Cloud IaaS in Portugal - A Go To Market Study

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Tim Berners-Lee
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Abstract

Cloud Computing services are replacing traditional Information Technology (IT), with Vendors and Enterprises shifting its investments to cloud infrastructures. Even though this is the global pace, there is no concrete knowledge on the solutions available in the Portuguese market.

This thesis, produced with Dimension Data (DD) collaboration, presents a report on the Infrastructure as a Service (IaaS) solutions advertised in the Portuguese Market, and an application designed and deployed in the DD public cloud.

The report consists of an analysis of several IaaS features that differentiate cloud solutions. These features were determined based on references in the analysis of the world market and reviewed during interviews with the solutions’ vendors. The Application (App) is a follow-up of in-house-developed applications but is the first to uses a cloud-based approach. It is used by two thousand DD’s employees on a daily basis.

The results obtained show that there isn’t a single cloud solution that fits all use cases, with vendors stronger for cloud-native applications and others providing a resilient infrastructure for general business applications. Using a benchmark tool on the Application, it was observed that the proposed cloud architecture is significantly faster than the non-cloud approach.

Within Dimension Data, the work presented enabled its sales team to understand the Portuguese market, by positioning the cloud solutions evaluated according to their use case. The application also empowered DD’s operations team with knowledge on their cloud offer and ground work for an internal shift to cloud environments.

Keywords

Resumo

Os serviços de Cloud Computing estão a substituir as Tecnologias de Informação (TI) tradicionais, com vendedores e empresas a mudar os seus investimentos para infraestruturas Cloud. Apesar deste ser o ritmo global, não existe um conhecimento concreto das soluções disponíveis no mercado português.

Esta tese, desenvolvida com a colaboração da Dimension Data (DD), apresenta um relatório sobre as soluções de Infrastructure as a Service (IaaS) vendidas no mercado português, e uma aplicação desenhada e implementada na cloud pública.

Tendo como base referências na análise do mercado mundial, foram identificadas várias características que diferenciam as soluções. Para elaborar o relatório, os vendedores foram entrevistados e estas características debatidas. A aplicação vem complementar outras já desenvolvidas internamente, e é utilizada diariamente por duzentos colaboradores da DD.

Os resultados obtidos demonstram que não existe uma solução que seja ideal para todos os casos, existindo fornecedores mais focados em potenciar aplicações cloud-native e outros com uma infraestrutura resiliente e preparada para aplicações gerais de negócio.

Utilizando um software de benchmark sobre a aplicação, foi possível observar que a arquitetura proposta para o ambiente cloud é significativamente mais rápida (tempo de resposta de páginas web inferior) do que a abordagem tradicional.

Este trabalho permitiu às equipas de vendas da DD entender o mercado português, posicionando as soluções de cloud avaliadas consoante a sua utilização. A aplicação muniu a equipa de operações (Engenharia Técnica) com conhecimento sobre a sua oferta e criou bases para a migração de aplicações internas para um ambiente cloud.

Palavras Chave

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Abbreviations

ACL  access control list
AD   Active Directory
ALM  Application lifecycle management
API  application programming interface
App  Application
AWS  Amazon Web Services
BAA  Business Associate Agreement
BU   Business Unit
CaaS Computing as a Service
CAPEX Capital Expenditure
CDN  Content Delivery Network
CentOS Community Enterprise Operating System
CIFS Common Internet File System
CPU  Central Processing Unit
CSS  Cascading Style Sheets
DaaS Desktop as a Service
DB   Database
DBMS Database management system
DC   Data Center
DD   Dimension Data
DDoS distributed denial-of-service
DN   Domain Name
DNS  Domain Name Server
DR  Disaster Recovery
DSS  Data Security Standard
ECS  Enterprise Cloud Suite
EOL  End of Life
FAQ  Frequently Asked Question
FY  Fiscal Year
GPU  graphics processing unit
HA  high availability
HIPAA  Health Insurance Portability and Accountability Act
HPC  Hosted Private Cloud
HPE  Hewlett Packard Enterprise
HSTS  HTTP Strict Transport Security
HTML  Hypertext Markup Language
IaaS  Infrastructure as a Service
IBM  International Business Machines
ICMP  Internet Control Message Protocol
ICO  IBM Cloud Orchestrator
ICT  information and communication technology
IDC  International Data Corporation
IDS  intrusion detection system
IEC  International Electrotechnical Commission
IOPS  Input/Output Operations Per Second
IPS  intrusion prevention system
ISO  International Organization for Standardization
ISP  Internet Service Provider
IT  Information Technology
JS  JavaScript
KVM  Kernel Virtual Machine
LDAP  Lightweight Directory Access Protocol
MFA   Multi-factor authentication
MPLS  Multi Protocol Label Switching
MS    Microsoft
MVC   Model View Controller
NFS   Network File System
NIST  National Institute of Standards and Technology
OPEX  Operating Expenditure
OS    Operating System
PaaS  Platform as a Service
PCEE  Private Cloud Enterprise Edition
PCI   Payment Card Industry
PTE   PT Empresas
RAM   Random Access Memory
RBAC  role-based access control
RHEL  Red Hat Enterprise Linux
ROI   Return on Investment
RTT   Round-trip Time
SaaS  Software as a Service
SLA   Service Level Agreement
SLO   service level objective
SMB   Server Message Block
SOA   Service-Oriented Architecture
SOC   Service Organization Control
SQL   Structured Query Language
SRS   Software Requirements Specifications
TCP   Transmission Control Protocol
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>UI</td>
<td>User Interface</td>
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<tr>
<td>vCPU</td>
<td>virtual CPU</td>
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<tr>
<td>VM</td>
<td>Virtual Machine</td>
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<tr>
<td>VMM</td>
<td>Virtual Machine Monitor</td>
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<tr>
<td>VPS</td>
<td>Virtual Private Server</td>
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<tr>
<td>WAN</td>
<td>Wide area network</td>
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</table>
1.1 Motivation

Cloud Computing adoption is rising each year, with International Data Corporation (IDC) estimating a growth of 44.2% in investment over the next 24 months [1]. Furthermore, RightScale reported that 95% of the companies, interviewed for their 2016 report, are leveraging Infrastructure as a Service (IaaS) [2].

IaaS that appears as an analog to the infrastructure and Data Center (DC) drive of Information Technology (IT), is bringing a shift from this traditional IT spending to provider sites, as shown in 1.1, with cloud investments replacing non-cloud ones in the next months.

![IDC CloudView: Shift in IT Spend to Provider Site and External Clouds](image)

Figure 1.1: IDC CloudView: Shift in IT spend to provider site and external clouds ([1]).

While this represents the evolution of clients, it is intrinsically related to the investments of the major IT manufacturers and providers, that may not have been the first companies to enter the cloud market, but have, through enterprise acquisitions and research developed their offers.

One example of continuous adaptation to the cloud business is Dimension Data (DD), a South African information technology services company founded in 1983 and solely owned by NTT [3]. DD has offices throughout fifty-eight countries, including Portugal, being this branch the collaborator in this thesis. The company entered the cloud IaaS market in 2011 with the acquisition of OpSource, a company well-known for its Software as a Service (SaaS) offer, culminating in the worldwide release of a proprietary cloud offer in October 2012. Since then, DD has improved in many aspects becoming one of the fifteen cloud vendors considered in Gartner’s IaaS Worldwide Magic Quadrant [4].

Although this is the global panorama for Dimension Data, at the beginning of 2016, the Portuguese
branch did not have a concrete knowledge of the solutions being presented to national companies nor had a Sales and Pre-Sales team dedicated and prepared to sell its own or others, IaaS Cloud Solutions to its clients.

This fact, combined with a rising number of Portuguese clients, including the public administration [5], looking to shift its IT investment created a need to analyze the cloud solutions sold by Providers and Manufacturers in Portugal, and also the need to learn and understand Dimension Data offers’ advantages and features.

1.2 Problem

Soon, Dimension Data Portugal will start approaching its clients to move their workloads to the cloud, turning this Fiscal Year (FY) into the first where one of the defined goals for Portugal is to sell IaaS solutions.

This goal, together with the lack of reports regarding the Portuguese market, provided the need to position DD (and its partners) in perspective with the remaining market.

The Portuguese branch of the operations department has also developed some applications for internal use. These applications are starting to lack on scalability, security and availability which are a constant in every other Cloud applications that the company uses every day, like Workday [6], Office365 [7] and Salesforce [8], creating a gap that needs to be extinct to assure their longevity.

The referred gap alongside with the lack of knowledge on DD IaaS offer gave rise to the necessity of developing a cloud-native application, using the public cloud offer as a prove of concept.

1.3 Solution and Results

The solution for the problems presented in the previous section was to research and produce a report and to design and implement an application, creating a starting basis for Pre-Sales, Sales and Operations Teams to start leveraging their offer with their clients, as well as in the in-house development.

The report mentioned above was named "Enterprise Cloud IaaS" [9] and consists of the analysis of 20 cloud solutions, by 11 companies. The companies analyzed in the report include all the important players, both multinational, like Microsoft and Amazon Web Services (AWS), as well as national, like PT Empresas (PTE) and Claranet. These companies were contacted with the objective of clarifying their solutions regarding Compute, Storage, Network, Service Level Agreement (SLA), and many other relevant areas.

This report was presented to the Portuguese Pre-Sales and Sales Teams and is available in Dimension Data’s collaboration applications, to be used, mainly by the European sales teams as a white paper on its IaaS offer positioning and features. Also, the report has some comments regarding the recommended roadmap for new features, which are of interest for Dimension Data Europe cloud department managers.
The developed application, named Dashboards (only available internally), was released for beta in July, and for production in August. Currently, it is used to get a better performance management by all the DD Portugal employees that are involved with the response to Business Opportunities, namely the Pre-Sales, Sales, Operations and Back-Office Departments.

This application was deployed both in the Portuguese private DC and in the DD’s Amsterdam Public Cloud DC, the first (Portuguese DC) for production purposes, due to the necessity to be in the same DC as other legacy applications, and the second environment (Amsterdam DC) for prove of concept and testing. One DD employee received tutoring and a document with architectural, implementation and development notes, was written and is available internally (Portuguese operation department).

For Dimension Data Portugal, this thesis brought a finer understanding of both the cloud market and DD’s cloud solutions. This knowledge empowers sales and pre-sales teams to pitch its offers to clients and enables the operations team to use its offers in future developments.

1.4 Thesis Outline

The Introduction (Chapter 1), gives a general framework about the theme developed in this thesis, addresses the problem and solution, and describes the structure of this document.

The thesis is divided into two sections, the first related to the report on Cloud IaaS and the second regarding the application mentioned above.

The first part is divided in two chapters. The first is Related Work (Chapter 2) and consists on a brief overview of the literature on cloud computing, describing the needed concepts to understand the report, and presents similar work that was taken into reference. The second is Enterprise Cloud IaaS Report (Chapter 3) and presents the methodology and the findings on the report done on the Cloud IaaS solutions available for Portuguese Enterprises.

The second part is Dashboards Web Application (Chapter 4). This chapter follows the IEEE Software Requirements Specifications (SRS) standard [10], with an introduction, an overall description and requirements of the application. Furthermore, the implementation, deployment, evaluation and continuity of the Application (App) are also reviewed.

The Conclusions and Future Work (Chapter 5) present a summary of the key findings, limitations, and contributions of the thesis, and some proposals for future work.
2 Related Work

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2.2 Reports and Benchmarks ........................................ 15
Research into cloud computing was needed to understand the relevant features in an Infrastructure as a Service (IaaS) solution, and how a proper comparison between solutions should be carried.

The present chapter contains an introduction to Cloud computing and the technologies that enabled it, followed by an extensive study of IaaS resources and features. In the second section of this chapter, reports and benchmarks already produced for similar ends were analyzed. These reports were also determinant to select the vendors that were evaluated in chapter 3.

2.1 Cloud Computing

While "Cloud Computing" terminology was only added to the Information Technology (IT) around 2007, its idea is far from new, and first implementations of systems where you paid, as a utility, for on-demand computing resources date to 1957, with the introduction of time-sharing [11].

Since then many new technologies have come to light, enabling Cloud Computing to became what National Institute of Standards and Technology (NIST) encompasses in five essential characteristics [12]:

- On-demand self-service - Human interaction with the service provider is not needed to provision computing capabilities;
- Broad network access - Capabilities are available over the network and may be accessed through standard mechanisms;
- Resource pooling - Computing resources are pooled to serve multiple consumers using a multi-tenant model. There is also a sense of location independence, meaning the consumer has no control over the exact location of the provider resources;
- Rapid elasticity - To the consumer the capabilities should appear unlimited and available for appropriation at any quantity and at any time;
- Measured service - Resource usage can be monitored, controlled, and reported, providing transparency for both the provider and consumer of the utilized service.

With the five key cloud characteristics defined, it is important to address the technologies researched for decades that capacitate Cloud Computing, like virtualization, utility computing, and others [13].

Server virtualization technologies play a key role, allowing the management of large distributed Data Centers (DCs) and overcoming the majority of the operational challenges. Virtualization is the abstraction of Operating System from the platform (hardware) and allows multiple instances of one or more Operating Systems (OSs) to be run on one or more servers. This abstraction is possible with the insertion of a hypervisor, also known as a Virtual Machine Monitor (VMM), between OS and the hardware [14].

The most common hypervisors in the market today are the so-called bare metal, or full VMMs, being the most known VMware ESX, Hyper-V (from Microsoft), XenServer (from Citrix), and Kernel
Virtual Machine (KVM) to the last [15]. These products are not only a different offer for bare-metal hypervisors but also represent distinct deployment manners.

Also important in this area, is the fact that VMware is the virtualization technology leader [16], with significant investments and innovation, dominating the virtualization (x86) and infrastructure market for on-premise, followed, with a gap closing each year, by Microsoft. According to Dimension Data, the majority of Portuguese enterprises that have DCs use VMware technology.

Autonomic Computing [17], introduced in 2001 by International Business Machines (IBM) vice-president for research, meant the use of Infrastructures that could analyze and respond to situations without the need of human intervention, letting the IT staff focus on solving business necessities. Using the developments in this area, Cloud Computing, appeared as the use of computational resources on demand and with minimal friction [18], and as since then evolved to bring unprecedented levels of automation to cloud solutions.

Several other technologies advancements were also very relevant, like grid and parallel computing, but will not be addressed in this document being the article by M.Hamdaqa and L.Tahvildari [19] considered an enjoyable reading on the relation between these technologies and Cloud Computing.

Regarding concepts, Cloud Computing has clear inheritances from Service-Oriented Architecture (SOA) [20] and utility computing. SOA is defined as an architectural style that supports service orientation, being loosely-coupled and designed to meet the business needs of the organization.

Utility computing was first heard by the words of Jonh McCarthy, at the MIT Centennial (1961): "If computers of the kind I advocate become the computers of the future, then computing may someday be organized as a public utility just as the phone system is a public utility" [21]. This approach is the basis for Public Cloud, where consumers only pay for what they use.

Utility computing brought a new perspective of Return on Investment (ROI) to the line of business, with the introduction of Operating Expenditure (OPEX), over Capital Expenditure (CAPEX), in the computing world. CAPEX brings two main disadvantages. The first is the depreciation associated with the products, requiring CAPEXs investments during all their lifetime [22], with the risk of the solution becoming obsolete. The second is the provisioning of resources, that are, in most cases, in an over-provisioning scheme or an under-provisioning one, as shown in figure 2.1. In the limit, utility computing makes the capacity line the same as the demand one, assuring the maximum ROI possible.

![Figure 2.1: Different approaches on provisioning (adapted from [23]).](image)
2.1.1 Cloud Services

The main differentiators in Cloud Services available in the market are related to the type of service offered. Ranging from storage space and computing power to platforms for own software deployment, or even online software applications [24]. Based on these differences, NIST, proposed three service models, to distinguish between the solutions that are available [12]:

1. Infrastructure as a Service (IaaS) - The closer model to the Traditional IT, abstracting everything from Data Center to Virtualization. In this model the client has only control over operating systems, storage, and deployed applications, and in some cases the client may also have limited control of select networking components (e.g. firewalls and load balancers).

2. Platform as a Service (PaaS) - Besides all the abstraction that IaaS has to offer, PaaS solutions also abstract from the consumer the OS, Database and Security layers.

3. Software as a Service (SaaS) - Is the result of abstracting everything from the final user, and giving him only access to use provider's applications, and sometimes the possibility to define user-specific application configuration settings. Examples are Gmail[25], Facebook[26], Office365[7] and others, used daily by millions and labeled cloud offerings, either officially or externally [27].

In Table 2.1 we may see an illustration of these three service models side by side with traditional IT, clearly defining the responsibility of both Provider and Consumer. There are other service models, like Desktop as a Service (DaaS) [28], also associated with the cloud, but these were considered out-of-scope for this document.

<table>
<thead>
<tr>
<th>Stack</th>
<th>Traditional IT</th>
<th>IaaS</th>
<th>PaaS</th>
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<td>Applications</td>
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</table>

Cloud Computing is also classified according to its deployment model, also defined by NIST [12]:

- Public - Initially this was what "Cloud" meant, it is provisioned for open use by the general public and exists on the premises of the cloud provider. The first well-known offer was Amazon Web Services (AWS) in 2006 [18], and this provider is still the market leader [29].
• Private - Very close to the traditional IT, it is a cloud infrastructure provisioned for exclusive use by a single organization comprising multiple consumers. Private Cloud may exist off or on-premises.

• Community - A Private Cloud deployment that is provisioned for several organizations that share the same concerns.

• Hybrid - The combination of two or more distinct cloud infrastructures, that remain unique identities, but are bound together to enable data and application portability.

Inside the public cloud, there are also semi-private solutions, called On-Demand Hosted Private Cloud (HPC) in International Data Corporation (IDC) studies [1], that consist of physical hosts dedicated for a single consumer (single-tenant hosts) with the rest of the stack shared.

It is also relevant to state that Cloud Computing has alternatives, existing other three well-known models that allow providers to run their workloads on remote servers, namely Dedicated Servers, Virtual Private Servers (VPSs) and Colocation Centers [11]. Although separated offers, VPSs are sometimes used as the baseline for cloud computing [30], dedicated servers as Private Clouds [31] and collocation centers for hosting private cloud solutions.

### 2.1.2 Infrastructure as a Service

In this section, there will be a presentation of important features that differentiate the IaaS solutions available in the market. For a better understanding of what certain features bring, they were grouped into categories, similarly to the methodology applied by Gartner [32], being the following relevant to general business applications:

• Compute resilience - referring to Virtual Machine (VM) availability, due to its importance for non-cloud architectures that used to assume that the hypervisor would assure their resilience;

• Architecture flexibility - because cloud environments need to be versatile and assure that the consumer may design the architecture to his liking;

• Security and compliance - ranging from security controls to governance, being one of the major concerns for the majority of the consumers [2];

• Hybrid IT - referring to enterprise integration, to assure that the cloud environment is easily used alongside the legacy environment;

• Backup and Disaster Recovery (DR), not consider by Gartner but contemplated in this document, for being essential and transversal to any system that requires business continuity [33].

Besides general business applications, important use cases for cloud environments are application development, batch computing, and cloud native applications [32]. Other categories which are relevant for these use cases are user management, automation and DevOps enablement, scaling and big data enablement.
Application development is significant, being the starting point for cloud adoption in many organizations. When the enterprise is leveraging a large team of developers that must have appropriate governance, security, and interoperability with the organization’s internal IT infrastructure, the main areas of interest are user management, enterprise integration and automation and DevOps.

Batch computing is the use case that has probably the best gain with cloud non-ending resources. With the price to run one instance for ten hours being the same of running ten instances for one hour its use becomes exceptionally cost-effective. Big data enablement, automation capabilities, and Enterprise integration are the main areas of interest for this use case.

Cloud-native applications is a relevant use case for cloud solutions due to its unique requirements. Enterprise integration, compute resilience, and architecture flexibility are all less considered when developing and running these workloads in detriment to automation, and scalability concerns.

Even though these categories are essential for us to understand the abilities of a particular IaaS solution, the framing of the following sections is done by analyzing the main resources associated with cloud computing [34] (Compute, Storage, and Network). These sections are followed by a section covering the remaining features and another to present Open Source Cloud Management Platforms, namely OpenStack [35], an open-source software platform that is used in several IaaS offers.

2.1.2.A Compute

Compute is the resource responsible for provisioning and managing virtual machines requested by the users [36]. Its features are associated to VMs, to the infrastructure, and to the hypervisor.

Starting from compute resilience, features like VM auto-restart and anti-affinity rules are imperative to achieve high resiliency. On the other hand, affinity rules allow reducing the response time and the capacity imposed on the network elements [37].

Live migration, a technology that allows the transference of VMs between distinct physical nodes without stopping the running tasks [38], enables VM-preserving during Host maintenance, being crucial to compute resilience.

Although there are different approaches on how to allow the customer to configure the VMs [39], the basic requirement to assure architecture flexibility is to have a full range of vCPU-to-RAM ratios [32], ideally by allowing non-fixed VM sizes. Other relevant features are non-virtualized machines, also known as bare metal and single tenant hosts (the basis of on-demand Private Cloud). [37].

Features such as import and export of custom VM images and deployment from snapshots contribute to Enterprise integration. To enable big data applications, there is a need for large VMs (up to 32 virtual CPUs (vCPUs) and 256 GB RAM) and graphics processing unit (GPU) on-demand capabilities.

2.1.2.B Storage

Regarding storage the providers’ offer is classified in the way it is consumed and interfaced on the client side, existing:
- File Storage – Also known as shared file system, it is the most traditional service type. The most popular protocols in use are NFS [40] and SMB/CIFS;
- Block Storage – Equivalent to raw block devices that may be formatted and used by the virtual machine as a local block device. Usually this blocks are mounted in a single VM;
- Object Storage - A relatively new technology [41] that is used to store unstructured persistent data by key/value through get/put requests usually submitted via a REST application programming interface (API) call [42].

These storage services classifications are shown in figure 2.2, providing an easy understanding on how they are consumed. The equivalent Linux commands to use these storage services are fopen [43] for File, fdisk [44] for Block and, for example, curl [45] for Object.

![Figure 2.2: Network storage services classifications [46].](image)

The offering of all these storage services assures that the consumer does not need to complement the solution with others. Likewise having several storage performance tires contributes to a greater architecture flexibility. The fact that block storage volumes are VM independent, not ephemeral or even allow the connection to multiple VMs, is also relevant.

Data portability capacities like the possibility to import or export data on physical media are considered critical [47] for Hybrid IT, while features like the possibility to expand block storage volumes or integrate storage with Content Delivery Network (CDN) solutions (usually in object storage) are considered enablers of scalability.

Object storage also plays a major role in big data enablement, with objects abstraction providing the advantages of both file and block storage, but with better flexibility and abstraction [48].

2.1.2.C Network

Networking assures that decoupled, highly scaled, and rapidly changing collections of service components can be provisioned and hooked together on-demand [49], being at the core of cloud computing.
Essential to provide architecture flexibility is the ability to create, in a self-service manner, complex hierarchical topologies (multiple network segments and multiple IP addresses per VM). Also important, is the possibility to have a static IP assigned to the VM.

Regarding hybrid IT, we may look at features like being possible to choose the IP private address that is associated with the VM and extending the enterprise Wide area network (WAN) to the cloud environment, ideally in a secure and dedicated connection (MPLS and Ethernet are the common solutions).

Finally, and for scaling purpose, there is the requirement for load balancing services, known as the distribution of incoming network traffic across a group of backend servers, usually called a server farm or server pool [50]. These services are essential, not only in its traditional form (Front and Back-end) but also at a Global level, using Domain Name Server (DNS) capabilities [51].

2.1.2.D Remaining cloud features

Regarding Security the relevant features are access control list (ACL), intrusion detection system (IDS), intrusion prevention system (IPS), Multi-factor authentication (MFA) as well as self-service firewall capabilities and distributed denial-of-service (DDoS) mitigation for all customers.

The creation of audit logs that record all the actions done in the cloud environment is a must-have. On the other end, the excess of provider capabilities, like the possibility to login into client’s VMs may be considered a security risk [32].

Alongside with these features, there is the use of techniques like overwriting the storage before reallocating it and sanitizing physical media before disposal [52].

Regarding Compliance there are several certifications available, being the following the most relevant:

- ISO/IEC 27001 [53] - Best-known standard providing requirements for an information security management system (ISMS);
- Service Organization Controls (SOCs) [54] - Available in three certifications:
  - SOC 1 - Report on controls at a service organization relevant to a user entity’s internal control over financial reporting, not covering domains not relevant from a financial audit perspective [55];
  - SOC 2 - Report on controls at a service organization relevant to security, availability, processing integrity, confidentiality, or privacy;
  - SOC 3 - This is a trust services report for service organizations, covering mostly the same as SOC 2 but in less detail and usually for marketing purposes. For this report to be considered relevant it should be accompanied by SOC 2;
- PCI DSS – Is composed of a set of requirements assuring that card-holder data (stored, processed or transmitted by merchants and processors) is secured [56, 57];
• HIPAA BAA - The Health Insurance Portability and Accountability Act (HIPAA) privacy rule is only applicable to covered entities (health plans, health care clearinghouses, and certain health care providers). Therefore, it is required a Business Associate Agreement (BAA) for these entities to be able to disclose protected health information for a certain function that is done in its behalf [58].

In the user management category the relevant features are role-based access control (RBAC), associated with the possibility of having multiple users and API keys per account, together with the possibility to define quotas and billing alerts. To allow the cloud user management to fit into the day to day management the integration with Microsoft (MS) Active Directory (AD) is also very relevant.

Where automation and DevOps' enablement are concerned, features like the ability to use relational Databases (DBs), NoSQL DBs and caching in an as-a-service approach are vital. Identically, the assurance that no maintenance window will compromise the availability of the control plane is also significant. These features were typically available in PaaS, but with only 1% of cloud users using solely this service [2], they are being adopted in some IaaS offers.

Infrastructure as code [59], related to the management and provisioning of infrastructure (virtual servers, network configuration) through definition files, is enabled by API capabilities and is contributing to more automated processes [60]. The API importance for automation is so relevant that it may be considered a lock-in factor and so there are some multiple cloud libraries, namely Apache LibCloud for Python [61], Apache jClouds for Java [62] and Fog for Ruby [63], that allow the abstraction between providers.

Furthermore, associated with the scaling category, we have auto-scaling features. In cloud computing the most common technique is threshold-based rules [64] and as the names say consists on defining thresholds for CPU or Memory uses that should trigger scaling. E.g.: If 70% for CPU use is defined as a high threshold then the system will know that if the VM is using 90% of the CPU capacity up-scaling is needed. In the application of this scaling, two different concepts are crucial [65]:

• Scaling up/down - also know as to scale vertically, meaning the provision of more or fewer resources for that particular VM;

• Scaling-out/in - also known as to scale horizontally, meaning the addition or removal of a VM in the load balancing pool.

In horizontal auto-scaling there are also two options related to how new instances are added and removed, with static auto-scaling referring to the power-on/off of pre-provisioned machines, and the dynamic auto-scaling, referring to the creation and destruction of machines using a pre-customized image.

In Enterprise Integration it is also important the existence software marketplace that eases the process of deploying third-party and open-source applications, being possible to do it and pay this software through the provider.

Lastly, there are backup and DR features that are critical for business, and may range from relatively simple off-site storage solutions to fairly complex real-time replication systems [66]. Features
in this category are snapshots, complete backups (with options for retention period and backup windows) that may cover the on-premises infrastructure and use a secondary site to assure DR.

2.1.2.E Open Source Cloud Management Platforms

An open source cloud management platform [67] refers to technologies and software used in the management of large pools of cloud resources. Cloud OS [68] is a software that allows this management. While there are several open source platforms, namely OpenNebula, Eucalyptus, Nimbus, OpenStack, and CloudStack, the focus will go solely to OpenStack. This emphasis is due to having, as of 2016, more than 500 companies supporting the project, including almost all the big and known IT manufacturers and providers [69].

OpenStack [35] is a cloud operating system that controls large pools of compute, storage, and networking resources throughout a DC, all managed through a dashboard that gives administrators control while empowering their users to provision resources through a web interface, as it can be seen in figure 2.3. Organized in six core services (compute, networking, object storage, block storage, identity and image service) and several optional services, OpenStack releases new versions each six months.

The OpenStack mission is “to produce the ubiquitous Open Source Cloud Computing platform that will meet the needs of public and private clouds regardless of size, by being simple to implement and massively scalable” [70]. It began in 2010 as a joint project of Rackspace Hosting and NASA.

2.1.3 Service Level Agreements

To define the exact conditions, both functional and non-functional, under which services are delivered companies need Service Level Agreements (SLAs) [71]. With the demand for agreements with clear terms, services guaranteed and accurate reporting on the service usage raising, SLAs are becoming a key criterion for service selection and for providers to establish their credibility [72].

In cloud computing, the service depends on the ability of the vendor to provide on-demand elastic resources provisioned over the network, and all of this needs to be measured through top-level metrics to ensure that the appropriate service is being delivered. In 2014, European guidelines for cloud computing [73] were created to bring more consistency between offers. The recommended

![Figure 2.3: OpenStack architecture ([35]).](image-url)
service level objectives (SLOs) are uptime (availability), response time (latency), capacity capability indicators, support, and reversibility and the termination process.

The importance of SLAs is becoming greater every day with the two major cloud providers experiencing outages superior to five hours this year [74, 75] compromising the investments of several clients. The importance of this matter pushed the development of standardization on what these agreements should contain, with the draft of ISO/IEC 19086 already released [76].

2.2 Reports and Benchmarks

As we have seen in the last section, Cloud Computing is ready and tested to be used for production workloads as an alternative to traditional IT. Two of the important decisions with a great impact on the line of business are the Migration of legacy workloads that support the business, and the investment in the development of new applications, that may be the next breakthrough.

To facilitate this decision making, two resources are usually used, and will be studied in the following sections:

- Benchmarks [77] - Bringing a quantitative evaluation, benchmarks are software suites that allow the measurement of a system (or part of it) to assure that the performance required to deploy a determined workload is available;

- Reports - Bringing a qualitative evaluation, reports allow to understand the evolution of the technology and the solutions that are potentiating it.

2.2.1 Cloud Benchmarking

A Benchmark is a computer program that, through the measurement of a system, allow to [78]:

- Position a certain offer against its competitors;

- Study infrastructure updates performance impact;

- Understand how the cloud-enablement of a certain workload will behave in a vendor’s cloud offer.

There are numerous areas of benchmarking to be considered, from Latency, Stream, Throughput to Bandwidth. These areas are usually associated with CPU, Memory, Storage, and Network and there are several benchmark tools available in the market [78]. Figure 2.4 is an example of the use of a tool named Geekbench 3 [79] to evaluate integer operations\(^1\), in this case, Image Compression.

When benchmarking solutions another critical analysis is the relation between performance and pricing [39], being the results of this relation usually the ones used to select a cloud solution. Looking at figure 2.5, that evaluates small VMs (1 vCPU and 2 RAM), we can conclude that the offers differ from each other non-linearly.

\(^1\)Integer and Floating point tasks represent vCPU performance [80].
Figure 2.4: Cloud offers performance comparison in Image Compression ([39]).

Figure 2.5: Cloud Spectator performance score comparison with monthly price, for Small VMs ([80]).
Besides the actual price (Compute, Network and Storage costs) it is relevant to understand billing. As an example, some providers offer minute billing, allowing to take the most of a batch job (running in one hundred machines during six minutes as the same costs as running in ten machines in one hour). Others offer hour billing, allowing the use of scaling techniques to have more machines on during business hours, and then others that allow month, year or longer agreements to assure that static workloads can still take benefits from the cloud environment [39].

Benchmarks studies also allow us to get to know that clouds are not uniform with network latency, age, configuration of physical hardware, and the prone to "noisy neighbors" varying between the same provider DCs [81]. These differences led to the creation of a parallel market to the cloud industry, composed of companies like CloudHarmony [82] and Cloud Spectator [83], that monitor cloud providers actively to measure performance and stability.

However, this necessity is starting to be fulfilled by hybrid cloud management solutions that present advanced capabilities when it comes to cost and performance management [84]. Two of the market leaders in this area, RightScale [85] and Cisco CloudCenter [86], have tools to compare the prices [87] or to do test deployments on several clouds and benchmark the performance/cost ratio [88], respectively.

2.2.2 Cloud Reports

Cloud Reports are documents that bring an analyze of the cloud market allowing the comprehension of its evolution, the solutions that are enabling this transformation and how clients are leveraging them.

In Cloud Computing reporting there are three big names behind market analysis which are Gartner [89], Forrester [90] and IDC [91]. These companies produce, yearly to quarterly, reports on the state of the market and comparisons of the various solutions existent in it.

These comparisons are very relevant for decision making and were used in this document both to gather information on the solutions, as well as to understand what is considered critical, important and differentiator in a Cloud solution. In this area, Gartner Magic Quadrant and The Forrester Wave are well-known references and were studied in detail in the following sections.

On the other hand, IDC is focused on understanding how the market is evolving, looking more towards clients and less to providers. IDC CloudView is a reference and will also be mentioned in the following sections.

2.2.2.A Gartner Magic Quadrant

Gartner [89] is very famous for its Magic Quadrant analysis [92]. Each Magic Quadrant is used to position technology players within a specific market, and Gartner suggests that it should be used as the first step in understanding which technology providers should be considered for a specific investment opportunity.

The report provides an image with four quadrants that are assigned based on the vendor ability to execute and completeness of vision, being the vendor classified as:
• Leader - Vendor that has a good solution, expressing well its current vision and well positioned for the future;

• Visionary - Vendor that as the correct vision on where the market is going and may even change the market rules, but currently has a solution that is not at its vision level;

• Niche Player - Vendor whose solution is well focused on a small segment. It is also applicable to vendors who are unfocused and don’t out-innovate or outperform others;

• Challenger - Vendor that as a good solution, possibly with a high market share, but shows no innovation or understanding regarding the market.

The report is produced by applying an each solution provider a set of evaluation criteria that helps assert how their solutions perform against Gartner’s market view. Interviews are also carried and therefore, not only the solution evaluated (Ability to execute) but also the strategy (Completeness of vision) is considered.

For this document, the relevant report is Gartner Magic Quadrant for Cloud Infrastructure as a Service (Worldwide) [4], presented in figure 2.6, that allow the rapid understanding of who are the big companies behind the Cloud IaaS market. It also offers a view of the market as a whole and what we can expect. However, this report is only related to industrialized solutions that are sold on-demand with the provider responsible for the solution and providing the resources.

![Gartner Magic Quadrant for Cloud IaaS 2015](image)

**Figure 2.6:** Gartner Magic Quadrant for Cloud IaaS 2015 ([4]).
In this report AWS [93] and Microsoft [94] are considered the Leaders and there are some visionaries, having most of the providers been considered niche players. Both IaaS market leaders (AWS and Microsoft) use this report to prove that their solutions are worthy [29, 95].

It is important to understand that even niche players may have offers that are better for some use cases from the ones presented by the Leaders, making the use of multi-cloud solutions a better choice, sometimes. Looking at figure 2.6 we see Dimension Data as a niche player and AWS as a Leader, but due to several reasons Dimension Data (DD) offer is sometimes preferable to some enterprises [96].

2.2.2.B The Forrester Wave

Forrester [90] produces numerous reports where vendors solutions are compared, using for that purpose The Forrester Wave. Similarly to Gartner, the analysis is done based on the weight of the current offer, alongside with the vendor strategy. Forrester also evaluates the market presence, by representing each vendor with a size representative bubble.

For this document, the Private Cloud Software Suite, presented in figure 2.7, was considered because it offers an important comparison on Private Cloud software offerings, which was missing from the Gartner Magic Quadrant for Cloud Infrastructure as a Service.

![Forrester Wave](image)

*Figure 2.7: The Forrester Wave - Private Cloud Software Suite, Q1 2016 ([97]).*

In this report it is possibly to see several well-known manufacturers as Leaders, due to its speed to provision, control of user experience and fully published APIs. Once again, all solutions are relevant,
with the reasons for less performance being possibly non-relevant for some customers. For example, Microsoft weaknesses include lack of cost monitoring and integration with alternative platforms, that may be irrelevant for some customers or provided by third-party tools.

Forrester has also produced another report on Private Cloud [98] were several conclusions were taken, being the most relevant for this document:

- Private Cloud ROI is difficult to get, with the benefits of Private Cloud being measured in developer and business engagement and not necessarily tech management cost-efficiency (that are usually associated to Public Cloud);
- Cloud and Traditional IT integration strategies are considered slow.

2.2.2.C IDC CloudView

IDC [91] develops a yearly report that consists of a visual analysis of responses to pertinent questions, named CloudView [1].

However, this report is very expensive and not accessible in any providers website, contrarily to Gartner’s and Forrester’s research, not being analyzed in this thesis.
3

Enterprise Cloud IaaS Report

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The lack of reports on the Portuguese Cloud Infrastructure as a Service (IaaS) market, together with the need to empower Dimension Data’s sales team to sell its offers, created the demand for the report examined in this chapter.

The report, named “Enterprise Cloud IaaS,” compares the cloud solutions available to Portuguese enterprises, with a highlight on Dimension Data offers.

### 3.1 Methodology

The fundamental pieces of this report were defined at the beginning of the investigation, being them:

- Which vendors would be selected;
- How would the information be obtained;
- Which features would be considered in the comparison;

The following sections will give a broader look into the first two aspects, while the relevant features were already covered in the previous chapter (2).

#### 3.1.1 Selection of the Vendors

To select the vendors four characteristics were considered mandatory:

- **Portuguese Market Participation** - The vendor should be present in the Portuguese market, either directly or through partners and resellers.

- **Portuguese Market Revelation** - The vendor should be leading in its relevant segments. Due to a lack of market studies in this field, Dimension Data estimated market share (perception) was used as a reference.

- **Relevant Business Capabilities** - The vendor should be ready for the enterprise market, being able to invoice and negotiate customized contracts and have a 24/7 customer support (including phone support).

- **Relevant Technical Capabilities** - The vendor should be suitable to support production workloads, both enterprise, and cloud-native. This capability needs to be based on successful implementations, not necessarily in the Portuguese Market.

Having the previous requirements at hand, Gartner’s Magic Quadrant for IaaS report [4] discussed in Reports and Benchmarks chapter, was used to identify vendors. This report was chosen because of its complete vision, addressing almost all the relevant vendors and written to address medium to big enterprises.

Since Gartner’s report excluded solutions that are only private Cloud, it was necessary to add some well-known vendors, whose software offers are flagships for private cloud. For this particular case, The Forrester Wave on Private Cloud Software Suite [97] was considered.
All participant vendors from Gartner’s and Forrester’s reports were included in the report, except CenturyLink, Interoute, Joyent, NTT Communications, Rackspace, Red Hat and Virtustream for not having reference to Portugal and Portuguese sales or support teams [99–105]. Further-on, Huawei [106], BMC [107], Citrix [108], CSC [109] and Verizon [110] were excluded for insufficient market participation. While this doesn’t mean that the solutions from this vendors are off limits for Portuguese companies, it will make them less usual and therefore less relevant.

Identically important are the inclusions, starting with PT Empresas [111] and Claranet [112] since both companies have Data Centers in Portugal and are relevant in the market. This inclusions end with OVH [113] that was mention in Gartner’s report has a significant European-based provider but not big enough to enter any quadrant. All these vendors’ public and private solutions, have case studies in Europe and have support in Portuguese being relevant to this study.

3.1.1. A Vendors

With the criteria, mentioned above, eleven cloud vendors were selected for the report:

- Amazon Web Services [93] - Subsidiary of Amazon.com created in 2006 [114], offers a suite of cloud-computing services. AWS is currently the Public Cloud Market leader [115], and takes pride in being a company for the “do-it-yourself” generation proposing a “buy-infrastructure-on-your-credit-card” business model [116];

- Cisco Systems, Inc. [117] - One of the biggest manufacturers worldwide. With its headquarters in California, the company was founded in 1984 and has been designing, manufacturing and selling networking equipment worldwide, since then;

- Claranet [112] - Based in London, was founded in 1996 and is a provider of managed ICT services in Western Europe;

- Dimension Data [118] - Founded in 1983, in Johannesburg, and is a global company specializing in information technology services, with operations on every inhabited continent. It was acquired in 2010 by NTT;

- Fujitsu [119] - A Japanese global information and communication technology (ICT) company, offering a full range of technology products, solutions, and services to more than 100 countries. Headquartered in Tokyo, the company opened its doors in 1935 and had today 159 thousand employees [120];

- Hewlett Packard Enterprise [121] - Founded in 2015, when the giant Hewlett-Packard was split in two. This Californian company had around 240 thousand employees and remained responsible for the HP servers, storage, and networking;

- International Business Machines Corporation [122] - Well-known as “Big Blue,” was founded in the State of New York 105 years ago (1911). It is a multinational technology company with operations in over 170 countries, and almost 360 thousand employees;
• Microsoft [94] - Founded in 1975 and headquartered in Washington, this American multinational technology company sells and develops consumer computer software, consumer electronics and personal computers and services;

• OVH [113] - French multinational Internet Service Provider (ISP), headquartered in Roubaix and founded in 1999, and it is mainly known for hosting dedicated servers;

• PT Empresas [111] - Subsidiary of Portugal Telecom, a Portuguese telecommunications operator, that operates in the Enterprise market;

• VMware [123] - Founded in 1998, is based in California and is the market share leader and thought the leader in virtualization. It has a broad global base of existing customers that are deeply committed to its technologies, giving it a unique position.

3.1.2 Information Discovery

The vendors considered were contacted in May, with an explanation of the study that was being conducted. The objective at this time was to gather contacts that could be later on used to corroborate the information discovered and to gather insights related to the solutions.

In July, with the layout and information to be addressed already defined, the contacts gathered, mainly employees in the Cloud Department, were contacted with an online form. This form, composed solely of closed questions, contained all the features under analysis and was pre-filed with information available online. The objective, successful in some cases, was for the employee to corroborate the data gathered online, filling the empty fields (information not available publicly) with the information related to the pertinent feature.

From this contact, it was possible to schedule some meetings. Besides bringing a better understanding of the vendor's solution, these interviews brought some insight on the view of the Portuguese Cloud Market and were conducted with:

• Jorge Portugal, Cisco's Consulting Systems Engineer for Data Center & Virtualization;

• José Pinto and Paulo Silva, Fujitsu's Digital Transformation Sales Director and Principal Consultant for Solutions Business Group, respectively.

• Bernard Paques, Dimension Data's Solution Architect for Cloud.

Besides Cisco, Fujitsu and Dimension Data (DD), also International Business Machines (IBM) and OVH responded to the form. Non-responding cloud vendors were introduced in the report when a search in their documentation, together with an analyze of recent reports, was enough to respond the most of the form.

The learning of the Dimension Data offer was done through an internal tutoring, based on live video conference classes, that ended with the presentation, by the Portuguese team (myself and a senior consultant), of a business cloud solution for a case study created by Dimension Data Europe.

Pricing was never addressed during the contacts to maintain the pricing chapter completely transparent, using only values obtained online.
Table 3.1: Cloud solutions of the vendors selected. Underlined offers were studied at the feature level.

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3.2 Report summary

The report [9], with 125 pages, starts with a short introduction on Cloud IaaS, similar to the one done in the Related Work chapter but shorter and less technical. It is followed by the solutions to evaluate where some comments regarding deployment model, geographic and services availability were introduced.

Further in the report there were added sections on Compute, Storage, Network, Backup, Security, Management and DevOps. In all the sections conclusions were drawn, using graphs and tables, that will be shortly presented in the Features section of the Report summary. Before conclusions, a pricing analysis on the public cloud solutions was produced.

Except for the Introduction, already covered in chapter 2, there will be made a digest of the different chapters and sections of the report in the following sections.

3.2.1 Solutions

Since most of these vendors have several cloud solutions, an effort was made to select only solutions that are being sold to a large set of customers and advertised in Portugal. Niche market offerings were not considered.

The solutions that are the focus of this study are presented in Table 3.1. The non-participating vendors whose solutions don’t have enough information online are Claranet, Microsoft (Only Azure Pack), PT Empresas and VMware. On the other hand, Cisco’s One Enterprise Cloud Suite (ECS), Fujitsu’s Primeflex and CaaS and HPE’s Helion solutions were not analyzed regarding features because they are hardware independent bundles, which allow the client to add or remove any capability.
Furthermore, DD Computing as a Service (CaaS) and Private Cloud Enterprise Edition (PCEE), Fujitsu k5 and IBM SoftLayer differentiate from its competitors in the following terms:

- CaaS is a public cloud offer that can be made hosted private if the client requires storage and compute hardware to be isolated from other customers and is leveraged by renting racks of the public cloud infrastructure. PCEE is similar to CaaS but with some added flexibility for client requirements and dedicated hardware;

- Fujitsu k5 has four modalities: public, virtual private, dedicated and dedicated on-premises. The first two are grouped together because the only difference is that in virtual private the physical host (compute hardware) is not shared with any other tenant. The dedicated and on-premises offers are the same as the public one but with some added flexibility for client requirement. While the first is hosted in the Fujitsu Data Centers (DCs) the second is at the client premises and so they were joined and analyzed as "k5 dedicated".

- SoftLayer is a traditional public cloud with access to bare-metal servers. The fact that on these servers it is possible to install any bare-metal hypervisor makes it also a private hosted solution when, for example, the client installs VMware cloud software. With several hypervisors supported the features are third-party solution dependent and therefore only the public offer is analyzed.

OpenStack as a clear dominating presence, with Cisco, Fujitsu, IBM and OVH having offers based on it. Looking at their pages in OpenStack website [124–126] (Fujitsu k5 doesn’t have a dedicated page) we can see that only BlueBox is up to date, while the remaining solutions use components in End of Life (EOL). Other difference visible on the supporters page for OpenStack [69] is that IBM is a platinum member, committing full-time resources to OpenStack, while Cisco and Fujitsu are Gold Members and OVH is a corporate sponsor and infrastructure donor.

In this chapter of the report the focus was:

- Geographic availability - referring to DC availability for Hosted solutions, by continent and in Portugal.

- Provider services - referring to responsibility and management of on-premises private cloud solutions and services levels available (from break-fix services to Information Technology (IT) outsourcing).

- Hypervisors - where the hypervisors used by public cloud solutions and the ones compatible with private cloud solutions were identified.

- Hybrid ready - A analyze of out-of-the-box capabilities of the private clouds solutions related to public cloud integration.

- Service Level Agreements - only analyzed for off-premises solutions the service level objectives (SLOs) identified in Related Work were compared.
**Geographic availability**

Fujitsu (only CaaS) and PT Empresas differentiate from other offers because of the possibility of being hosted in Portugal.

Looking towards Europe, all vendors have two or more DCs available, with Fujitsu (only k5) being the exception. k5 is only available in Japan and London DCs but with plans for three new European DCs shortly, including one in Spain.

In a global perspective, Dimension Data CaaS is the only public cloud available in all inhabited continents, being the only provider with DCs in Africa.

**Provider services**

While AWS, Azure, and OVH follow a do-it-yourself approach, the other vendors have an all-managed approach (with several managed services available and even IT outsourcing). This contrast is observed even in the software solutions analyzed (Cisco Metapod and Fujitsu k5 on-premises), that are sold with 24/7 monitoring provided by the vendor.

The great differentiation goes to DD and to Hewlett Packard Enterprise (HPE) that have its private cloud on-premises offers available in a renting model (Operating Expenditure (OPEX)), with PCEE being sold exclusively in this model.

**Hypervisor**

From figure 3.1, we conclude that most solutions are VMware compatible (10 from 17), followed by KVM (6) and Hyper-V (5).

KVM is the second most compatible Virtual Machine Monitor (VMM) due to, in most OpenStack implementations, the fact that it is the only hypervisor supported.

![Number of solutions compatible by Hypervisor](image)

**Figure 3.1:** Number of cloud solutions compatible by Hypervisor.

The featured solution is Cisco One ECS compatible with VMware, Hyper-V and KVM (RedHat), followed by HPE Helion and Fujitsu k5 that are compatible with VMware and KVM.
Hybrid readiness

Most vendors that sell private and public solutions can integrate both solutions. However, only Fujitsu and DD use the same UI for both.

Cisco, Dimension Data, Fujitsu and IBM leverage multi-cloud orchestrators, namely Cisco CloudCenter for the first two, Fujitsu MetaArc (not an orchestrator but a set of services) and IBM Cloud Orchestration, to assure that their offers are integrable with AWS, Azure, and other clouds.

Service Level Agreements

Regarding Service Level Agreements (SLAs) the following results and considerations were obtained:

- 99.95% is the most common for availability (server uptime). Dimension Data and OVH Public Cloud differentiate themselves positively with a five nines uptime and IBM SoftLayer negatively with an SLA equivalent to three nines.

- SLO for uptime is the only available in all offers and SLO for maximum support delay depends on, in many cases, the support level subscription. The exceptions are DD and Fujitsu with several SLOs.

- All vendors, except Amazon Web Services (AWS), cover all the offers with SLAs. This is relevant because this services (other then Compute, Network or Storage) may be differentiators for AWS but dangerous for enterprises.

- Multi-fault-domains is an SLA clause used by AWS and Azure. Dimension Data covers solutions deployed on the same host but if anti-affinity rules are set the maximum reimbursement goes from 50% to 100%.

- Reimbursement changes drastically from provider to provider, with AWS, Fujitsu and Azure having caps bellow thirty percent and Dimension Data, IBM SoftLayer and OVH Dedicated having caps of one hundred percent.

- The tendency is not to allow the negotiation of the SLAs, justified by the ease of management when every customer is seen in the same way. The exceptions are Fujitsu and OVH Dedicated.

SLAs like the ones from AWS and Azure led Gartner analyst Lydia Leong to say that Cloud IaaS SLAs can be meaningless [127], pointing out the complexity of AWS SLA that, even during prolonged outbreaks, wasn’t activated due to several clauses like the multi-fault-domain referred above. However, there is a tendency in new products to present better SLAs with the objective of differentiating themselves, showing a higher “bet” in their infrastructure resilience.

1SoftLayer public cloud User Interface (UI) may be used for private cloud for a certain hypervisor selection, including VMware and Hyper-V.

2Multi-fault-domain refers to the need to assure that the workload does not depend on a single availability zone. It is similar to requiring high availability (HA) at a geographic level.
3.2.2 Features

This section will present the main results obtained from the solution analyzes based on the features discussed in Related Work.

During the report, these features were grouped firstly regarding the resource they contribute to, and then regarding the purpose (similarly to what was done in Related Work).

The features, by solutions, are presented in Annex A, grouped in the categories defined in the Infrastructure as a Service section to allow the comparison of the solutions by use case.

3.2.2.A Compute

Regarding compute resilience, most offers are capable of assuring VM auto-restart and VM preserving during host maintenance. IBM Softlayer is incapable of assuring these two features while OVH Public Cloud doesn’t have auto-restart.

Azure and AWS lack Virtual Machine (VM) preserving during host maintenance. This preservation is usually accomplished with live migration and since Google brought this capability to its cloud offer (not evaluated in this report) [128], AWS and Azure are being criticized.

Affinity and anti-affinity rules are available in numerous solutions. While OpenStack has native support for both, AWS, IBM SoftLayer and Azure don’t have it. AWS and Azure have, however, tools to assure high availability in multiple zones, obtaining the benefit of anti-affinity rules in another way. Dimension Data doesn’t have affinity rules but its SLA defined a maximum latency between servers of 1ms and therefore the benefit of affinity rules is negligible.

Regarding architecture flexibility, Dimension Data differentiates itself from the other solutions allowing to select any value of RAM and vCPU (maximum is 32 for vCPU and 256 for RAM).

From figure 3.2, looking closely at vCPU to RAM ratios, we can observe that it is offered in SoftLayer, with a semi-tiered offer\(^3\), AWS, and Azure. On the other hand, OVH and Fujitsu have very limited tiers. Also relevant is the fact that AWS and Azure are the only solutions in which the size is fixed after provisioning, with the process of resizing without re-provisioning being limited and complex [129, 130].

Regarding architecture flexibility differentiating features, almost all public clouds allow the use of single tenant hosts. However, looking at Azure’s (that doesn’t have this capability) feature request portal the number of customers who requested this capability is around fifty [131], while the number of customers asking for live migration goes over one thousand [132]. Also interesting is that all private clouds vendors are capable of, through negotiation, arranging the use of non-virtualized machines. In public clouds, only SoftLayer has this possibility.

Regarding hybrid IT enablement all the offers analyzed are strong and allow import, deploy from snapshots and export of VM images. A negative remark goes to AWS export that is only available for imported VMs.

Big data enablement, through the access to GPUs, is limited to AWS, Azure, and SoftLayer solutions. IBM and OVH have the only public cloud offers that don’t allow for VM sizes of 32 vCPUs

\(^3\)A semi-tiered offer is when there are tiers for RAM and vCPU, but they can be chosen independently of one another
by 256 GB of RAM, considered critical by Gartner. However, both vendors have hosted private cloud offers capable of assuring this size.

### 3.2.2.B Storage

Starting from architecture flexibility, AWS, IBM SoftLayer, and Azure are the high performers with file and object storage as well as three tiers of block storage. Fujitsu and Dimension Data offers differentiate negatively, with the first only offering one tier of block storage and the second lacking an object storage in its European DCs and private cloud solution.

Other relevant remarks regarding architecture flexibility are:

- SSD storage is far from standard, being only available in AWS, BlueBox, and Azure. Dimension Data offers SSD accelerated storage.\(^4\)

- All solutions have VM-Independent storage. However, AWS and Azure have some VM tiers that only support ephemeral local storage.

- Multiple VMs connected to the same volume feature is only supported by SoftLayer and OVH Dedicated.

- Only 45% of the offers analyzed allow to resize a storage volume.

From figure 3.3 we can see that three tiers are the standard in public cloud while in private cloud the average is two tiers. In figure 3.4 we observe that object storage is almost in all offers while file storage availability is shorter. The offering of file storage in the public cloud is something recent with AWS only launching its offer this year [133], which may dictate that this feature will start appearing in other offers changing the shape of the graph.

Ending the storage section we only have AWS, SoftLayer, and Azure potentiating scaling capabilities with Content Delivery Network (CDN) integrated into storage. On the other hand, most vendors

\(^4\)SSD is used for cache.
allow import and export of data in physical media, potentiating hybrid IT.

3.2.2.C Network

In terms of architecture flexibility, all solutions allow the creation of complex hierarchical network topologies, with the only difference between solutions being that OpenStack and SoftLayer don’t permit the choice of private IP address.

Regarding enterprise integration, all providers allow the connection of their network to the client outside the internet and all offers, except OVH Public Cloud, can extend the enterprise Wide area network (WAN).

SoftLayer is the only solution without load-balancing integrated but allows the clients to acquire one of the several load-balancing hosted appliances available in its software marketplace. Dimension Data load-balancing capabilities don’t include global load balancing, because Domain Name Server (DNS) services are not available as a service in its offers, and are required for this kind of load balancing.

3.2.2.D Backup

Backup is assured by all providers, but AWS and OVH Public Cloud don’t have complete backup solutions, being only capable of saving snapshots. On the other hand, DD doesn’t have snapshot capabilities for backup.

Trough the analysis of the offers it was also possibly to conclude that the providers that offer complete backup also assure that this backup can be replicated at a secondary site. AWS is also capable of doing this because its snapshot functionality is coupled to object storage.

Also relevant, is the availability of "backup to the cloud" solutions integrated into IaaS off-premises offers, with DD, SoftLayer, and Azure offering the capability to backup on-premises machines.

Lastly, regarding Disaster Recovery strategies it was possible to conclude that Managed Services with this objective are provided by most vendors, with the exception of AWS and OVH Public Cloud that stay clearly bad positioned in this section. Azure, on the other hand, offers a self-service Disaster Recovery (DR), that is what is expected in a cloud solution in which everything is as-a-service.
3.2.2.E Security

In the security chapter, it was possible to cover numerous features regarding security, compliance and user management (when associated with permissions and authentication).

Regarding compliance, and looking at the results presented in figure 3.5, it was possible to conclude that ISO 27001, SOC 2 and PCI DSS are almost assured by all providers, followed by SOC 1. Only OVH Public Cloud lacks compliance, but, during the response to this study, it was denoted that these four certifications are in road-map.

![Figure 3.5: Compliance in off-premises cloud.](image)

Addressing security in general, OVH Public Cloud was also outperformed by all the other offers, followed by OVH Dedicated and with lesser problems SoftLayer and Azure. It was observed that Multi-factor authentication (MFA), access control list (ACL) and distributed denial-of-service (DDoS) mitigation are offered in most solutions, and that intrusion detection system (IDS)/intrusion prevention system (IPS) and a self-service firewall are also available in more than 60% of the solutions.

Regarding user management, SoftLayer was the lowest performer not allowing the Active Directory integration and having few and predefined roles in role-based access control (RBAC). There is, however, a tendency for less granular RBACs in OpenStack, that natively only has four roles.

3.2.2.F Management

Measured service [12], is one of the five characteristics that define a cloud computing solution, being the one essential for empowering management. Looking at the offers analyzed it was possible to conclude that only OpenStack allows the definition of Quotas while most offers allow the creation of billing alerts.

Regarding scaling, it was observed that most vendors offer horizontal auto-scaling. Vertical auto-scaling is only provided by Dimension Data since all other vendors have tiered offers, which don’t allow independent resource scaling.
Hybrid IT related to management was a downside for the majority of the offers, with only AWS, Azure, and IBM SoftLayer being able to provide a software marketplace. In the case of AWS and Azure, this is even more relevant, with several software developers having exclusive products for these clouds.

Monitoring and continuous availability of the control plane are assured by most vendors, enabling DevOps and automation. On the other hand, Service Catalogs are not common. AWS differentiates itself from the other vendors with all these features available.

3.2.2. G  DevOps

DevOps [134] is a conceptual framework to address the development and operations of Information Systems departments collaboration, leading to the automation of the process of software delivery and infrastructure changes.

One of the ways to enable DevOps is by offering Relational and NoSQL DB as well as in-memory caching services in a self-service manner. While AWS, Azure, and IBM SoftLayer offer these services natively, almost all vendors have options, from integration with Platform as a Service (PaaS) services to open-source libraries. The same applies for Hadoop services, enabling big data.

Application lifecycle management (ALM) is supported in few solutions, but infrastructure as code is a standard being available in most solutions. Regarding multiple-provider libraries, Apache LibCloud is very well positioned with almost all proprietary solutions supporting this library. jClouds and Fog seem less relevant with fewer supporters.

3.2.3  Pricing

In this chapter of the report only the public cloud solutions were analyzed\(^5\), and all data is accurate as of May 10, 2016. The fast changing offers and prices make this section accurate for a short time but its conclusions nonetheless relevant.

Firstly, there was an analysis of pricing options, with Microsoft being the only provider supporting minute billing, that may be very useful for batch computing, and the rest of the providers having hour billing. Month and Year agreements are also common but have two different options:

- Enterprise Agreements - The case of DD and Microsoft Azure allow enterprises to make compromises to spend a certain amount and receive discounts regarding that amount;
- Reservation Discounts - The case of AWS and OVH, that provide reduced prices for a compromise to use an instance for a longer period.

Although prices and solutions change with frequency, figure 3.6 is relevant to understand how the providers are positioned at a VM cost level, with AWS having a low-cost approach for small and medium VMs, and OVH and IBM being bellow average for all sizes. Microsoft and DD are around the average for every size and Fujitsu s5 is the most expensive offer.

\(^5\)When this chapter was being developed Fujitsu k5 was only available in Japan and therefore the Fujitsu offer being evaluated was s5. According to Fujitsu the prices are entirely different, with k5 being frequently cheaper than AWS.
A very relevant differentiator was Windows Licensing with each company offering its pricing (difference between Linux and Windows OS per hour) and making the first pricing analysis inadequate for Windows only enterprises. Figure 3.7 shows the big difference existent, with Claranet and DD differentiating themselves by offering the licenses.

On storage, the relevant characteristic was Input/Output Operations Per Second (IOPS). The IOPS bill, when they are charged, may become greater than the storage price. It is important to refer that 20% of the offers analyzed charged for IOPS, with this percentage rising to 40% when only the performance storage offers are considered.

The last set of prices examined were the ones about to data/network charges, and it was in this department where big differences were found, with three approaches defined as follow:

- Everything paid – Providers charge for every transfer, even between services offered by the provider and its DCs in different regions;
- Internal connectivity offered – Providers charge for outgoing bandwidth but offer internal transfers between its services and DCs;
- Free Bandwidth – Providers don’t charge for any Data transfer.

These differences made pricing very hard to analyze, with some providers that offer the transfers charging to have higher bandwidths, and with providers that charge for everything having different prices according to the services and DCs from where and to where the data is coming and going.

Concluding, in this chapter of the report it was possible to understand that the pricing is something that depends on many factors and is very difficult to be analyzed impartially just looking at compute, storage and network. That said, pricing should be something that is studied for specific workload requirements.

### 3.2.4 Conclusions

Remembering the categories defined in the section Infrastructure as a Service, the graphic on figure 3.8 was created from the features discussed above. In it, the number of critical capabilities lacking in each solution is added meaning a bigger bar represents a weaker solution.

For example, Cisco Metapod only fails in one critical capability, relevant to hybrid IT, while Fujitsu k5 dedicated fails in two, related to security and compliance and hybrid IT. Looking at Table A.6, we see that the hybrid IT critical feature that is lacking in both solutions is a software marketplace, while in table A.5 is possible to understand that Fujitsu k5 security failure is the fact that Storage is not over-written.

![Figure 3.8: Number of critical capabilities lacking by solution.](image)

The first easy conclusion that we draw is that the private cloud solutions are globally better prepared to handle critical requirements, followed by the understanding that native OpenStack is well build to handle all the critical features.
The critical features importance can’t be discarded, but they are usually assumed, making the non-critical features, presented quantitatively in Figure 3.9, vital when it comes to choosing between one of the solutions. In this figure, the logic is the opposite, with the bars corresponding to the number of non-critical capabilities existent in each solutions meaning a bigger bar represents a stronger solution.

![Number of non-critical capabilities by solution](image)

**Figure 3.9:** Number of non-critical capabilities by solution.

Looking at this graphic (Figure 3.9), the conclusions are also the opposite, with public cloud solutions being clearly more feature prone.

As discussed in Related Work there are several use cases, with the previously mentioned categories having different weights in each one. From the report, it was possible to highlight the following solutions for each use case:

- **General business applications** - favoring compute resilience, architecture flexibility, security and compliance and enterprise integration:
  - Public - DD CaaS followed by Microsoft Azure.
  - Private - IBM Blue Box is the best-suited offer, followed by Dimension Data PCEE.

- **Application development** - favoring user management, enterprise integration and automation and DevOps enablement:
  - Public - AWS and Azure, followed by Fujitsu k5.
  - Private - Fujitsu k5 dedicated, followed by IBM BlueBox

- **Batch computing** - favoring automation and DevOps enablement and big data enablement:
  - Public - AWS followed by Azure.
  - Private - Cisco Metapod followed by Fujitsu k5 dedicated.
• Cloud-native applications - favoring automation and DevOps enablement, scaling, big data enablement and backup:

  – Public - Azure followed by Fujitsu k5.
  – Private - Cisco Metapod followed by Fujitsu k5 dedicated.

The good positioning of Cisco Metapod and Fujitsu k5 dedicated, both OpenStack-based, comparing to IBM BlueBox, which is also OpenStack, is related to the flexibility of software solutions. However, there may also be downsides or restrictions not evaluated in this document. Looking at the best solution for each use case it is clear that IaaS solutions with PaaS capabilities (AWS, Azure, k5, and Metapod) are in advantage.

However, these results were obtained giving the same weight to every critical capability considered relevant for the use case, which can be inadequate for some enterprises. The relevant data for this conclusions was presented by category in figures 3.8 and 3.9, and by feature in Appendix A, so it is possible to adjust the evaluation according to need.

The report proceeded with the documentation of enhancements recommended for Dimension Data that will not be discussed in this document.
Dashboards Web Application

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The previous chapter compared cloud solutions regarding high-level features, providing knowledge on each solution use cases and capabilities.

However, the lack of technical expertise and experience regarding Dimension Data (DD)’s Infrastructure as a Service (IaaS) offers, appealed for the development of an application, using DD’s Public Cloud, that will be described in this chapter.

The application, named “Dashboards,” is a modern web-application, that was developed using the Public Cloud benefits to enrich the internal range of applications.

The present chapter is organized into several sections, with the first three following the usual chapters addressed in IEEE Software Requirements Specification standard [10] (Introduction, Description, and Requirements). The fourth section is focused on implementation and the fifth on deployment. The six section consists of a series of tests that evaluate the offer and compare cloud and non-cloud deployments. Lastly, there is a section addressing how this application continuity was addressed in the DD environment.

4.1 Introduction

4.1.1 Purpose

Dimension Data Dashboards is a web-application, part of a set of several internally-consumed applications, which are leveraged every day by Portuguese employees.

4.1.2 Product Scope

At Dimension Data Portugal the workflow related to business opportunities is the following:

1. The Sales Department, in response to a client contact or self-initiative, open what is called an opportunity. An opportunity has with final objective the presentation of a proposal and is a description of what is pertinent to the client.

2. The Pre-Sales Department (Solution Engineering), is then asked to design one or more solutions. For example, the development of a client Data Center (DC) requires a security solution, a data center solution, and so on.

3. The Operations Department (Technical Engineering), may need to present budgets and documentation for tasks required by a certain solution. In the DC example, the tasks would be related to the construction, deployment and implementation of the solution.

4. The Sales Department, with the complete information on the opportunity and respective solutions and tasks, produces a proposal, that is delivered to the client.

Summing up, there are four activities in the sales workflow: Opportunities, Solutions, Tasks, and Proposals. Each one of these may have different performance indicators, for example, “Won” (money) is an indicator for proposals and “Pre-Sales Support” is an indicator for opportunities.
This workflow gave rise to the in-house deployment of an application named Sales Workflow, that supports all the peculiarities of the process described above.

The new application brought to the existent Sales Workflow App an upper layer from where monitoring could be an enabler of better performance.

4.1.3 References

For developers, an extensive documentation was produced, covering code decisions, future developments, and recommendations. This documentation is available internally, and the relevant employees have access to it.

The application was developed according to the twelve-factor app methodology, which defines good practices for cloud-native applications [135].

4.2 Overall Description

4.2.1 Product Perspective

Dashboards is one Application (App) in the universe of in-house developed applications used by Portuguese employees. From figure 4.1, it is possible to obtain a high-level vision on the production environment of DD’s Apps. In this environment, named e-portal, several applications use the Microsoft (MS) Structured Query Language (SQL) Database (DB) and the MS Active Directory (AD) to respond to employee requests.

![Figure 4.1: Dimension Data E-portal high-level architecture.](image)

Dashboards, besides a component of a larger system, is a follow-on member for the product family. It was designed with the objective of being easily expanded to create dashboards of legacy application and even to create new Apps. The first legacy Apps supported is Sales Workflow.

4.2.2 Product Functions

The application was developed in decoupled modules allowing future developments:
• Main - The core of the application, from class inheritance to static and template reuse. This module lets users see its profile information and to see a Frequently Asked Question (FAQ) section;

• Back-office - Portal for system administrators, that allows the management of the data in the App DB;

• Authentication - Helper for everything related to Authentication. This module is responsible for login and logout operations and, in the back-office, it is possible to add and remove users, groups, and respective permissions;

• Dashboards - Helper for everything related to dashboard pages. This module is responsible for the notion of time, having a class to handle date selections in the User Interface (UI);

• Sales Workflow - Developed to bring Dashboards to the existing Sales Workflow App, allowing users and managers to evaluate their performance through a series of graphics and numbers.

As it was referred in the previous section (4.2.1), the remaining e-portal applications may be added to the list presented above, in future developments.

4.2.3 User Classes and Characteristics

Users are grouped according to their position and department. Although, the creation of custom groups and permissions was enabled the groups are being mirrored from the ones used by all e-portal applications.

These groups are:

• Back Office;

• Sales;

• Pre-Sales;

• Operations;

• Managers.

All these groups may access the sales Workflow App, each one looking at the respective information. For example, Sales may see the opportunities and proposals dashboards, while Operations group members only see the tasks dashboards. Managers and Back Office may see every activity, mirroring the permissions that are already defined for the legacy applications.

There is also a set of users, not a group, that are admins, having access to the back-office. These users are from the Operations department and are responsible for the development and maintenance of the application.

All these groups are governable, in the back-office portal, and integrate with legacy applications. This integration allows admins to define if they pretend to mirror a group or to manage it independently of e-portal. The priority in the development was firstly for department groups, followed by admins.
4.2.4 Design and Implementation Constraints

The two primary constraints presented for this App are related to authentication and data access. Authentication needs to be processed by MS AD, which is the directory service used in DD. The data required for the application is stored in an MS SQL server that is located in the Lisbon DC. Due to the nature of the application, the interest is to have live data, and so the application server needs to be on the same network as this DB.

The last implementation constraint was the Operating System (OS). This should be Community Enterprise Operating System (CentOS) to maintain consistency in the production environment and because it is the only open Linux OS with drivers for all its versions [136] (Since it may use the same drivers as Red Hat Enterprise Linux (RHEL)).

4.2.5 Assumptions and Dependencies

It is assumed that the network is secure and managed by Dimension Data Information Technology (IT) department. The application depends on the availability of the MS AD and MS SQL servers, with 100% uptime being assumed.

The other applications are solely used in Portugal, and so it was assumed that this would be the case of this application. However, it should be easy to make the App multilingual, if other countries show interest in European meetings where the other applications are and will continue to be presented.

4.3 Requirements

In this section, the external interface requirements will be the first to be addressed, followed by functional and non-functional requirements.

4.3.1 External Interface Requirements

4.3.1.A User Interfaces

The user interface is a web browser, and the application is mobile-ready, with the content being adapted to the screen size automatically.

4.3.1.B Software Interfaces

Two Database management system (DBMS) are used in this request, and its access is done by Transmission Control Protocol (TCP) sockets. The data source is an MS SQL, and the connection is read-only. The application database is where session keys, user data, and other information are stored.

To assure that the application is accessible with the enterprise credentials a connection with DD’s Microsoft Active Directory was established using Lightweight Directory Access Protocol (LDAP), also through TCP sockets.
The authentication process used is called Bind and Search. As the name suggests a bind is made between the web application and the AD, with administrative credentials, followed by a search for the user’s Domain Name (DN), that together with its password is used to do a second bind. The result is simply success, if everything is correct, or failure if either the user-name or password are incorrect.

4.3.1.C Communications Interfaces

The User Interface is only accessible through HTTPS, with HTTP requests being redirected to the secure protocol. For developers, the server is accessible through SSH using key pair authentication.

The connections between components were encrypted by the IT department, according to the company policies. Several remarks in the documentation were devoted to explaining how this may be done.

4.3.2 System Modules

As referred in section 4.2.2, this project is composed of the Main, Back-office, Authentication, Dashboards and Sales Workflows modules.

The functional requirements of these modules will be discussed in the following sections.

4.3.2.A Main

Description and Priority

Main implements the Class that handles the MS SQL Server connection, as well as the template that is inherited in all HTML pages.

This module is mandatory for the correct operation of the system, but there shouldn’t exist a requirement to change anything in it when other modules are added.

Functional Requirements

The main module introduces several features:

- Auto-refresh may be enabled in the navigation bar, as displayed in figure 4.2, and results in an Ajax POST request that changes the cookies;

- Profile Menu is consistent throughout the application, allowing users to log out and to see their personal information, as demonstrated by figure 4.3.

![Figure 4.2: Dashboard App, auto-refresh feature.](image)

![Figure 4.3: Dashboard App, profile menu.](image)
• FAQ system allows users to have access to a predefined set of questions and respective answers, in a help page, that is easily accessible through the top bar. The FAQs can be created, modified and deleted in the back-office portal.

4.3.2.B Back-office
Description and Priority

The Back-office module creates a portal to change the Data that is managed by the application DB.

This module is an enabler of fast development, but everything it allows may be defined in code. Each module needs minor adjustments to assure it may be managed through this portal.

Functional Requirements

A back-office application is available for system administrators, and any model (data representation in the application DB, usually a table) may be manageable from this back-office.

4.3.2.C Authentication
Description and Priority

This module defines permissions and is responsible for mirroring the user groups.

This application is mandatory for the correct operation of the system, but there shouldn’t exist a requirement to change anything in it when other modules are added.

Functional Requirements

• Every time a user logs in, his first and last name, as well as his e-mail address, are mirrored to the App DB.

• The mirroring will be accompanied by a basic permission verification (user exists and may access the application), and an HTTP 403 (Forbidden) custom error page will be displayed if they don’t exist.

4.3.2.D Dashboards
Description and Priority

The Dashboards module brings dashboards capabilities, from static files (JavaScript (JS) and Cascading Style Sheets (CSS)) to the notion of time (beginning and ending). During the analysis of dashboard pages, the dates are essential, because the data is analyzed according to it.

This module is mandatory for the correct operation of part of the system (pages with dashboards), but there’s no need to change anything in it when other modules are added.
Functional Requirements

1. The time period is a date (without time) for the user, but for the system, it is presented in hours and minutes. If the end of the date is the present day then the current time (hour and minutes) is used in queries. If the end of the date is another day, the complete day is used in queries (23:59).

2. The time period may be selected from the calendar, beginning and end data, only limited by the start of records (Release of the legacy App) and by the current date, respectively.

3. The time period may also be select as a Fiscal Year (FY) date, for example, "This Quarter" or "Last FY."

4. The time period selected is kept as long as the user is logged in.

5. If no selection was made, the last 30 days is the predefined time period. In this cases, an info message appears in the UI.

6. The FY information is translated on runtime, because "This" always has different meanings.

4.3.2.E Sales Workflow

Description and Priority

This is the Application per-say, meaning the others, described above, were designed in a decoupled way, but for now they are only helpers to this App, and they could be written inside it.

This module as two important objectives, described as follow:

* Collaborators can see their activities and their team members’ activities, analyzed by a set of parameters, as business unit, state, type and so on.

* Managers can see the activities of everyone analyzed by the same set of parameters.

This module may be removed without any impact on the system. Regarding priority, most of the development efforts were made in this application.

Functional Requirements

1. Each activity (Opportunities, Solutions, Tasks, and Proposals) has state pages, where the performance of a user, a team or even the entire company, is analyzed with numbers and graphics.

2. Every combination of status (delayed, due to next week, incomplete), state (New, Ongoing, Standby, Concluded, ...) and activity has a page listing the related objects.

3. Each activity has a by-collaborator page that allows the comparison of collaborators.

---

1 A team member is a definition applied internally to someone that works in the same Business Unit (BU), for example, all the engineers that develop DC solutions are considered team members.
4. Each Opportunity has a high-level view where all solutions, tasks, and proposals associated with it are visible.

State pages, like the one in figure 4.4, must help understand, through numbers and graphics, the performance of a user, a team or even the entire company. The following variants exist, for each activity (Opportunities, Solutions, Tasks, and Proposals):

- Global - With a view over every activity, like the one in figure 4.4.
- Group - With a view over the activities of a collaborator and his team members.
- Individual - With a view over the collaborator's activities.

Figure 4.4: Dashboard App, Sales Workflow global solutions state page.

In this page we may choose the date (top right corner), see the delayed and almost delayed activities (red and yellow bars), and see the global activity panorama. This panorama can be seen by state, either graphically (at the bottom) or with numbers (boxes in the middle), and by other indicators (in the bottom) like BUs.

Clicking in "View Details" ("Ver detalhes" in the image) sends the user to a page with a list containing the appropriate activities. This list is structured as a table with all the relevant parameters of the activity, being possible to order, search and filter, according to desire. For example, in a won proposal list, it is possible to filter it by client and get the average of value and margin of all the proposals sent to that client.

The by-collaborator set of pages, shown in figure 4.5, is probably the most relevant tool from a management point of view. This set of pages, one for each activity type, has the so-called performance indicators but by collaborator, meaning it is possible to understand how each collaborator is performing comparing to his colleagues.

The page that presents a global view of the opportunity and all its stages is called Tree View and is displayed in figure 4.6. In this page we can gather basic information on the Opportunity, and
see the other activities related to it, making it possible for anyone associated with this opportunity to understand where it’s stopped.

This view is accessible from the List View or by searching the opportunity code to it in the left bar.

4.3.3 Other Nonfunctional Requirements

4.3.3.A Performance Requirements

The human time constants [137] have the following definitions:

- 0.1 second (Perceptual processing) - the system is seen as an animation that reacts instantaneously;
- 1 second (Immediate response) - the maximum time for which the user waits without needing any notice.
10 seconds (Unit task) - the limit for keeping user's focused. The user will most likely start doing another task in parallel unless feedback for the delay is given.

To justify the future adoption of cloud initiatives for DD' internal applications the performance of the application in a cloud environment needs to be at least the same to the production DC.

With this information, the following requirements were set:

1. UI must take less than 10 seconds to load.
2. If the data takes more than one second to load, a loading signal should appear in the UI.
3. The cloud deployment can't be worst (response time) than the non-cloud deployment.

4.3.3.B Security Requirements

1. The web-application connection is encrypted and authenticated.
2. In dynamic pages, a 404 (Not Found) error is preferred, in detriment to 403 (Forbidden). This limits the exposure of potentially sensitive information just by acknowledging it exists.
3. The servers are only locally (console or SSH over a VPN).

These requirements were already analyzed in section 4.3.1.C when external interface requirements were being defined.

4.3.3.C Software Quality Attributes

The following quality characteristics are required:

- Availability;
- Maintainability;
- Reusability;
- Testability;
- Usability.

4.4 Implementation

The implementation started at the beginning of April and was followed by several releases, described in Table 4.1. The content of each release is excluded from this document as this information was kept up-to-date in a proper Yammer [138] group create to support this App.
### Table 4.1: Application major and minor releases.

<table>
<thead>
<tr>
<th>Version</th>
<th>Date (DD/MM)</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>v0.0a</td>
<td>26/05</td>
<td>Alpha</td>
</tr>
<tr>
<td>v0.1a</td>
<td>20/06</td>
<td></td>
</tr>
<tr>
<td>v0.0</td>
<td>27/06</td>
<td>Beta</td>
</tr>
<tr>
<td>v0.1</td>
<td>07/07</td>
<td></td>
</tr>
<tr>
<td>v0.2</td>
<td>15/07</td>
<td>Feature Freeze</td>
</tr>
<tr>
<td>v1.0</td>
<td>21/07</td>
<td>Production</td>
</tr>
<tr>
<td>v1.1</td>
<td>12/08</td>
<td></td>
</tr>
</tbody>
</table>

The release covered in this chapter is the Production one, but there will be some comments regarding development stages. A git [139] repository was set to provide version control, assuring that there was no code difference between the initial environments:

1. Development - This is the environment where the development was done, and doesn’t have any server capabilities;

2. Testing - This environment is located on the same network as the Development one, in the laboratory DC. The difference is in the server capabilities that allowed this environment to be tested by humans and benchmarked.

After first beta release, there was as need for a more agile development, with the following change of environments:

1. Development (DD’s Amsterdam DC) - Cloud environment, with the same components as the Production one. Unit tests were run against each micro change, and a snapshot of the last working version was used when they failed;

2. Production (DD’s Lisbon DC) - Environment holding the application used, every day, by the Dimension Data’s employees.

The deployment of releases (from development to production) was merely done by replacing the code files and restarting the application server because all the configuration (IPs, Passwords) were kept in environment variables.

Besides the 25 Hypertext Markup Language (HTML) pages that compose the documentation, produced using Sphinx [140] and presented in the read the docs format [141], all the code was commented. The Sphinx’s autodoc tool was used to append the code comments to the documentation.

### 4.4.1 Software Architecture

To fulfill the requirements presented in the past section, the operating environment is composed by:

- OS: CentOS [142];
- DB: MS SQL (read-only, managed by IT);
• Directory: MS AD (managed by IT);

• App framework: Django [143]. It is a Model View Controller (MVC) framework with a very extensive set of features accompanied by well-written documentation, being the most popular Python web framework [144]. A pre-build back-office portal and an LDAP authentication library (django-auth-ldap [145]) were just two of its advantages;

• App DB: PostgreSQL [146]. Is the only engine that supports all the Django features [147];

• HTML/CSS/JS framework: Bootstrap 3 [148]. Bootstrap is an extraordinary framework to develop responsive (is adaptable to the screen size) web projects. A template (sb-admin 2 [149]) was used for all the pages and navigation of the site, together with some CSS and JS packages (complete list of packets only available in the technical documentation);

• Web Server and reverse proxy: NGINX community edition [150];

• Application Server: uWSGI [151]. Is one of the recommended application servers by Django [152].

In figure 4.7 we can observe the software architecture where the UI is a common browser that makes an HTTPS connection to the Web-Server. NGINX responds itself if the request is a static file (e.g.: image), or acts as a proxy if the request is for the App server.

uWSGI receives the request (from NGINX), and according to the URL, Django will send the request to the appropriate module (e.g.: if the path starts with admin/ the back-office module is the one to respond2). Any module may interact with the DBs and AD when required.

2The modules Main, Authentication and Dashboards may be used even when not called, because they’re mandatory and imported by the others.
All the connections between software units are done through TCP socket unless they are hosted on the same machine. In that case, and if possible, Unix sockets are used.

During the design of the application, three types of non-functional requirements were set. The first was performance and will be discussed in section 4.6. The other two were Security and Software Quality and their implementation details are presented in the rest of this section.

Security

In section 4.3.3.B, security requirements were set. Encryption and authentication, as well as the policy for lack of permission, were implemented in the following way:

- If the connection is sent through HTTP, the reply is a redirect to HTTPS;
- All the responses set an HTTP Strict Transport Security (HSTS) header, assuring that the browser will expect an HTTPS connection from that site in the future;
- Every time a request is received by the application server the login is checked, and if not existent or expired the response is to redirect the user to the login page. The address of the page that the user was trying to access is saved, so a proper redirection is possible after login;
- When the request page is a global one, for example "sales\state\opportunities\global\," the response to a lack of permissions is to redirect the user to the login page, with a warning message;
- When the request page is individual, for example "sales\state\opportunities\john.doe\," the response to a lack of permissions is a 404 HTTP error;
- When an HTML page is build to respond to a request, the permissions are also checked, assuring consistency on the interface, meaning the user will not see a button for an action to which he doesn’t have permissions.

The access control to servers is usually performed through the firewall and is a responsibility of DD IT team.

Software Quality

The application was implemented according to the non-functional requirements for software quality defined in 4.3.3.C. Availability was assured by the use of modern and advanced components (Nginx and uWSGI), that use several processes to assure that fault recovery is possible.

The use of the application DB together with the back-office portal to set most of the options. These options are, for example, activity states, where the name, color and even icon information are kept in the App DB and may be changed in the back-office. While this brings some overhead to the

3DBMSs are always accessed through TCP sockets, and usually have predefined ports. For example, PostgreSQL predefined port is 5432.
application (multiple queries to the DB that usually have the same response), it was considered that the benefit of easy management overcame the extra milliseconds.

Reusability was assured by the use of decoupled applications. This way, the addition of a new set of features can be done by creating an application and using the Main, Authentication and optionally Dashboards modules. Regarding good programming practices, the code repetition was kept to a minimum allowing easy modifications in the application, if and when required. For example, the sales workflow application is only supported by three main templates: "state.html," "list.html," and "tree-view.html."

Unit tests were created for the python code (covering 65% of the lines) and assure the Testability of the application. Tests were created to support a test-driven bug resolution, and so basic methods are not covered by them.

Lastly, to assure Usability the Bootstrap framework was used and an effort to keep every option easily understandable was done. During the Beta release comments on usability were taken into consideration to improve the UI.

4.5 Deployment

Software must be built on a solid foundation [153], able to support existing or future business requirements, as well as easily deployed or managed in a production environment. It is in the architecture design that these requirements are assured.

Regarding final deployment two environments were set:

1. Production Environment - Located in the Dimension Data DC in Lisbon, this is a traditional VMware virtualized DC and is the one that hosts this and other internal consumption Apps.

2. Cloud Environment - Located in the Dimension Data Public Cloud (Computing as a Service (CaaS)) DC in Amsterdam, which is also a VMware virtualized environment already studied in the Enterprise Cloud IaaS Report chapter. This deployment was solely done for prove of concept and was not used by Dimension Data employees.

4.5.1 Production Environment

This environment is used by more or less two hundred DD employees that work in Lisbon and Porto, on a daily basis.

With the Portuguese Branch of Dimension Data not forecasting any major change in employee numbers, the App architecture followed a maintainability approach. Although the core components (Web, App, and DB servers, defined in section 4.4.1) are designed in a way that decoupling is easy, they were installed on the same machine.

Figure 4.8 represents the architecture of this environment, with the core components installed on the same machine (Dashboards App) and two external connections established by the application server (uWSGI). These connections to MS SQL and MS AD were already dissected in section 4.3.1.B.
The connection to MS SQL (dashed) is read-only due to the credentials used, meaning that if in the future there is the desire to add features to the App that require INSERT or MODIFY queries it would be just a matter of permissions in the MS SQL Server. As the decoupling of the PostgreSQL DB is essential to scale horizontally there is a tutorial on the documentation on how to do it.

### 4.5.2 Cloud Environment

This environment was only created for a prove of concept purpose, and to allow the understanding of the advantages of using cloud infrastructures to deploy workloads.

The architecture used, presented in figure 4.9, kept the NGINX and uWSGI servers on the same machine. This option allows the use of valuable cloud features, as the load balancer and auto-scaling. Three, precisely equal, servers were deployed (from snapshots) and each one of these servers can answer to static (file request) and dynamic (application page) requests.

Regarding networking, the servers were added to a pool, with load balancing set to Round-Robin. Auto-scaling was set with the following rules for CPU and Memory use:

- Minimum: 10%;
- Maximum: 70%.
- Scale-up interval: 5 minutes;
- Scale-down interval: 30 minutes.
4.6 Evaluation

For evaluation purposes *Apache Benchmark* [154] was used. Only a small and fast evaluation of the production environment was done to assure the results were consistent because a large set of tests would have an impact in the applications, such as performance downgrades in all the internal applications that use MS SQL.

To assure consistency the page under analysis was always the one that presents a global view of the opportunities. This page does sixteen queries to PostgreSQL and nine queries to MS SQL, and all tests were based on one thousand requests.

The bottleneck was the Central Processing Unit (CPU) of the applications servers that regularly reached more than 95% of use. The PostgreSQL and MS SQL servers that were deployed were monitored, and its memory (Random Access Memory (RAM)) use never went over 80%, and its CPU use never went over 36%.

4.6.1 Tuning

First, there was a need to assure that the configurations of the NGINX and uWSGI were optimal.

NGINX was simply configured to accept the maximum number of connections possible for its memory, which were 1024. As the application has only 200 users this number is more than sufficient. The rest of the configurations were left automatic, including the number of processes.

In uWSGI, there were two decisions to make, the number of workers (processes) and the number of threads per worker.

To understand the threads four tests were done, as shown in Table 4.2. From the results, it was
possible to conclude that threads don’t bring any advantage, on the contrary. Although they allow more concurrency, there is no benefit in using them in this case as the total response time becomes worst.

Table 4.2: Impact of threads in uWSGI in the response time, server with 1 vCPU (standard speed and 1 core/socket), 2GB RAM and 1 uWSGI slave process.

<table>
<thead>
<tr>
<th># threads</th>
<th># concurrent req</th>
<th>time [s]</th>
<th>time/req [ms]</th>
<th>std dev [ms]</th>
<th>req/s [#/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>130,88</td>
<td>130,88</td>
<td>49,40</td>
<td>7,64</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>135,08</td>
<td>135,08</td>
<td>37,50</td>
<td>7,40</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>129,48</td>
<td>258,95</td>
<td>73,60</td>
<td>7,72</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>134,08</td>
<td>268,15</td>
<td>85,90</td>
<td>7,46</td>
</tr>
</tbody>
</table>

The next step was to understand how many slave processes the uWSGI should use. To understand this point several tests were done, with changes in the concurrency level and in the number of workers from test to test. The results are presented in Table B.1.

In figure 4.10 we are able to draw, at least, two conclusions. The first is that with one worker the total response time is always lower, and the second is that while for one worker the total response time gets lower with the increase of concurrent requests, the same doesn’t apply in the other cases. One possible explanation for this may be the struggle for CPU resources between processes, but this is considered off-topic and will not be analyzed.

In figure 4.11 we can understand that the response time for a request is always lower for one uWSGI worker than for more.

Therefore, it was defined that the most optimal way to configure uWSGI is one master and one slave worker.

To make sure that this results were only related to the CPU and not with other factors, there were made two extra sets of tests. Table 4.3 presents the results of the first tests that consisted of using a
Figure 4.11: Response time per request (averaging one thousand requests), for one, two or three uWSGI workers, server with 1 vCPU (standard speed and 1 core/socket), 2GB RAM. Number of uWSGI workers doesn’t include master process. Based on the values from table B.1.

Table 4.3: Impact of the number of workers in uWSGI in the response time, server with 1 vCPU (high-performance speed and 1 core/socket), 2GB RAM.

<table>
<thead>
<tr>
<th># uWSGI workers</th>
<th>time [s]</th>
<th>time/req [ms]</th>
<th>std dev [ms]</th>
<th>req/s [#/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>101,10</td>
<td>202,20</td>
<td>7,90</td>
<td>9,89</td>
</tr>
<tr>
<td>2</td>
<td>94,62</td>
<td>189,24</td>
<td>29,20</td>
<td>10,87</td>
</tr>
</tbody>
</table>

faster CPU. These tests allow us to understand that the number of slaves is dependent on the CPU because in this test two workers responded faster to two concurrent requests.

In the second set of tests two vCPUs were chosen, instead of one, but the speed of the CPU was maintained, and the results, presented in Table 4.4, clearly show that two workers are more beneficial than one. In this case, the time of response is even lower, easily justified by the fact each worker is using the resources available in one vCPU. However, according to dimension data pricing [155], this configuration is more expensive than the one used above.

4.6.2 Production versus Cloud

One of the important parts of this thesis was to understand the benefits of using cloud computing.

While the ease of running these tests (in the cloud), together with the development advantages, are qualitative results, in this chapter the focus will go to quantitative tests.

The architecture differences will be tested first followed by environment characteristics.

Table 4.4: Impact of the number of workers in uWSGI in the response time, server with 2 vCPU (standard speed and 1 core/socket), 4GB RAM.

<table>
<thead>
<tr>
<th># uWSGI workers</th>
<th>time [s]</th>
<th>time/req [ms]</th>
<th>std dev [ms]</th>
<th>req/s [#/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>104,40</td>
<td>208,90</td>
<td>7,90</td>
<td>9,58</td>
</tr>
<tr>
<td>2</td>
<td>67,80</td>
<td>135,61</td>
<td>29,20</td>
<td>14,75</td>
</tr>
</tbody>
</table>
Architecture

Regarding architecture comparison, one set of tests was done. These consisted of testing an architecture with three servers against one with one server, and the results are presented in the table B.2.

Firstly, in figure 4.12 we can see the total response time and conclude that it is lower for cloud architecture (three times inferior, for more than three concurrent requests). Secondly, in figure 4.13 it is possible to see that the response time rises slower (approximately three times) with three servers, as expected.

The fact that the servers were configured in an auto-scaling pool makes the cost of the two architectures almost similar, when there are few requests. When the number of requests rises, the efficiency of a scalable system is exploited.

Environments

To compare both environments two set of tests were conducted. The first one, shown in table 4.5, refers to the response time to a request in these environments. It is possible to conclude that under the same conditions the Cloud deployment performs better than the Production one.

Table 4.5: Production versus Cloud in the response time, server with 1 vCPU (standard speed and 1 core/socket), 2GB RAM and 2 uWSGI slave processes.

<table>
<thead>
<tr>
<th>Environment</th>
<th>time [s]</th>
<th>time/req [ms]</th>
<th>std dev [ms]</th>
<th>req/s [#/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>189,44</td>
<td>189,44</td>
<td>16,9</td>
<td>5,28</td>
</tr>
<tr>
<td>Cloud</td>
<td>134,69</td>
<td>134,69</td>
<td>48,00</td>
<td>7,42</td>
</tr>
</tbody>
</table>

The second test was on latency because one server is located in Amsterdam and another in Lisbon. For these tests Internet Control Message Protocol (ICMP) [156] was used because it provides the Round-trip Time (RTT). The results are presented in table 4.6 leading to the conclusion that an extra forty-three milliseconds are needed to communicate with the cloud servers.
Table 4.6: RTT for Production and Cloud application servers from Lisbon and Porto Offices.

<table>
<thead>
<tr>
<th>Test locale</th>
<th>Environment</th>
<th>Minimum (ms)</th>
<th>Maximum (ms)</th>
<th>Average (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lisbon Office</td>
<td>Production</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lisbon Office</td>
<td>Cloud</td>
<td>42</td>
<td>46</td>
<td>43</td>
</tr>
<tr>
<td>Porto Office</td>
<td>Production</td>
<td>10</td>
<td>21</td>
<td>10</td>
</tr>
<tr>
<td>Porto Office</td>
<td>Cloud</td>
<td>51</td>
<td>122</td>
<td>53</td>
</tr>
</tbody>
</table>

The combined results of both tests add up to a similar performance between both environments for the page under analysis, with a tendency for a better efficiency of the cloud servers in more complex requests.

4.6.3 Response Time

In the Performance Requirements section, it was defined that pages should load in less than ten seconds, ideally in less than one.

As it can be seen in table 4.7 the maximum mean response time is less than 500 ms. However, the longest request reached almost one second, which led to the inclusion, in the by-collaborator pages, of a loading bar that is removed as soon as it is completely loaded.

Table 4.7: Mean and longest response time by set of Pages, adapted from B.3.

<table>
<thead>
<tr>
<th>Set of Pages</th>
<th>time/req [ms]</th>
<th>longest request [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index</td>
<td>41,707</td>
<td>278</td>
</tr>
<tr>
<td>State</td>
<td>138,607</td>
<td>414</td>
</tr>
<tr>
<td>By Collaborator</td>
<td>454,782</td>
<td>937</td>
</tr>
<tr>
<td>List</td>
<td>132,009</td>
<td>435</td>
</tr>
</tbody>
</table>

4.7 Continuity

To assure that all the work developed would not be in vain three important things had to be considered: How to assure that the application will be used, continuously updated and maintained. This section deals with the work done in each one of these areas.

4.7.1 Use

This application has a big importance in the correct use of the Sales Workflow App. Before the introduction of this App, to save time filling of some of the activities values (that are mandatory), predefined values were selected. With dashboard capabilities, the analyze potentiated will only be completely useful if all fields are filled with the appropriate values.

With this in mind, there was a desire to obtain big “sponsors” for the App since the begging, accomplished with the inclusion of senior leadership and other carefully selected employees in the beta tester group.

To empower users, two presentations were delivered, one in Lisbon and another in Porto, where the applications features were explained and demonstrated. These presentations were recorded and
published in a collaboration tool to be leveraged by any employee.

Regarding on-line help, a Yammer (collaboration application) group was set, being accessible from the application, so that developers and other users may answer questions and comment on suggestions.

If a Frequently Asked Question arises, a developer, after answering it in Yammer, should access the admin portal and add the question, respective answer and optionally a link for further information. The FAQ page is available for all users to see previously answered questions.

4.7.2 Development

To assure the continuous development of this App, an extensive technical documentation on all its aspects was written, with two crucial sections, that usually are not part of this documents:

- An extensive tutorial on how to set the application up, including OS configuration and the installation of all the components, and possible alternatives, for e.g. there is a tutorial to deploy the PostgreSQL in the same server as the App and another to deploy the PostgreSQL in a standalone server;

- A section dedicated to the future development, with reference to the tools and processes used for the initial development, as well as some feature suggestions and other tips.

Besides this, two meetings were set with the developer that will be in charge of the App in the future with the following agenda:

1. Introduction to the App, in a technical point of view, with a brief explanation of how the documentation was written. At the end of the session a challenge for a new feature was made;

2. Evaluation of the feature implementation and doubt session for all the problems that appeared during its development.

4.7.3 Maintenance

The maintenance was assured by one of the sections of the documentation that was written like a tutorial on how to update the different components of the application.

Initial considerations, such as using CentOS 7 to assure consistency in the production environment, were also essential to ensure the business continuity of the App.
Conclusions and Future Work
This thesis will enable Dimension Data to start selling cloud solutions, both by understanding the offers in the Portuguese market, as well as by learning the features and capabilities of its Infrastructure as a Service (IaaS) offers.

The report on the IaaS Portuguese cloud market was the first comparison of offers sold in Portugal and has proven itself useful for Dimension Data Sales and Pre-Sales teams. It led to the conclusion that there are several vendors with production and enterprise-ready offers, that will certainly act as a replacement to the traditional non-cloud Information Technology (IT).

Unfortunately, not all vendors considered participated in the study, resulting in the exclusion of some solutions from the feature analyze. It was also noted that the cloud readiness of Portuguese sales teams was sometimes insufficient, with the answers and clarifications about the solutions being delivered by European (non-Portuguese) employees.

All things considered, different solutions fit distinct use cases, with some vendors clearly focused on resilience whereas others wager on advanced automation features.

The fact that this report was done in Dimension Data (DD) was crucial due to the training on cloud solutions (internal) and participation in product and benchmark presentations (internal and partners, e.g.: Cisco) received during the internship. The increased responsibility, brought by the relevance of the report for the sales team together with the absolute need for information accuracy, motivated the assembly of a report that improved my knowledge not only on Cloud solutions in the Portuguese market, but also in what is pertinent for an IaaS offer.

The implementation of a mobile-ready web application was successful, leading to the empowerment of about two hundred DD employees with a tool to analyze how they perform and how the sales processes evolve.

The deployment of the application in the cloud environment allowed the understanding of its advantages, like the:

- Easiness selecting CPU speeds (Table 4.3) that in traditional IT could require the acquisition of new physical servers that out-performed the ones installed;

- The possibility to have three servers working at peak times while paying for the compute resources of just one for most of the time. In traditional IT this would imply the need for three servers, two of them frequently in idle;

- The enabling of DevOps, with a direct translation in this application development, that started in a lab environment and was later moved to a cloud environment. While the first depended on the IT department, the second was accessible through the internet, and with self-service control over the infrastructure, releasing IT human resources and allowing for a faster, more dynamic approach to development.

It was proven that the application could run with better performance in cloud environments, which may lead to an adoption of cloud initiatives by DD Portugal, that has so far, a non-cloud approach for their house-developed applications.
Concerning learning, the application empowered me to improve programming skills, mainly in test and debug fields, being this the first academic project where there was a needed to assure that further development (by someone else) was possible and wouldn’t disrupt the already accomplished features and assurances. Knowledge of infrastructure and architecture was another major improvement granted by the development of this application, where availability and fault recovery were mandatory, making the choice of the components and its connections critical.

About results applicability, the report is a DD’s working paper leveraged by its European sales teams, and the application is not only used by two hundred employees on a daily base, but also constitutes a test case for DD’s public cloud.

The report analyzed some features and implications lightly, so I recommend further researched on this matter. This recommendation applies to the case of multi-cloud libraries and hybrid cloud management solutions, that bring advantages due to different cloud offers being featured in separate use cases. An extend analyze on the implications of public cloud versus private cloud in the use cases was also not conducted, yet it has extreme relevance for some companies that are now trying to understand the benefits and downsides of these deployment models.

Regarding the application, the proposed future work is the migration of the several house-developed applications to cloud environments. This proposal would qualify in-house development with DevOps capabilities, for a more agile development. The ground work for this was already done during the development of the "Dashboards" application.


Enterprise Cloud IaaS solutions features
### Table A.1: Compute resilience features by solution analyzed. Critical features are empathized, "✓" for Yes, "," for Not Applicable, "x" for No, "∂" for Partial and "?” for No Information.

<table>
<thead>
<tr>
<th>Solutions</th>
<th>VM Auto-restart</th>
<th>Affinity-rules</th>
<th>Anti-affinity rules</th>
<th>VM-preserving Host maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWS</td>
<td>∂</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Cisco Metapod</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>DD CaaS</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>DD PCEE</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Fujitsu k5</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Fujitsu k5 Dedicated</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>IBM SoftLayer</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>IBM BlueBox</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>?</td>
</tr>
<tr>
<td>Microsoft Azure</td>
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<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
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<td>✓</td>
<td>✓</td>
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### Table A.2: User Management features by solution analyzed. Critical features are empathized, "✓" for Yes, "," for Not Applicable, "x" for No, "∂" for Partial and "?” for No Information.

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<thead>
<tr>
<th>Solutions</th>
<th>Active Directory</th>
<th>Multiple users</th>
<th>Multiple API keys</th>
<th>RBAC</th>
<th>Quotas</th>
<th>Billing alerts</th>
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<tbody>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
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<td>Cisco Metapod</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
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<td>✓</td>
<td>x</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>DD PCEE</td>
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<td>✓</td>
<td>✓</td>
<td>x</td>
<td>x</td>
<td>✓</td>
</tr>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>∂</td>
<td>✓</td>
<td>✓</td>
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<td>✓</td>
<td>✓</td>
<td>∂</td>
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<td>∂</td>
<td>x</td>
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<td>∂</td>
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### Table A.3: Big Data Enablement features by solution analyzed. Critical features are empathized, "✓" for Yes, "," for Not Applicable, "x" for No, "∂" for Partial and "?” for No Information.

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<th>Solutions</th>
<th>VM 32x256</th>
<th>Access to GPUs</th>
<th>Object Storage</th>
<th>Services for Hadoop</th>
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<td>∂</td>
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<td>∂</td>
</tr>
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<td>x</td>
<td>✓</td>
<td>∂</td>
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<td>∂</td>
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<td>∂</td>
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<td>-</td>
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<td>x</td>
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</table>
Table A.4: Architecture flexibility features by solution analyzed. Critical features are empathized, "✓" for Yes, "-" for Not Applicable, "x" for No, "∂" for Partial and "?" for No Information.

<table>
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<th>Feature</th>
<th>Customization</th>
<th>Non virtualized Machines</th>
<th>Single Tenant Host</th>
<th>File storage</th>
<th>Performance Block Storage Tier</th>
<th>Economy Block Storage Tier</th>
<th>VM Independent</th>
<th>Multiple VMs Connected</th>
<th>Expandable Volumes</th>
<th>Static IP address</th>
<th>Complex hierarchical network topologies</th>
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Table A5: Security and Compliance features by solution analyzed. Critical features are emphasized. ✓ for Yes, x for No, for Not Applicable, ∂ for Partial and ? for No Information.
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Table A.7: Automation and DevOps Enablement features by solution analyzed. Critical features are emphasized, “✓” for Yes, “-” for Not Applicable, “x” for No, “∂” for Partial and “?” for No Information.

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<td>✓</td>
</tr>
<tr>
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<td>✓</td>
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<td>✓</td>
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<td>✓</td>
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</tr>
<tr>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microsoft Blue Box</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For No Information, “?” is used. Critical features are emphasized, “✓” for Yes, “-” for Not Applicable, “x” for No, “∂” for Partial and “?” for No Information.
Table A.8: Scaling features by solution analyzed. Critical features are empathized, "✓" for Yes, "-" for Not Applicable, "x" for No, "∂" for Partial and "?” for No Information.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Feature</th>
<th>Resizing</th>
<th>Simultaneous provisioning</th>
<th>Fast provisioning</th>
<th>Object Storage CDN Integrated</th>
<th>Load-Balancer</th>
<th>Auto-Scaling Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWS</td>
<td></td>
<td>∂</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Cisco Metapod</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
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<td></td>
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<td>✓</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>Fujitsu k5</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
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<td>✓</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>IBM BlueBox</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>Microsoft Azure</td>
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<td>∂</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
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<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
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<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td>∂</td>
</tr>
</tbody>
</table>
**Table A.9:** Backup features by solution analyzed. Critical features are empathized, "✓" for Yes, "-" for Not Applicable, "x" for No, "∂" for Partial and "?" for No Information.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Feature Snapshots</th>
<th>Complete</th>
<th>On-Premises Infrastructure</th>
<th>To Secondary Site</th>
<th>Disaster Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWS</td>
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<td>x</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Cisco Metapod</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DD CaaS</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>∂</td>
</tr>
<tr>
<td>DD PCEE</td>
<td>x</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fujitsu k5</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td>∂</td>
</tr>
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<td>✓</td>
<td>-</td>
<td>-</td>
<td>∂</td>
</tr>
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<td>x</td>
<td>✓</td>
<td>∂</td>
</tr>
<tr>
<td>IBM BlueBox</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>∂</td>
</tr>
<tr>
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<tr>
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<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
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<td>✓</td>
<td>∂</td>
<td>-</td>
<td>∂</td>
</tr>
</tbody>
</table>
Application Benchmark results
Table B.1: Impact of uWSGI workers in uWSGI in the response time, server with 1 vCPU (standard speed and 1 core/socket), 2GB RAM. Number of uWSGI workers doesn’t include master process.

<table>
<thead>
<tr>
<th># uWSGI workers</th>
<th>concurrent req</th>
<th>time [s]</th>
<th>req/s [#/s]</th>
<th>time/req [ms]</th>
<th>std dev [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>130.88</td>
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<td>130.88</td>
<td>49.40</td>
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<tr>
<td>2</td>
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<td>129.48</td>
<td>7.72</td>
<td>258.95</td>
<td>73.60</td>
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<tr>
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<td>7.71</td>
<td>388.90</td>
<td>86.60</td>
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<tr>
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<td>4</td>
<td>128.90</td>
<td>7.76</td>
<td>515.59</td>
<td>97.70</td>
</tr>
<tr>
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<td>5</td>
<td>129.34</td>
<td>7.73</td>
<td>546.68</td>
<td>101.80</td>
</tr>
<tr>
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<td>10</td>
<td>129.27</td>
<td>7.74</td>
<td>1292.73</td>
<td>175.30</td>
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<tr>
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<td>128.51</td>
<td>7.78</td>
<td>3212.67</td>
<td>462.60</td>
</tr>
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<td>7.42</td>
<td>134.69</td>
<td>48.00</td>
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<tr>
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<td>133.05</td>
<td>7.52</td>
<td>266.10</td>
<td>101.40</td>
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<td>397.34</td>
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<td>7.58</td>
<td>527.52</td>
<td>123.80</td>
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<td>7.55</td>
<td>662.60</td>
<td>143.90</td>
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<td>7.49</td>
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<td>7.44</td>
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<td>7.39</td>
<td>3380.71</td>
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</tr>
</tbody>
</table>

Table B.2: Impact of number of servers in the response time, server with 1 vCPU (standard speed and 1 core/socket), 2GB RAM, 1 uWSGI slave worker.

<table>
<thead>
<tr>
<th># servers</th>
<th># concurrent req</th>
<th>time [s]</th>
<th>req/s [#/s]</th>
<th>time/req [ms]</th>
<th>std dev [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>130.83</td>
<td>7.64</td>
<td>130.83</td>
<td>52.70</td>
</tr>
<tr>
<td></td>
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<td>7.66</td>
<td>652.86</td>
<td>107.50</td>
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<tr>
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<td>25</td>
<td>129.40</td>
<td>7.73</td>
<td>3234.92</td>
<td>465.00</td>
</tr>
<tr>
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<td>112.68</td>
<td>8.87</td>
<td>112.58</td>
<td>28.20</td>
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<td>5</td>
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<td>23.69</td>
<td>211.07</td>
<td>93.90</td>
</tr>
<tr>
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<td>25</td>
<td>42.64</td>
<td>23.45</td>
<td>1065.97</td>
<td>541.50</td>
</tr>
</tbody>
</table>

Table B.3: Mean and longest response time by URL, server with 1 vCPU (standard speed and 1 core/socket), 2GB RAM, 1 uWSGI slave worker.

<table>
<thead>
<tr>
<th>URL</th>
<th>time/req [ms]</th>
<th>longest request [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>/</td>
<td>33,831</td>
<td>253</td>
</tr>
<tr>
<td>/sales/</td>
<td>49,583</td>
<td>278</td>
</tr>
<tr>
<td>/sales/opportunities/state/global/</td>
<td>134,016</td>
<td>339</td>
</tr>
<tr>
<td>/sales/solutions/state/global/</td>
<td>130,743</td>
<td>376</td>
</tr>
<tr>
<td>/sales/tasks/state/global/</td>
<td>124,028</td>
<td>376</td>
</tr>
<tr>
<td>/sales/proposals/state/global/</td>
<td>165,641</td>
<td>414</td>
</tr>
<tr>
<td>/sales/opportunities/state/by-collaborator/</td>
<td>459,033</td>
<td>639</td>
</tr>
<tr>
<td>/sales/solutions/state/by-collaborator/</td>
<td>513,765</td>
<td>747</td>
</tr>
<tr>
<td>/sales/tasks/state/by-collaborator/</td>
<td>236,774</td>
<td>470</td>
</tr>
<tr>
<td>/sales/proposals/state/by-collaborator/</td>
<td>609,555</td>
<td>937</td>
</tr>
<tr>
<td>/sales/opportunities/state/global/list/all/</td>
<td>138,000</td>
<td>397</td>
</tr>
<tr>
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<td>383</td>
</tr>
<tr>
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</tr>
<tr>
<td>/sales/proposals/state/global/list/all/</td>
<td>165,667</td>
<td>435</td>
</tr>
</tbody>
</table>