, combine with use of data envelopment analysis	Single-level	Stochastic (response time) through the incorporation of a risk averse approach	Capacitated	Exact Method
(Núñez Ares, de Vries, & Huisman, 2016)	Public (Clinics)	Static	Single Objective	Single-level	Stochastic	Capacitated	Exact Method
(T. Cardoso et al., 2016)	Public (LTC)	Dynamic	Multi-objective	Single-level	Deterministic	Capacitated	Exact Method
(Zhang et al., 2016)	Public (Health care facilities)	Static	Multi-objective	Single-level	Deterministic	Capacitated	Non-exact Method

Authors	Public vs. Private	Static vs. Dynamic	Single vs. Multi-objective	Hierarchical vs. Single-level	Deterministic vs. Stochastic	Capacitated vs. Uncapacitated	Resolution method
Fire Protection							
(Murray, 2013)	Public (Fire stations)	Dynamic	Single Objective	Single-level	Deterministic	Uncapacitated	Exact Method
(Wang, Liu, An, & Cui, 2016)	Public (Fire service facilities)	Static	Single Objective	Single-level	Deterministic	Capacitated	Exact Method
(van den Berg et al., 2017)	Public (Vehicles' base stations)	Static	Single Objective	Single-level	Deterministic	Capacitated	Exact Method
Schools							
(Antunes & Peeters, 2001)	Public (School network)	Dynamic	Single-objective	Single-level	Deterministic and stochastic	Capacitated	Non-exact Method
(Haase & Müller, 2013)	Public (School network)	Static	Single-objective	Single-level	Stochastic	Capacitated	Exact Method
Others							
(Canel, Khumawala, Law, & Loh, 2001)	-	Dynamic	Single-objective	Hierarchical	Deterministic	Capacitated	Exact Method
(Cao, Çelik, Ergun, Swann, & Viljoen, 2016)	Public (Donated breastmilk distribution)	Static	Multi-objective	Hierarchical	Stochastic	Capacitated	Non-exact Method
(Yan, Lin, Chen, & Xie, 2017)	Public (Rental bikes)	Static	Single objective	Single-level	Deterministic and Stochastic	Capacitated	Deterministic: Exact method Stochastic: Non-exact Method

Appendix 2 – Citizens' weighted average travel time to the CSs in the current and optimized current network

Table 14 – Citizens' weighted average travel time to the CSs in the current network, sorted from smallest to largest value

#	Citizen Shop	Weighted Average travel time of the citizens to the CS	#	Citizen Shop	Weighted Average travel time of the citizens to the CS
1	Cascais	12,00	26	Arruda dos Vinhos	26,52
2	Gondomar	12,00	27	Batalha	26,56
3	Mafra	12,00	28	Castelo Branco	27,04
4	Penalva do Castelo	12,00	29	Coimbra	27,44
5	Sintra	12,00	30	Nelas	28,43
6	Valongo	12,00	31	Cantanhede	28,79
7	Vila Nova de Gaia	13,35	32	Tavira	28,88
8	Aveiro	16,23	33	Guarda	30,61
9	Torres Vedras	16,84	34	Resende	30,97
10	Odivelas	17,43	35	Tarouca	31,53
11	Ovar	18,12	36	Rio Maior	31,56
12	Anadia	18,81	37	Carregal do Sal	33,82
13	Lisboa	19,01	38	Belmonte	35,65
14	Águeda	19,63	39	Sardoal	35,71
15	Setúbal	20,26	40	Palmela	36,22
16	Viseu	20,63	41	Campo Maior	36,82
17	Santo Tirso	20,83	42	Ponte da Barca	39,22
18	São João da Madeira	21,22	43	Faro	40,56
19	Santarém	21,50	44	Valpaços	40,74
20	Porto	21,83	45	Murça	41,20
21	Sátão	22,38	46	Mação	41,29
22	Vila Nova da Barquinha	23,99	47	Borba	44,56
23	Amares	24,14	48	Freixo de Espada à Cinta	46,26
24	Penafiel	25,34	49	Vimioso	46,77
25	Braga	26,19	50	Serpa	55,15

Table 15 – Citizens' weighted average travel time to the CSs in the optimized current network, sorted from smallest to largest value

#	Citizen Shop	Weighted Average travel time of the citizens to the CS	#	Citizen Shop	Weighted Average travel time of the citizens to the CS
1	Almada	12,00	26	Coimbra	16,42
2	Amadora	12,00	27	Vila do Conde	16,94
3	Cascais	12,00	28	Vila Nova de Famalicão	17,05
4	Gondomar	12,00	29	Pombal	18,74
5	Lisboa	12,00	30	Anadia	19,12
6	Maia	12,00	31	Vila Franca de Xira	20,37
7	Matosinhos	12,00	32	Loulé	20,77
8	Odivelas	12,00	33	Santa Maria da Feira	21,94
9	Oeiras	12,00	34	Santa Comba Dão	22,12
10	Porto	12,00	35	Fafe	22,33
11	Sesimbra	12,00	36	Olhão	22,37
12	Sintra	12,00	37	Portimão	23,63
13	Valongo	12,00	38	Viseu	23,73
14	Vila Nova de Gaia	12,00	39	Penafiel	24,87
15	Loures	12,34	40	Lousã	25,20
16	Seixal	12,81	41	Castelo Branco	25,38
17	Guimarães	12,99	42	Seia	25,53
18	Setúbal	13,15	43	Santarém	25,99
19	Barcelos	13,36	44	Leiria	26,82
20	Aveiro	13,41	45	Peso da Régua	30,74
21	Braga	14,32	46	Pedrógão Grande	31,61
22	Ílhavo	14,86	47	Guarda	33,74
23	Figueira da Foz	15,29	48	Estremoz	48,09
24	Mafra	15,61	49	Macedo de Cavaleiros	50,41
25	Alcochete	15,63	50	Aljustrel	54,08