An Evaluation Model for GI SMEs migrating to GeoCloud Services

Final Report

Student: Eoin Scollard
Solis ID: 6146368

Supervisor: Dr. Frederika Welle Donker
Responsible Professor: Dr. Peter van Oosterom

Place of Research: Tralee, Ireland
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In-Company Contacts:
Christian Lloyd (Geo Smart Decisions)
Marco Baars (Vicrea Solutions)
Joep Grispen (Nelen & Schuurmans)

Preface

This thesis was written in fulfilment of the course requirements of the Geographical Information Management and Applications (GIMA) programme. Cloud computing was something I knew little about starting out and my knowledge and interest has only grown since then. Here's hoping that I can work 'in the cloud' in future projects.

I would like to thank a number of people, without whom this final document would not have been possible. First and foremost, my fellow GIMA students have always offered inspiration with regard to all things spatial. Secondly, I would like to give special thanks to my supervisors Dr. Frederika Welle Donker and Dr. Peter van Oosterom, who were encouraging and supportive throughout this often meandering topic.

My in-company contacts, Christian Llyod and Crona Hodges (Geo Smart Decisions), Marco Baars (Vicrea) and Joep Grispen and Casper van der Wel (Nelen & Schuurmans) kindly gave me their time and facilitated this research. Thank you all very much.

Finally, I would like to thank Marta van Genderen (Oracle), Jas Bajwa (OmniSci), Antonin (My Geodata Cloud) and Yuri Raizman (GeoCloud), who answered my questions and gave me free access to their softwares and without whom I would have nothing to write about.

I hope that you find this read to be interesting and informative,

Eoin Scollard

21st of February 2019

List of Abbreviations

AHP – Analytical Hierarchy Process

Apdex – Application Performance Index

AWI – Ancient Woodland Inventory

AWS – Amazon Web Services

CaaS – Cloud-as-a-Service

CSMIC - Cloud Services Measurement Initiative Consortium

CSS – Cascading Style Sheets

DaaS – Data-as-a-Service

Db – Database

Db2 – ‘Database 2’

DSRM – Design Science Research Methodology

DTM – Digital Terrain Model

EIU- Economist Intelligence Unit

ESRI – Environmental Systems Research Institute

FAHP- Fuzzy Analytical Hierarchy Process

FTE – Full Time Equivalent

FTP – File Transfer Protocol

GDAL – GeoSpatial Data Abstraction Library

GI – Geographic Information

GIS – Geographic Information Systems

GSD – ‘Geo Smart Decisions’

HTML – Hyper Text Mark-Up Language

I/O – Input/Output

IaaS – Infrastructure-as-a-Service

IBM – International Business Machine

IDE – Integrated Development Environment

IoT – Internet of Things

IP Address – Internet Protocol Address

IS - Information Systems

ISO – International Organisation for Standardisation

IT – Information Technology

MAGDM - Multi-Attribute Group Decision Making

MCDA – Multi-Criterion Decision Analysis

N&S- ‘Nelen & Schuurmans’

NDVI – Nominalised Difference Vegetation Index

NMCDA – Neutroscopic Multi-Criteria Decision Analyses

OECD - Organisation for Economic Co-operation and Development

OGC – Open GeoSpatial Consortium

PaaS – Platform-as-a-Service

QGIS – Quantum GIS

QoS – Quality of Service

RDaaS – Remote-Desktop-as-a-Service

RE – Run Environment

ROI – Return On Investment

RQ – Research Question

SaaS – Software-as-a-Service

SaMoH - Space Assets for Monitoring of Habitats

SEF – Software Evaluation Framework

SLA - Service Level Agreement

SME – Small to Medium Enterprises

SMI – Service Measurement Index

SQL – Structured Query Language

SQuaRE – Software Quality Requirements and Evaluation

SSH - Secure Shell Keys

SVG – Scalable Vector Graphics

URL – Uniform Resources Locator

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Summary

The current thesis follows the 'Design Science Research Methodology' (DSRM) guidelines for the academic assessment of new IT innovations presented by Hevner et al. (2004). This work will contain six chapters: 1) Introduction to Cloud Computing, 2) Problem Context ,3) Problem Definition, 4) Solution Design and Development, 5) Demonstration, 6) Evaluation. The key findings are summarised below.

Background: The cloud is a new paradigm in IT and data management. Cloud technologies allow for data services (e.g. storage and processing) to be carried out using remote IT infrastructures (e.g. servers, software) via an internet connection. The cloud industry is growing rapidly and spatial or "geocloud" infrastructures are now an emerging niche within that industry.

Problem Context: This research investigates geocloud migration in Geographic Information Small to Medium Enterprises (GI SMEs). Previous research has suggested that 52% of SMEs do not engage in migration planning and that the evaluation methods adopted by SMEs tend not to be rigorous due to limited organisational resources (e.g. finance, time, IT skills). Furthermore, no cloud evaluation model has yet been developed which takes infrastructural, spatial data considerations into account in cloud environments. The aim of this research is to design a geocloud evaluation model, which can be easily applied by GI SMEs.

Solution Design and Development: A combined application index (Apdex) and Analytical Hierarchy Process (AHP) approach was designed in the current thesis which aimed to integrate both user needs and vendor testing. This approach involved reviewing relevant features across (geo) cloud platforms within a cloud matrix. GI SME decision makers were then presented with 81 feature scenarios and asked to rate their favourability relative to Apdex. Apdex calculations were then carried out for eight cloud attributes, rating their preferability between 0 and 1. In the case of variable cloud features (e.g. query response time), case specific performance testing was carried out to provide data for calculations. An overall cloud platform or scenario rating was then provided by weighing Apdex scores relative to cloud attribute importance, which had been adjusted relative to decision maker's certainty.

Demonstration: The applicability of the proposed geocloud evaluation approach was demonstrated in three GI SMEs in this thesis. All enterprises had an interest in migrating applications or spatial data products to the cloud. Participating organisations were all different sizes and offer a good cross-section of GI SMEs as a whole. Following the methodology above, the favourability of different geo-SaaS platforms or I/PaaS scenarios was quantified relative to user needs. Analysed as a percentage, geo-SaaS evaluation had a wider spread in terms of favourability, whereas, I/PaaS scenarios were quite homogenous in terms of their favourability.

Evaluation: The proposed evaluation model, in its current form, is more suitable to evaluating geo-SaaS offerings than more complex I/PaaS scenarios. No significant differences were observed when quantifying the favourability of different I/PaaS scenarios, in two of three cases. This result is unrealistic and likely occurred because feature preference questions were overly focussed on geo-SaaS. Withstanding this content-related shortcoming, the overarching framework presented here is still likely to be use-worthy, if improved. Each element of the proposed approach was evaluated with feedback from the participating decision makers,

Apdex: The applicability of Apdex to geocloud evaluation was rated with moderate positivity by decision makers, who stated that it was a straightforward method with which cloud favourability could be quantified.

AHP: Decision makers highly rated the AHP element of the current research as it simplified the complexity of cloud selection.

The need for further validation of this methodology is also highlighted. Ideally, a longitudinal analysis of outcome satisfaction, post cloud migration, would be carried out to assess the current model. Future work on this evaluation model should focus on the standardisation of evaluation matrices or indices and the quantification of the performance of different spatial cloud infrastructures such as PostGIS and Oracle Spatial.

1. Introduction to Cloud Computing

1.1 What is Cloud Computing?

In the past, digital content was confined to personal devices such as desktop computers, laptops and flash drives. However, in the mid-noughties, it became apparent that data processing and management could be done more efficiently, remotely, from large data farms. The outsourcing of data processing and management tasks became known as cloud computing.

Cloud computing was made possible by advances in internet connectivity as reliable, high bandwidth internet became widely available. The advantages of cloud computing became apparent as users could have "on the fly" access to content, without having to locally maintain hardware or software. Data can also be processed in a more sophisticated and less labour-intensive manner, remotely (Marinescu, 2012).

The cloud is not only attractive to large enterprises but also to SMEs and to governmental and non-profit organisations. The cloud gives users an opportunity to essentially rent computing power, digital storage space and IT tools from a cloud provider, via an Internet connection (Kumar & Mishra, 2012).

Today, major IT companies such as Google, Amazon, IBM, Microsoft and Oracle have become cloud computing vendors and manage data remotely. 'The cloud', as such, broadly describes all the data services which can be provided at a distance, via an internet connection (see figure 1.1).

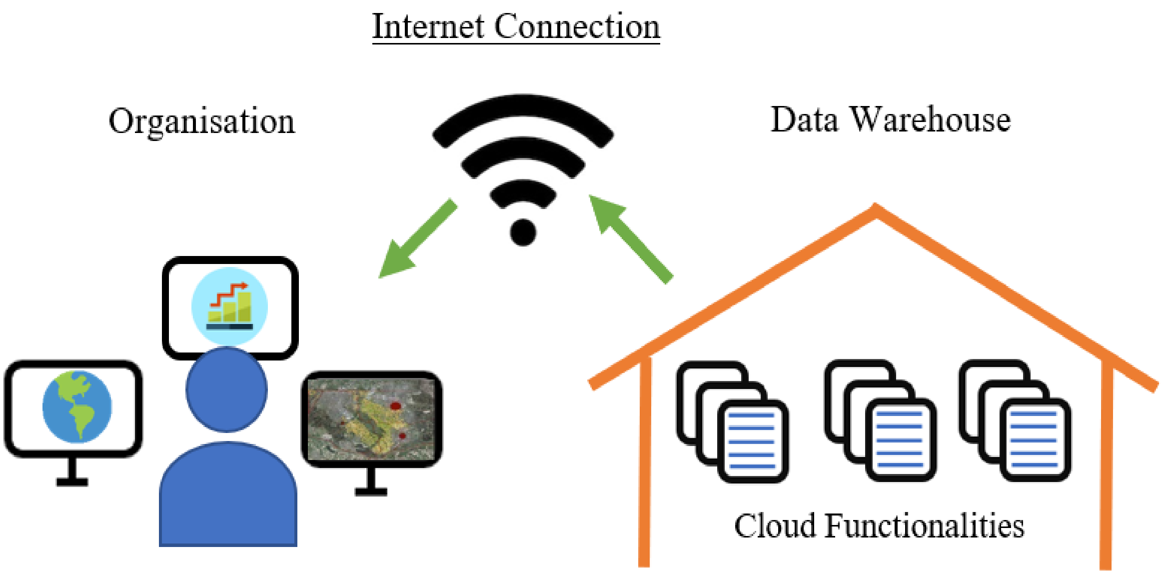

Figure 1.1 A conceptual model of cloud computing.

1.2 Cloud Functionalities

At present there are several prominent cloud delivery models: Infrastructure-as-a-Service (IaaS), Software-as-a-Service (SaaS) and Platform-as-a-Service (PaaS). A number of other 'as-a-service' models such as Data-as-a-Service (DaaS), Remote Desktop-as-a-Service (RDaaS) and Cloud-as-a-Service (CaaS) also exist but have not been considered in detail in this research.

This research will consider IaaS, SaaS and PaaS, as they are by far the service models which are most utilised by cloud vendors and consumers. A more detailed review of as-a-service models and cloud is provided in a 'cloud briefing document' in Appendix I.

Infrastructure-as-a-Service (IaaS): An IaaS system involves the virtual provision of computing power and/or memory by means of the (automated) management of hardware (servers) and software related to remote data storage, monitoring and retrieval (Mereno, 2013). Examples of IaaS include: Amazon Web Services (AWS) and Cisco.

Software-as-a-Service (Saas): Software-as-a-service is the provision of remote access to software as a web-based service. SaaS users gain online access to existing software applications, that can be used directly by a lay-person (Apostu et al., 2013). Examples of SaaS include online writing software like Google Docs and Grammarly, customer relations software like Bitrix24 and Asana and analytical software like Qualtrics.

Platform-as-a-Service (PaaS): Platform as a Service is the provision of an online environment for application development or content customisation. Several programming languages can be used including python, CSS, SQL and HTML (Devi and Janesen, 2012). The most prominent example of a PaaS is Google App Engine, however other PaaS systems exist such as Heroku, Amazon EC2 and Windows Azure.

Hybridised Cloud Functionalities: While IaaS, SaaS, PaaS are best described as separate entities from a theoretical perspective, hybridised versions of these services are often implemented in practice. Cloud providers such as AWS, Azure and Oracle offer integrated IaaS and SaaS services, for example. A simple illustration of an integrated IaaS and SaaS is Google Drive, which stores data remotely but also provides an easy- to- use interface for data retrieval, formatting and sharing.

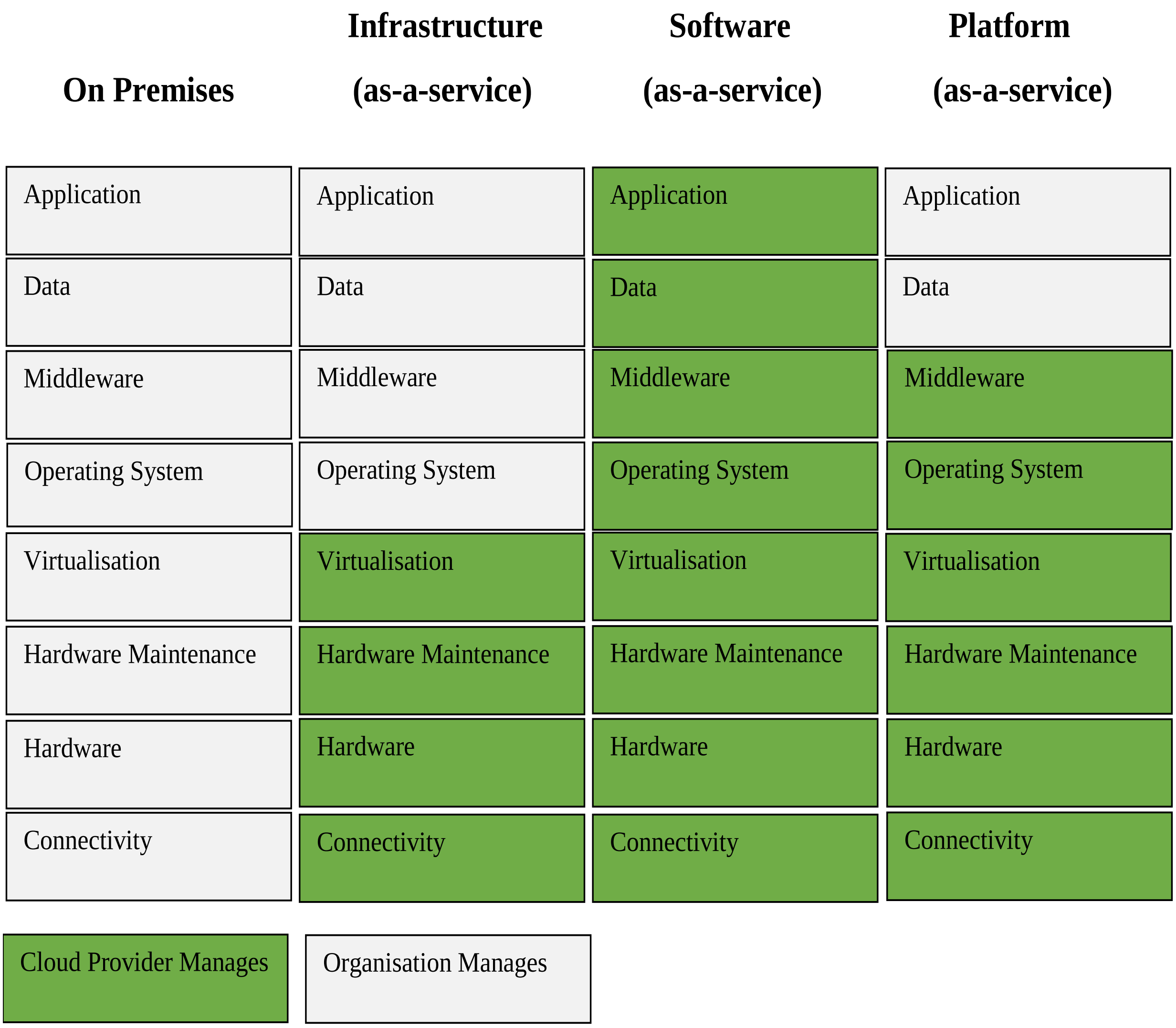

Figure 1.2 Management of Cloud Components

Figure 1.2 above displays the IT responsibilities which are involved in providing IaaS, SaaS and PaaS cloud services. Hybridised services, not displayed above, will have a different distribution of responsibilities depending on the hybridised services involved.

Cloud services can also be built from scratch (e.g. ‘on premises’), by an organisation that wish to control and maintain their data themselves. More detailed information about cloud components and architecture can be found in chapter 2 of the briefing document.

1.3 How Does the Cloud Work?

Cloud computing introduces new concepts and terminologies to the field of IT. In this research, these processes have been grouped into five steps: 1) Cloud Management, 2) Hardware Management, 3) Cloud Configuration, 4) Organising Cloud Services, and 5) Cloud Connectivity. All of the concepts will apply to large cloud vendors (e.g. AWS, Azure and Oracle), whereas all steps may not be relevant to smaller cloud providers (e.g. GeoCloud or OmniSci). Figure 1.3 (next page) displays the typical stepwise processes of establishing a cloud service. For a full review of the cloud concepts and terminologies see Section 1.3 in the cloud briefing document.

1) Cloud Management: Cloud management involves the migration of legacy products or services and/or the creation of new cloud services on the console (or command prompt) of the cloud vendor. This allows the user to interact with the cloud vendor's infrastructure and build their desired services.

2) Hardware Management: One of the first cloud considerations which needs to be attended to is the physical location of the hardware, on which the user- desired services will run. Cloud vendors have unique data regions (e.g. "Europe, Middle East and Africa") and data zones (e.g. "Central Europe). Different cloud services are available in different data regions and data zones and different legal and tax obligations also apply in different jurisdictions.

3) Cloud Configuration: The typical route to establishing a cloud service is to utilize an operating system/ middleware/ runtime template (e.g. 'Oracle Windows 2012, 10.6.0'), which is known as an 'Image', 'Virtual Machine' or 'Amazon Machine Image' in cloud computing.

4) Organising Cloud Services: Cloud vendors maintain several infrastructures which serve as a 'backend' for cloud services. Relative components of cloud services are known as 'resource groups or clusters' and will typically be assigned both public and private IP addresses.

5) Cloud Connectivity: Dissemination is the final aspect of establishing cloud services. Randomly- generated codes or *Secure Shell Keys* (SSHs) are typically utilized by cloud vendors. SSH allow for secure content access on an unsecure network. A pair of SSH keys will typically be provided to administrators, as login credentials.

Building a Cloud Service

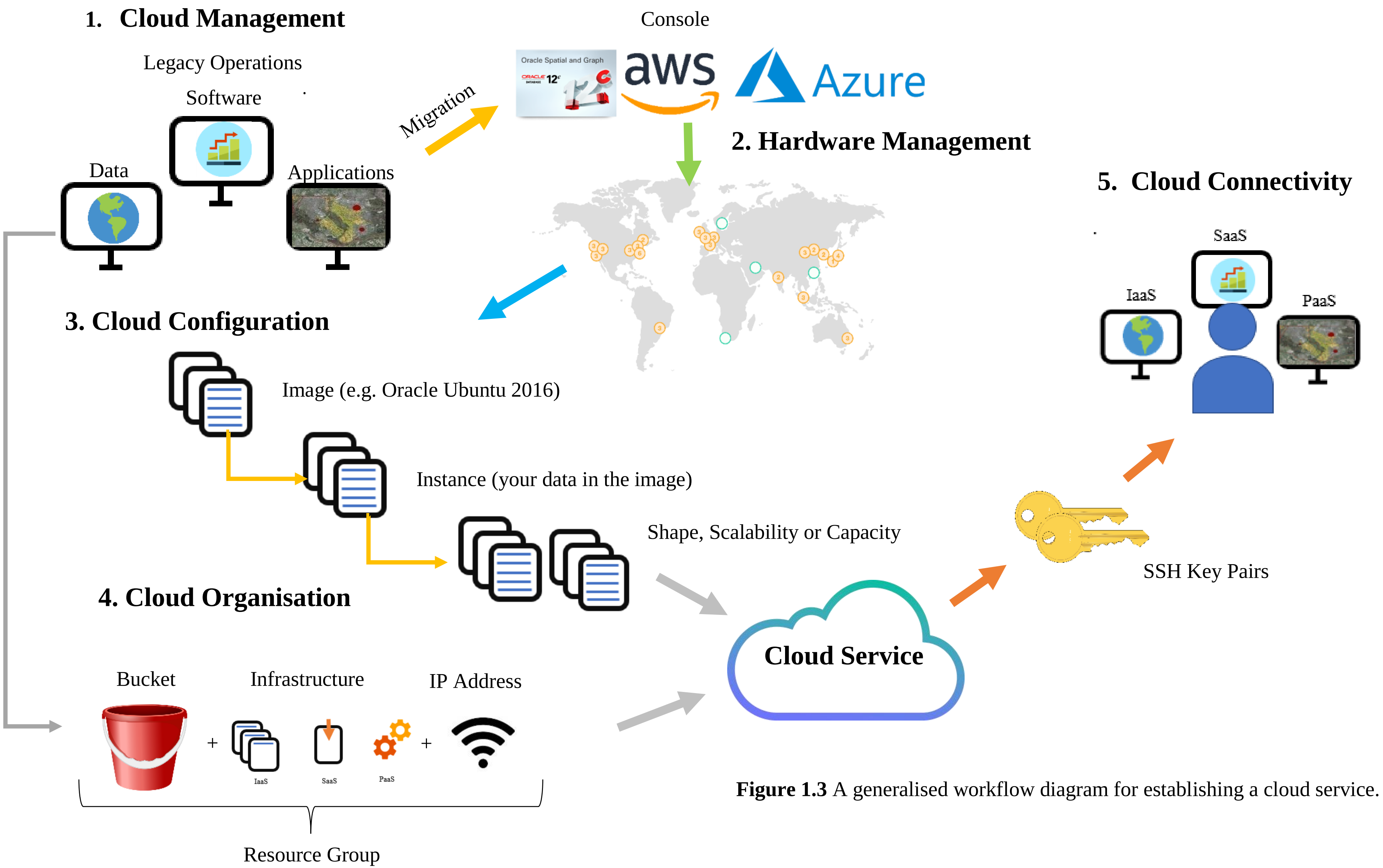

Figure 1.3 A generalised workflow diagram for establishing a cloud service.

1.4 Spatial Functionalities in the Cloud

Specialised ‘geocloud’ services are now an emerging niche within the cloud industry. The spatial functionalities which are now being offered by cloud vendors are described below (see also sections 2.2 and 3.1)

IaaS

Spatial functionality in IaaS services is provided in several ways by different cloud vendors. IBM’s DB2 (database 2) utilizes a “Spatial Extender” software extension which allows IaaS users to run geometric queries, utilize spatial “ST” functions and to geocode and make spatial indices. Similarly, Azure now offers ‘SQL DataWarehouse’ with a spatial extension allowing for the integration and manipulation of geometric data within the database. Both IBM and Azure’s spatial extensions for their database software are in line with OGC’s standards for geographic instances (IBM, 2017; Azure, 2017). AWS also has a number of (geo)cloud database offerings including Amazon RDS and S3. These IaaS offerings are compatible with MySQL and PostgreSQL for which spatial extensions can be utilized. AWS also has its own internal query engine “Amazon Athena“ which is again compatible with MySQL and PostgreSQL. The most recent development relevant to IaaS has been the launch of non-relational or ‘No SQL’ databases such as AWS’s Dynamo DB and Azure’s Cosmos DB. These databases can natively incorporate and index spatial data in formats such as JSON and GeoJSON. An additional advantage of No SQL IaaS is that geospatial data can be created using Python and NET and make it easier to connect IaaS databases and PaaS applications (Azure, 2017b).

IaaS within SaaS

SaaS platforms (e.g. GeoCloud, OmniSci etc.) also have ‘in-built’ IaaS functionalities. Spatial data could be uploaded to, and stored within, these SaaS platforms, by means of user-friendly HTML interfaces. The spatial formats (e.g. shapefile, tiff image etc.) which could be uploaded to these SaaS services vary depending on the vendor. Typically, data can be retrieved as a zipped file in the same format in which it was uploaded to the SaaS. Of the geo-SaaS offerings reviewed, only OmniSci had the capacity to natively query the data which was uploaded to the platform.

SaaS

Several geo-SaaS are now available on the cloud market (see figure 2.3). These online softwares differ significantly in terms of the spatial functionality which they provide. GISCloud, ArcGIS Online and My GeoData Drive provide subscribers with the opportunity to store, view or publish finished vector layers. OmniSci provides users with the opportunity to create vector maps and embed them in dashboards with other charts and visualisations from vector-attribute or separately uploaded data. Where applicable, data can also be queried with SQL and the results easily visualised. GeoCloud, AWS and Azure all provide remote access to third party GI softwares (e.g. ArcMap) via ArcServer or a Remote Desktop Protocol (RDP). This allows users to utilise any programmes which they may not have physically installed on their hard drive. These platforms also allow for interaction with raster data which is not possible in the SaaS platforms presented heretofore. The storage of, and online interaction with open raster data is also possible via AWS Earth. Oracle Spatial and Graph is a proprietary database environment for spatial and graph data wherein data can be stored and visualised.

PaaS

Platform-as-a-Service is the least developed of the three ‘as-a-service’ models considered heretofore. GISCloud presents a ‘developers centre’ where some useful codes for spatial applications can be gathered. ArcGIS Online allows for map applications to be built ‘code free’ but these spatial end products are proprietary and end- users need ESRI licencing to access the application. Notably, imagery from AWS Earth and maps from Oracle Spatial and Graph can be integrated in their respective PaaS environments and deployed publicly.

2. Problem Context

2.1 The Growth of the Cloud Industry

The cloud is a much-hyped paradigm in IT processing and data management. An increasing importance is being placed on IT enhancement and the utilization of the most up-to-date software and hardware. Migrating IT operations to the cloud is often a tactical move by decision makers, who wish to optimise their IT workflows or improve the attractiveness of their organisation's brand (Wilcocks and Lacity, 2012). Globally, the cloud industry is seeing exponential growth and according to Gartner (2018), the public cloud industry will grow from a value of $175 billion in 2018, to $278 billion by 2021. Gartner (2018) also forecasts that 90% of data-using organisations will have migrated to integrated IaaS and PaaS services by 2022.

According to Rackspace Australia (2016), the four primary motivations for cloud adoption among IT decision makers are: 1) increased resiliency, 2) increased agility, 3) stabilising existing platforms/apps, and 4) reducing cost. These factors, together with an array of other more minor influences (see below) are steadily increasing the popularity of the cloud over time.

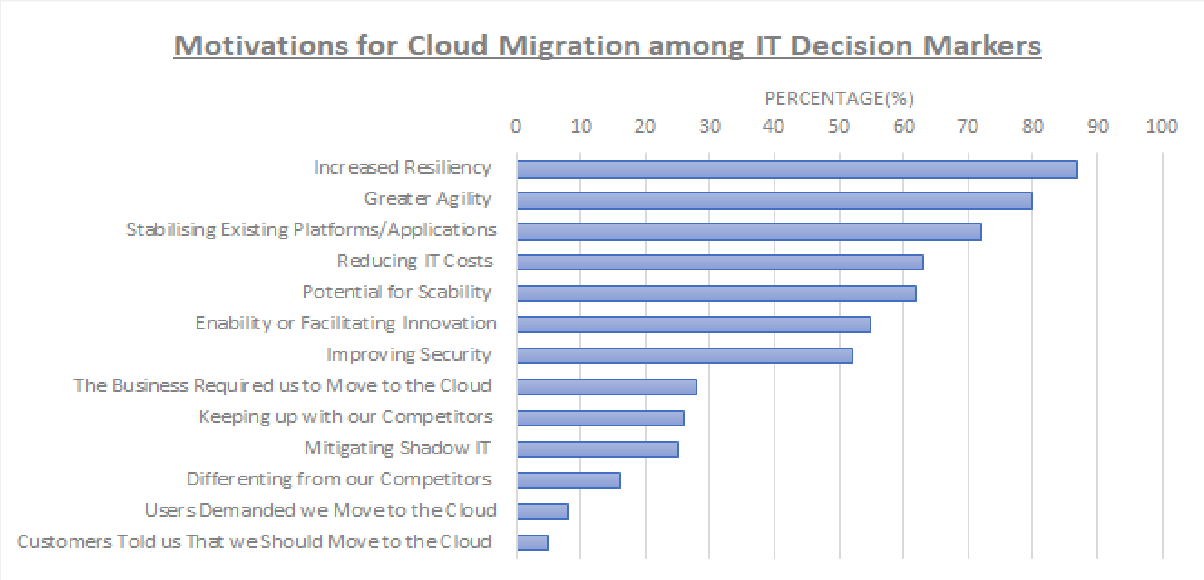

Figure 2.1 *The percentage of IT decision makers to include the above rationale in their decision to move to cloud environments. Sample was taken from 100 IT professionals in Australia in 2016. This survey was completed by Rackshare Australia (2016).*

Marinescu (2012) suggests that cloud computing is now being adopted, in some form, across all data-related industries including: academia, gaming, retail and manufacturing. The Economist's Intelligence Unit (EIU) published a more detailed report in 2016, assessing the growth of the cloud across industries. The 2016 report attempted to assess the growth of cloud technologies in several sectors: 1) financial services, 2) retail, 3) healthcare, 4) education, and 5) manufacturing. Figure 2.2 demonstrates the responses of 360 senior executives and thought-leaders when asked about the prevalence of the cloud across these industries. Responses shown in figure 2.2 were either classed as being 'significant' (e.g. the cloud is being widely used in this industry) or 'pervasive' (e.g. cloud technologies are widely available in this industry but are not necessarily being widely adopted).

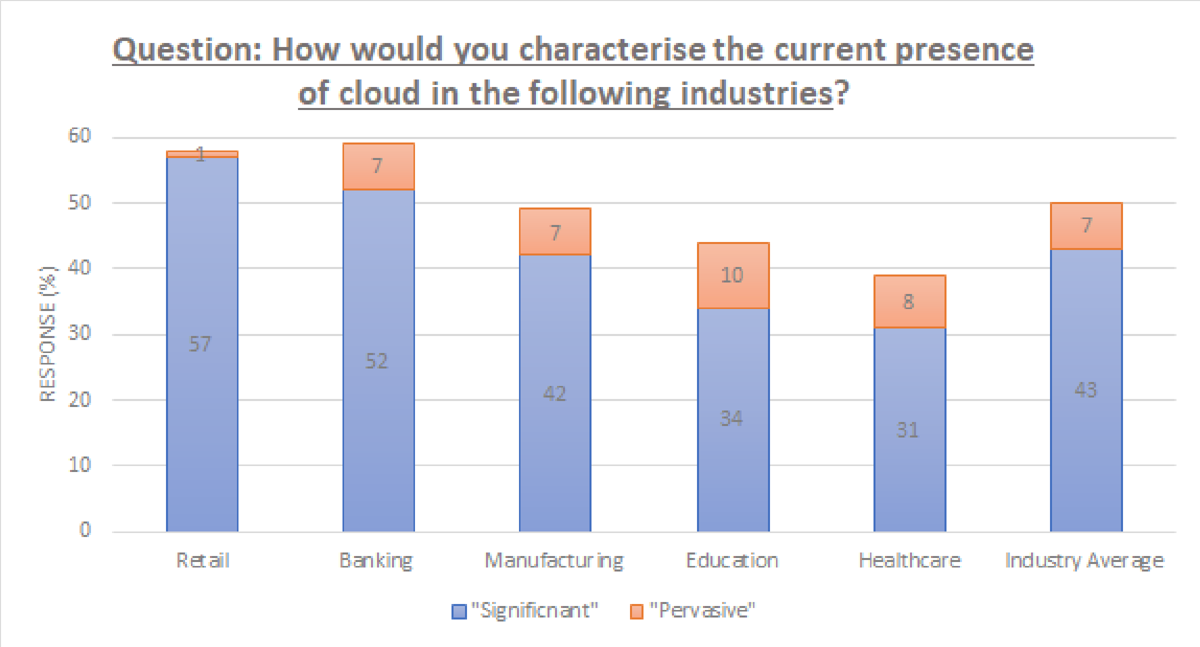

Figure 2.2 *The percentage of industry experts and thought leaders to respond to the above question with answers which could be classed as 'significant' or 'pervasive'. The sample was taken from 360 individuals in October 2015. Respondents were distributed across developing and developed countries. This survey was completed by the Economist Intelligence Unit (EIU, 2016).*

The EIU's research suggests that the quickest adopters of cloud technologies are retail and banking. These two industries appear to be adopting the cloud more readily as they can develop cloud infrastructure whilst maintaining their offline legacy operations (e.g. digital/ in-house banking and electronic/high-street shopping). The competitive nature of these industries appears also to be acting as a catalyst to cloud adoption in these sectors.

In contrast, cloud adoption is notably more subdued in manufacturing, as physical infrastructures such as distribution hubs and assembly lines need to be taken into account when implementing a cloud. Slower cloud adoption in educational and healthcare industries is attributed to bureaucratic hindrances as well as to the lesser competitive pressure in these industries (EIU, 2016).

The EIU's report identifies some of the key trends and challenges related to cloud adoption across several sectors. However, this report fails to specifically focus on the quaternary or knowledge sector, which has been highlighted as a growing field in cloud computing by several authors (e.g. Marinescu, 2012; Dave et al. 2013). Cloud solutions for knowledge purposes are also particularly relevant to spatial cloud uses.

Some of the industry- specific challenges to cloud adoption, identified in the EIU report are also relevant to the adoption of spatial cloud services. However, more specific technical challenges are faced in the adoption of spatial or 'geocloud' services, which will be further discussed in chapter 3.

2.2 The Emergence of the 'GeoCloud'

Cloud infrastructures,, which are built to predominantly handle spatial data or 'geoclouds', are now being developed in several ways. Several cloud vendors such as AWS, AZURE and IBM, have recently developed database links with ESRI's ArcGIS server. In addition, major cloud platforms have begun to incorporate spatial functionality into their existing services such as Microsoft's "Azure Cosmos DB" and Oracle's "Oracle Spatial and Graph". Furthermore, spatially dedicated geocloud providers such as OmniSci, GeoCloud, MyGeoData and GIS Cloud have also recently emerged (see below).

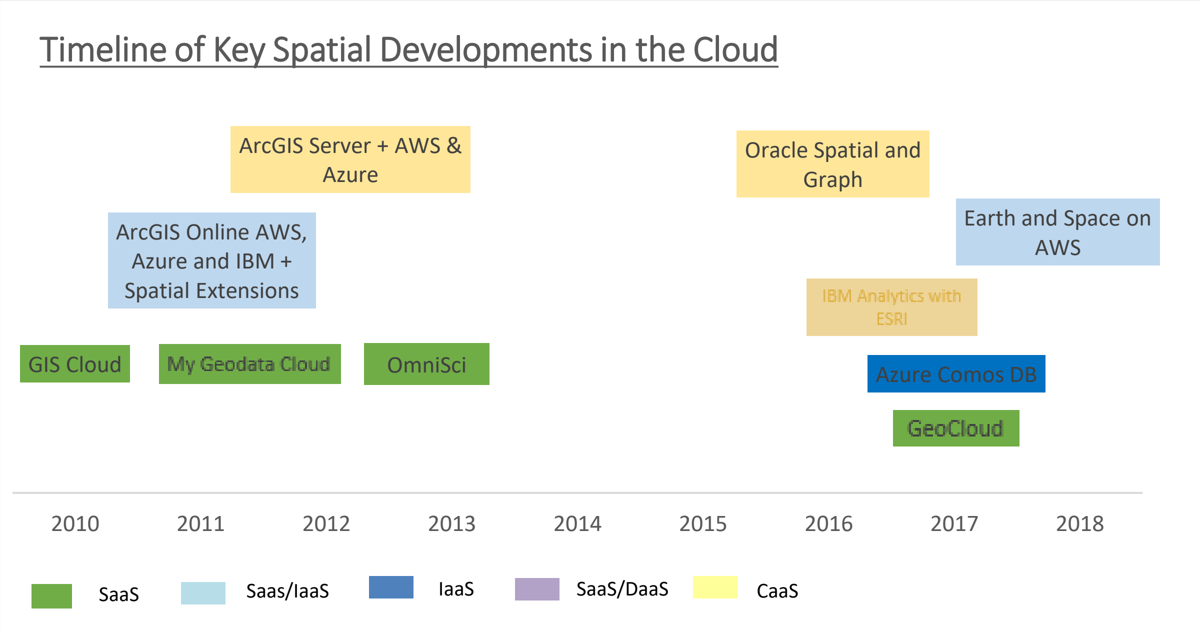

Figure 2.3 *Key Spatial Developments in the Cloud. Compiled from the launch dates or spatially related features on vendor websites. For more information about the different "as-a-service" categories please see Section 1.3 of the briefing document. The above review is by no means exhaustive but provides insight into some of the developments most relevant to this research.*

It is clear that geo-functionalities are emerging and will continue to emerge, within the cloud industry. The early 2010's saw spatial extensions added to IaaS databases and the emergence of ArcGIS server software linking ArcGIS desktop to the cloud. At this time, geo-SaaS platforms such as ArcGIS online, My GeoData Cloud and OmniSci also came to the fore offering the hosting and manipulation of vector data in an online environment.

2016 saw the advent of Oracle Spatial and Graph which boasts the capacity to visualise spatial data and graph triples. In more recent years the spatial data functionalities available via cloud vendors have grown to focus on higher volumes of data (e.g. the 'Internet of Things' and 'Big Data').

IBM and ESRI launched a joint analytical cloud service in 2017, aimed at processing live data and most recently AWS announced AWS 'Earth and Space', which will allow satellite imagery to be linked with applications built in AWS's PaaS environment.

2.3 Cloud Migration

While the spatial functionalities within the cloud are undoubtedly growing, the process of moving legacy operations (e.g. offline databases, software etc.) to the cloud – or *cloud migration,* remains difficult for relevant decision makers. Objectively weighing up the advantages and disadvantages of cloud adoption is challenging for decision makers as multiple factors such as data integration, cost and security need to be taken into account (see figure 2.4).
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A considerable number of IT decision makers, continue to express concern about cloud adoption. In a global survey in 2015, 40% of relevant decision makers were sceptical about cloud adoption (Harris Poll, 2015). Costa (2013) attributes this scepticism to 'stigmas' surrounding cloud disadvantages. Nonetheless,the cloud industry continues to grow, and it is estimated that 50% of all IT processes will be carried out in the cloud by 2020 (Garrison et al., 2015).

It is clear that questions of *what, when, how* and *which* regarding cloud migration, are all difficult questions to objectively answer for relevant IT decision makers. The key issues faced by decision makers in migrating to the cloud are summarised below.

- **Weighing up the cloud benefits**: The identification and weighing up of cloud risks and benefits is often done subjectively by decision makers.

- **Multiple cloud vendors**: A myriad of different (geo) cloud vendors now exists on the market, offering various services, with different infrastructures and pricing plans.

- **Different interests among decision makers**: Different individuals within an organisation may have different requirements from the cloud. In the absence of a consensus, adopting a cloud which "fits all" can be difficult.

- **A lack of previous cloud experience**: Making informed decisions about cloud adoption depends on having previous experience with cloud services. Many decision makers migrating to the cloud, however, have little previous cloud experience (Adbel Basset et al., 2018).

The above factors remain difficult to disentangle for decision makers migrating to the cloud. Liu et al. (2016) suggests that many decision makers are now taking a 'best guess' approach when selecting an appropriate cloud provider as they are under competitive pressure to implement cloud technologies.

Apostu et al. (2013) further highlight that migration challenges are likely to be particularly difficult to navigate for decision makers in smaller organisations as such individuals have less personnel and monetary resources. It is speculated here that this issue is worsened for decision makers in GI SMEs in particular, which will form the core focus of this research.

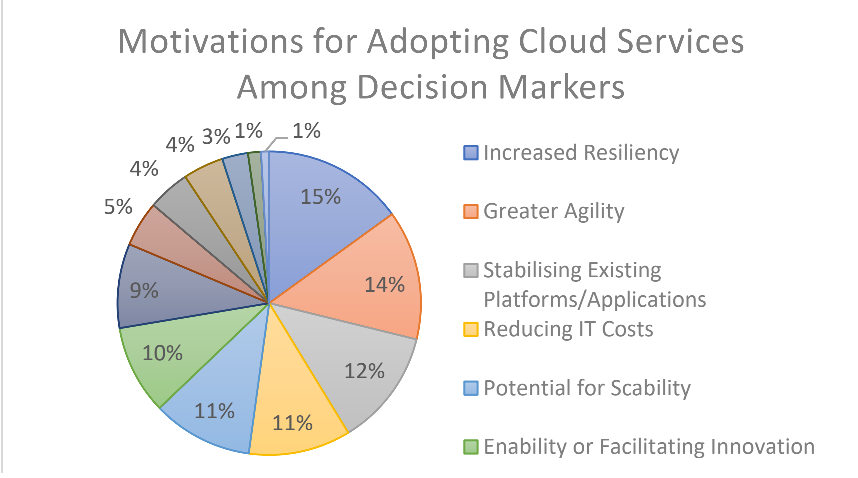
<table>
<tr><th colspan="3">Cloud Considerations for Decision Makers</th></tr>
<tr>
<td>Advantages</td>
<td>The cloud is becoming increasingly popular among data- using organisations, for several reasons. In the past hardware and software needed to be installed and maintained locally. In contrast, a cloud environment will provide “on-demand” access to content and software on multiple devices such as laptops, smartphones and tablets (Marinescu, 2012). Additionally, most cloud providers adopt a pay-per-use pricing model, meaning that customers, avoid overpaying and under-using physically installed IT services (Obrutsky, 2016). The cloud will also typically provide easy backup and recovery processes as well as virtually ‘unlimited’ storage (Apostu, 2013). Attractively, the cloud also provides potential customers with the opportunity to rent sophisticated data services, such as live map analytics, at a fraction of the build cost (Opara-Martins et al. 2014).</td>
<td>

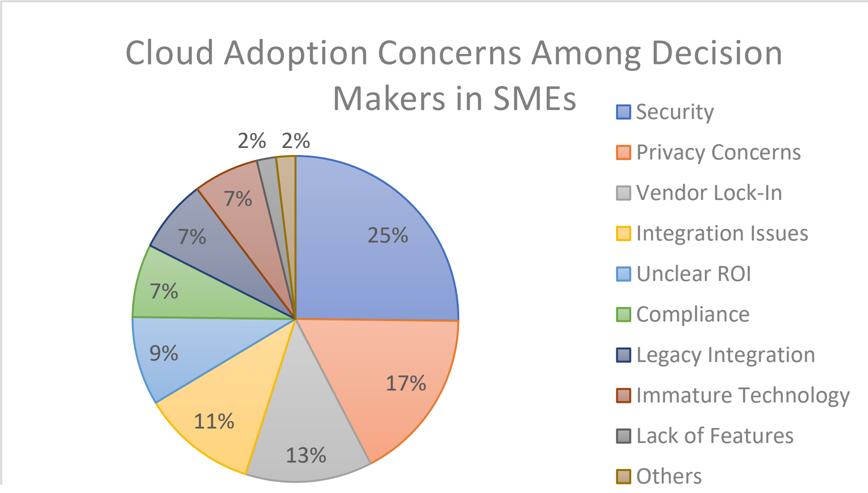
Figure 2.4.1 Motivations for Cloud adoption adapted from RackShare (2016)</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>While the on-demand delivery method of cloud services is advantageous, it brings with it security concerns, which are considered to be the major challenge to cloud adoption. Increased accessibility carries with it a higher risk of content mis-use and data breach, which can be a major concern (Subramanian and Jeyarai, 2018; Kumar and Mishra, 2012; Marinescu, 2012). At a glance, pay-per-use pricing models may appear to be more cost effective, however cloud users often report facing cost creep due to hidden charges (Al-Duraibi, 2018; Apostu et al. 2013). In addition, cloud IaaS, SaaS and PaaS are often designed not to be interoperable (e.g. with unique data formats), this cloud feature is known as “vendor lock-in”, which makes it difficult for users to exit the cloud service (Opara-Martins et al., 2014).</td>
<td>

Figure 2.4.2 Concerns about cloud adoption among decision makers in SMEs (Nazir and Jamshed, 2016)</td>
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</table>

Figure 2.4 A summary of cloud advantages and disadvantages (see cloud briefing document in Appendix I for full review).

2.4 Cloud Migration in SMEs

As defined by the OECD, small to medium enterprises (SMEs) are non-subsidiary firms which employ fewer than 250 individuals. Within SMEs ‘micro’, ‘small’ and ‘medium’ organisations can also be defined. ‘Micro’ enterprises employ fewer than 10 individuals and ‘small’ businesses employ fewer than 50. ‘Medium’ sized enterprises provide employment for between 50 to 250 individuals (OECD, 2005). With the growth of the cloud, different adoption trends are emerging within SMEs.

Cloud services are particularly attractive to (geo) start-ups and SMEs as they provide these organisations with the opportunity to ‘rent’ IT services, which would typically be beyond their means to develop from scratch (Marinescu, 2012; Opara Martins et al., 2014). Cloud IT infrastructures provide smaller organisations with three major advantages: 1) avoiding upfront server cost, 2) avoiding build and maintenance costs or responsibility, and 3) fast and scalable deployment (Mahmood, 2011). To illustrate, take for example a start-up company which has built an online application. This organisation can 1) purchase, set-up and maintain a server to host this application or 2) use an existing cloud PaaS to make the online application live quickly.

Objectively deciding between option 1 and option 2 above is difficult because numerous factors need to be taken into account (see figure 2.4). However, the key issues affecting decision makers in cloud selection (see section 2.3) are more likely to adversely affect SMEs, whose resources to systematically investigate potential cloud services are limited. SMEs are also likely to have less cumulative cloud experience among staff and are more likely to have less time or personnel resources to dedicate to cloud migration planning (Apostu, 2013).

Surveying 95 SMEs in Ireland, Carcary et al. (2013) found that less than half had migrated to cloud services and of the percentage that did migrate, less than 20% had engaged in any significant cloud evaluation or readiness assessment. Figure 2.5 below displays the typical cloud preparation activities undertaken by Irish SMEs.

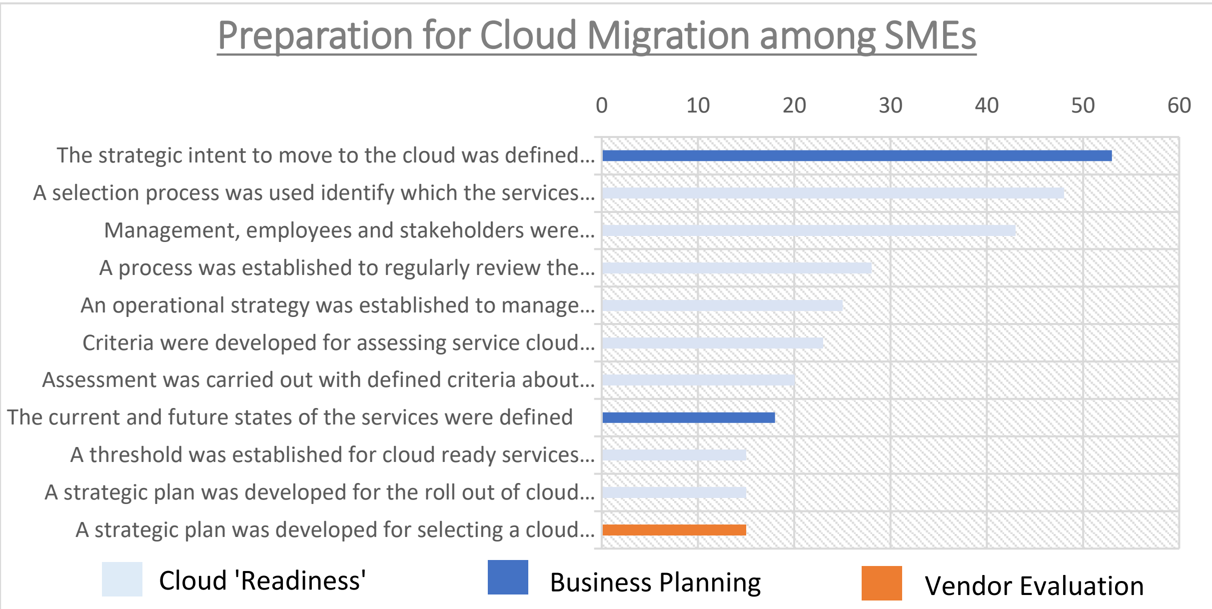


Figure 2.5 *Typical Preparation for Cloud Migration among SMEs (Carcary, 2013). Sample taken from 95 SMEs in Ireland in 2013*. 48% of cloud adopters established a preparatory ‘cloud strategy’. *Categorisation has been added.*

Figure 2.5 represents only 48% of respondents among SMEs. The remaining 52% did not engage in any cloud planning/evaluation prior to migrating. Of the SMEs that did adopt a cloud evaluation strategy, approaches fell into 1 of 3 categories: 1) decisions based on business planning, 2) decisions based on the assessment of 'cloud readiness', and 3) decisions based on vendor evaluation or planning. Employed on their own,, each of these approaches has merit but they do not comprehensively assess the migration process. Carcary concludes that cloud preparation is less rigorous in SMEs due to limited resources and more informal work protocols.

The tendency not to engage in rigorous cloud planning or evaluation and the lack of resources among (GI) SMEs are identified as the two organisational problems in this research. Figure 2.4 previously, also displays the major concerns which SME decision makers have about cloud migration and it is evident that the issues raised (e.g. vendor lock-in, unclear ROI etc) suggest a lack of cloud awareness or expertise among relevant SMEs. Interestingly, of the Irish SMEs to migrate to the cloud, 79% were micro-firms (under ten employees). It is suggested that the cloud gives micro-firms, in particular, the opportunity to compete more effectively.

Also relevant are trends garnered from decision makers in SMEs, who decided not to migrate to the cloud. Figure 2.6 below demonstrates the typical reasons for cloud non-adoption. Among the primary reasons for cloud non-adoption in SMEs were 'security concerns' (40%), 'lack of time' (40%), 'lack of IT skills' (35%) and 'lack of finances' (26%). Again, two relevant categories emerge from this data: 1) The lack of resources for cloud infrastructures among time and IT skills) appears to be hindering SMEs from adopting and planning for cloud migration. Some of these issues (particularly time and IT skills) can be helped by providing SME decision makers with accessible tools (e.g. an evaluation model) which will allow them to more readily weigh up (geo) cloud infrastructures.

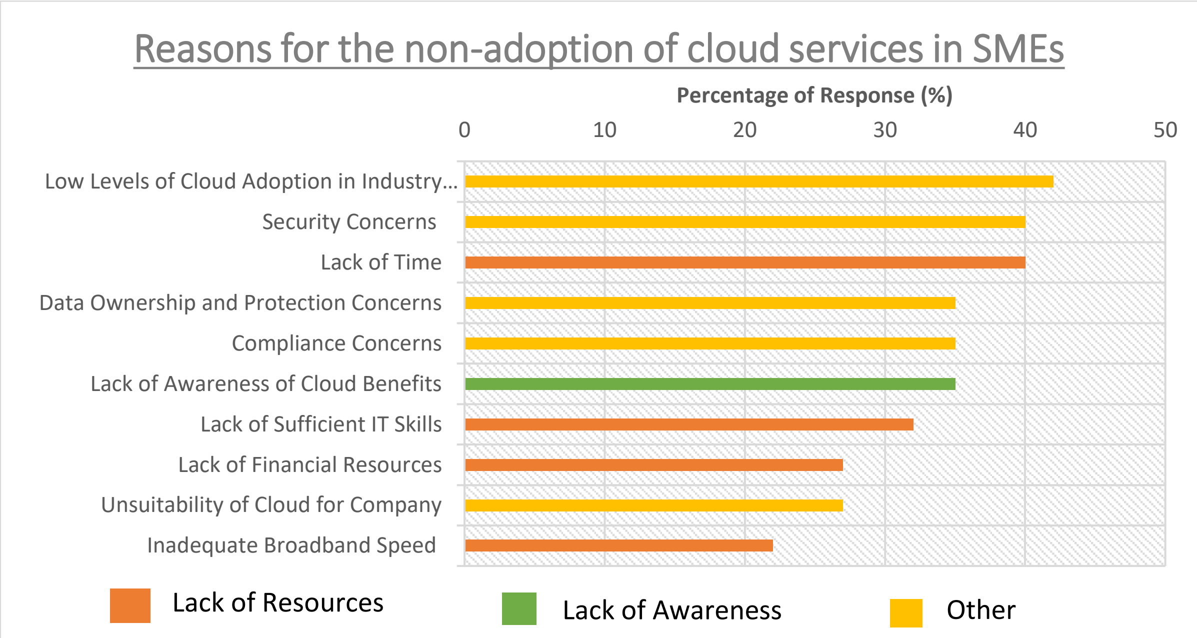


Figure 2.6 *Reasons for the non-adoption of cloud services in SMEs (Carcary et al., 2016). Sample taken from 95 SMEs in Ireland in 2016. Categorisation has been added.*

SME migration trends also appear to be independent of economic conditions. Surveying 149 SMEs in Australia, Senarathna et al. (2018), for example, also found that cloud adoption is correlated positively with greater ‘cloud awareness’ and organisational size.

Similar trends are also observed in emerging economies. For example, assessing adoption factors among 45 SMEs in Kenya, Wachanga et al. (2018) found the “lack of ICT skills” to be the biggest barrier to cloud adoption. Adam and Musah (2015) further highlight that Quality of Service (QoS) factors such as ‘broadband quality’ and ‘network reliability’ are additional deterrents to cloud adoption in developing economies. Such global cloud adoption trends among SMEs support suggestions that ‘on the fly’ approaches to cloud evaluation are widely adopted in SMEs. The need for a systematic cloud evaluation technique, given the organisational constraints of SMEs, is apparent.

2.5 Cloud Migration in GI SMEs

To the knowledge of the author, no previous research has specifically focussed on the migration of spatial data to the cloud in GI SMEs. The next chapter (‘problem definition’) will formalise the research gap to be filled by this research.

3. Problem Definition

Carcary et al. (2014) carried out a quantitative assessment of the appropriateness of existing cloud evaluation frameworks for Irish SMEs. Results found that existing frameworks were unsuitable 'as-is', for SMEs, due largely to organisational constraints. Authors advocate for the development of a cloud evaluation framework designed for the organisational needs of SMEs. Here such a framework for SMEs will be constructed, but which more specifically, takes spatial data considerations into account.

For this reason, both *organisational* (i.e. related to company resources) and *infrastructural* (e.g. geocloud functions) considerations serve as the key inputs into the current model. Firstly, the existing cloud evaluation techniques are described and discussed in Section 3.1. *Spatial data* considerations for GI SMEs are outlined in Section 3.2. The *organisational* considerations are described above in Section 2.4 and will be discussed further here.

3.1. Existing Cloud Evaluation Techniques

There are two generic (non-spatial) approaches which are relevant to critically assessing which cloud provider is best suited to an organisation's needs:1) Software Evaluation Frameworks (SEFs), and 2) Multicriteria Decision Analysis (MCDA).

3.1.1 Software Evaluation Frameworks

Several general and cloud orientated SEFs have already been established. These methods use metrics combined with user input to allow potential implementers to assess the Quality of Service (QoS) of different software or clouds. Three of the most relevant techniques will be discussed here, ISO 25010:2011, Apdex and CSMIC SMI.

3.1.1.1 ISO/IEC 2011 Software Quality Requirements and Evaluation (SQuaRE)

SQuaRE is the international standard for the evaluation of software. SQuaRE has eight product-quality characteristics and 31 product-quality sub-characteristics, by which a software can be evaluated. Using the SQuaRE method software is assessed from three perspectives: 1) Factors, 2) Criteria, and 3) Metrics. *Factors* evaluates the external users' perspective of the software, whereas *Criteria* and *Metrics* are both internal assessments of software from developers' and performance perspectives, respectively (ISO, 2011).

In terms of the applicability of SQuaRE to cloud selection, both the *Factors* (users) and *Metrics* (performance) evaluations are highly applicable as these perspectives are difficult to disentangle for relevant decision makers. However, SQuaRE's '*Criteria'* evaluation is somewhat redundant in the case of cloud technologies, as cloud technologies are typically developed externally to individual organisations. SQuaRE's 'Criteria' may however, be of use in the evaluation of a PaaS in particular.

3.1.1.2 Application Performance Index (Apdex)

Apdex is an industry standard for measuring software performance. Within the Apdex method, physical measurements of an application's performance (e.g. server capacity or response time) are recorded and scored in relation to user satisfaction. The Apdex formula (below) is then traditionally used to calculate the performance of the application relative to user needs.

$$Apdex_t = \frac{Satisfied\ Count\ + \frac{Tolerating\ Count}{2}}{Total\ Samples}$$

For example, if the target 't' cloud server response time is 3 seconds but up to 5 seconds is tolerated then anything under 3 would be the 'Satisfied Count' and anything between 3 and 5 would be the 'Tolerating Count'. In the end, the Apdex method would provide a rating of the software's applicability between 0 ('Completely Unsatisfied') and 1 ('Completely Satisfied'), for server response time.

For example, if there are 100 response time tests, with a target time of 3 seconds, where 60 are below 3 seconds, 30 are between 3 and 5 seconds, and the remaining 10 are above 5 seconds, the Apdex score is 0.75 (see below).

$$Apdex_3 = \frac{60 + \frac{30}{2}}{100} = 0.75$$ (Apdex Alliance, 2018)

The Apdex approach integrates objective measurements and user needs. However, different attributes cannot be weighted differently (e.g. 'security is more important than processing speed'), which limits it's applicability to cloud selection. From an organisational perspective, the Apdex approach is favourable as it requires less time or expertise to apply. Nonetheless however, this approach allows for the combination of quantitative cloud testing and user preferences.

3.1.1.3 Cloud Services Measurement Initiative Consortium Service Measurement Index (CSMIC SMI)

The Cloud Services Measurement Initiative Consortium (CSMIC) builds on previous Service Measurement Indices (SMI) and Cloud SMI models (Kumar et al., 2011; Siegel and Purdue, 2012). The CSMIC SMI is a framework which establishes a relative index which allows for the performance of different cloud vendors to be comparatively assessed. In the latest version of the CSMIC SMI, cloud characteristics are broken down into 7 categories and 51 attributes (e.g. 'security' and 'security management'). The CSMIC have developed a tool, whereby decision makers can weigh the importance of each of the categories, which will be combined with performance testing based on SMI index formulas (CSMIC, 2018).

The CSMIC SMI method is one of the most robust decision-making tools, to be built so far, as it combines qualitative user preferences with objective measurements of cloud vendor performance. However, the CSMIC method, is not currently suitable for geodata, as spatial attributes are not included in this method. Also, calculated manually the CSMIC SMI would be very time consuming as different formulas need to be applied to each attribute, for each cloud vendor. If ten cloud vendors are being assessed, over 500 unique calculations will need to be made by a decision maker, to establish the index.

3.1.2 Multi-Criterion Decision Analyses

The second body of relevant research has focussed on aiding cloud selection by utilizing multi-criteria decision analyses (MCDA), to address the complexity of the problem. In contrast to the SEFs described above, these models are largely based on data from qualitative judgements or previous cloud experiences. A summary of the most prominent approaches, the Analytical Hierarchy Process (AHP) and Multi-Attribute Decision Making (MADM) are described below.

3.1.2.1 Analytical Hierarchy Process (AHP)
An AHP method involves the hierarchal breakdown of complex decision making (e.g. “alternatives”→ “sub-criteria”→ “criteria”→“final software goal”) (Drake, 1998). Each of the criteria and sub-criteria is judged (weighed) relative to the goal and nominalised. Employed in the context of cloud migration, the AHP method has been used as a top down method, with which to choose the most appropriate cloud vendor based on decision makers’ judgement (e.g. Abdel Basset et al., 2018; Misra et al., 2011). While the AHP method provides a clear framework for choosing a cloud vendor, it is dependent on qualitative judgements regarding cloud vendor performance. Several academic attempts have been made to increase the statistical robustness of the AHP method by incorporating “fuzzy” parameters into AHP calculations. Fuzzy parameters address issues of ambiguity and in-consistency by incorporating statistical variance and statistically analysing the consensus among multiple decision makers.

AHP utilization for cloud comparison has been criticized as it is dependent on decision makers having cloud experience and/or expertise. It can also be stated that AHP would be better applied to quantified cloud or software testing, rather than user preferences alone (Martens et al., 2012; Kahraman; 2015).

3.1.2.2 Multi Attribute Decision Making (MADM)
Several adapted Multi-Attribute Decision Making (MADM) approaches, similar to AHP, have also been presented. Liu et al. (2016) further emphasise the importance of subjective cloud considerations such as technology, organisation and environment. The authors propose a ‘Multi-Attribute Group Decision Making’ (MAGDM) approach for choosing an appropriate cloud vendor. The MAGM approach involves the weighing of grouped (objective and subjective) considerations and the ranking of the appropriateness of potential cloud vendors. Abdel Basset et al. (2018) also presented a ‘Neutrosophic Multi-Criteria Decision Analysis’ (NMCDA) to help decision makers to choose a cloud provider. Neutrosophy involves the statistical comparison of two or more criteria together (e.g.” cloud security is better with vendor A than with vendor B, but worse than with vendor C”).

New MADM approaches have helped to add statistical robustness to more traditional AHP methods. However, issues due to the non-expert status of many decision makers remain. Additionally, new MADM methods are statistically complex, perhaps making them less accessible to decision makers, particularly in (GI) SMEs.

3.2 Infrastructural Considerations
As stated above, the core problem in this research is the absence of an existing cloud evaluation model for geocloud services and spatial data needs. Several ‘uniquely spatial’ considerations ought to be taken into account when migrating geodata to cloud infrastructures (e.g. IaaS). These factors warrant explicit consideration within a geocloud evaluation model. This will allow relevant decision makers to make more objective migration decisions. Some of the key infrastructural considerations for spatial data in the cloud are outlined below.

Storage: Spatial data poses some unique challenges, when stored in the cloud. X, y and z coordinates need to be stored in relation to an object in a mapping project. For this reason, storing spatial data in the cloud requires more computing power than storing non-spatial data. For example, when working with ArcGIS in AWS an “m5.large” instance, rather than a standard instance is required as a pre-requisite (Obarski, personal communication). This means that spatial data will have different costs and technical requirements and warrants unique consideration by decision makers. Maintaining the topological or geometrical integrity of spatial data within an IaaS is important in terms of the overall usefulness of an IaaS database. Topology is the ‘rules of construction’ when building a spatial model (e.g. allowances for gaps, overlaps, partitions etc.). Geometry, on the other hand, relates to the internal geometrical integrity of the data's inputs (polyhedron, 3Dpolygon etc.) (van Oosterom et al., 2002). The potential to store or integrate topological or geometric data within a relational and ‘NoSQL’ IaaS database, is an important consideration for decision makers.

Interaction: Within IT operations, spatial data is kept in different file formats to non-spatial data (e.g. shapefile, JSON, TIFF, KML etc). In order for IT operations to remain fluid the format of spatial data needs to be compatible with that of the cloud platform. Thus, data conversion is a consideration which is particularly important to spatial data in the cloud. This is demonstrated by the geocloud: “ MyGeoData“ which has a unique spatial data conversion service. Such features are not easily assessed within existing cloud evaluation models.

Display: Similarly, geospatial data has unique requirements in terms of data retrieval and interaction. Spatial data needs to be displayed as a map in order to be understood. Azure and AWS all have the capacity to display maps directly from ArcGIS Server, whereas other cloud platforms such as ArcGIS Online provide map interfaces in HTML. The interlinkages between cloud platforms and other desktop software (e.g. ArcMap) should be made clear to the geo cloud decision maker.

3.3 Summary of Problem

Previous cloud evaluation techniques are poorly accessible to SMEs due to their limited resources. Moreover, no previous cloud evaluation technique has explicitly dealt with spatial data considerations. Table 3.1 below summarises the respective disadvantages of SEF and MCDA approaches.

The ISO/IEC 2011 and Apdex methods allow for objective performance measurements (e.g. server speed) to be combined with user preferences (e.g. “I want the fastest cloud available”). However, these approaches do not allow decision makers to comparatively assess the merit of different cloud characteristics (e.g. “functionality is more important than cloud cost”). The CSMIC SMI framework allows for decision maker preferences to be combined with quantitative measures of cloud performance.

In contrast, MCDA approaches, such as AHP and MADM, for choosing a cloud vendor, largely rely on decision maker’s judgement, as to the importance of cloud attributes or vendor performance. The subjective nature of this process, however leads to uncertainty and ambiguity. ‘Fuzzy AHP’ and NMCDA methods employ measures to improve the statistical robustness of these approaches. On a whole however, MCDA approaches are hindered without performance testing and potentially by the lack of cloud experience among decision makers.

In synthesis, SEF methods particularly the CSMIC SMI, offer a robust approach to cloud selection. However, key spatial considerations have not been taken into account in this approach. The utilisation of MCDA techniques is also possible in a geocloud context, however gaining statistical robustness can be difficult with MCDA approaches.

Table 3.1 Overview of relevant evaluation techniques, adapted from Costa (2013).

	Is judgment based	Lacks User Weighting	Statistically Complexity	In-ability to incorporate spatial considerations
Software Evaluation Frameworks				
ISO/IEC 25010:2011		✘		✘
APDEX		✘		
CSMIC SMI				✘
Cloud Related Multi-Criteria Decision Analyses				
AHP*	✘			
MADM*	✘		✘	

*Includes methodological variations

3.3.1 Mixed Methodologies Gap

As is evident from table 3.1, currently there is a dichotomy in approaches to cloud evaluation with either SEF or MCDAs being adopted. Carrying out a meta-analysis of the use of cloud evaluation techniques in SMEs, Adam and Musah (2015) found that the absence of mixed method approaches to be the largest gap in the field. Similarly, in this research, it is speculated that a combined SEF and MCDA approach could provide 'the best of both worlds' in terms of the reliability of an evaluation model for geocloud services.

3.4 Research Objective

Based on the above, the goal of this research will be to answer the following research question:

"How can a mixed geocloud evaluation method be optimally designed for GI SMEs migrating to geocloud services?"

Several sub-questions apply to this research:

Model Design

RQ 1 How can SEF and MCDA approaches be combined to reliably assess geocloud offerings also considering organisational and infrastructural factors?

Model Inputs

RQ 2 What are the most important infrastructural factors to be included in a geocloud evaluation model for GI SMEs?

RQ 3 What are the most important organisational factors to be included in a geocloud evaluation model for GI SMEs?

Model Validation

RQ 4 How can the applicability, effectiveness and reliability of the model be tested?

4. Solution Design and Development

4.1 ***RQ 1*** **How can SEF and MCDA approaches be combined to reliably assess geocloud offerings also considering organisational and infrastructural factors?**

The solution design is summarized in figure 4.1. A detailed description and justification of each of the model components is also provided below.

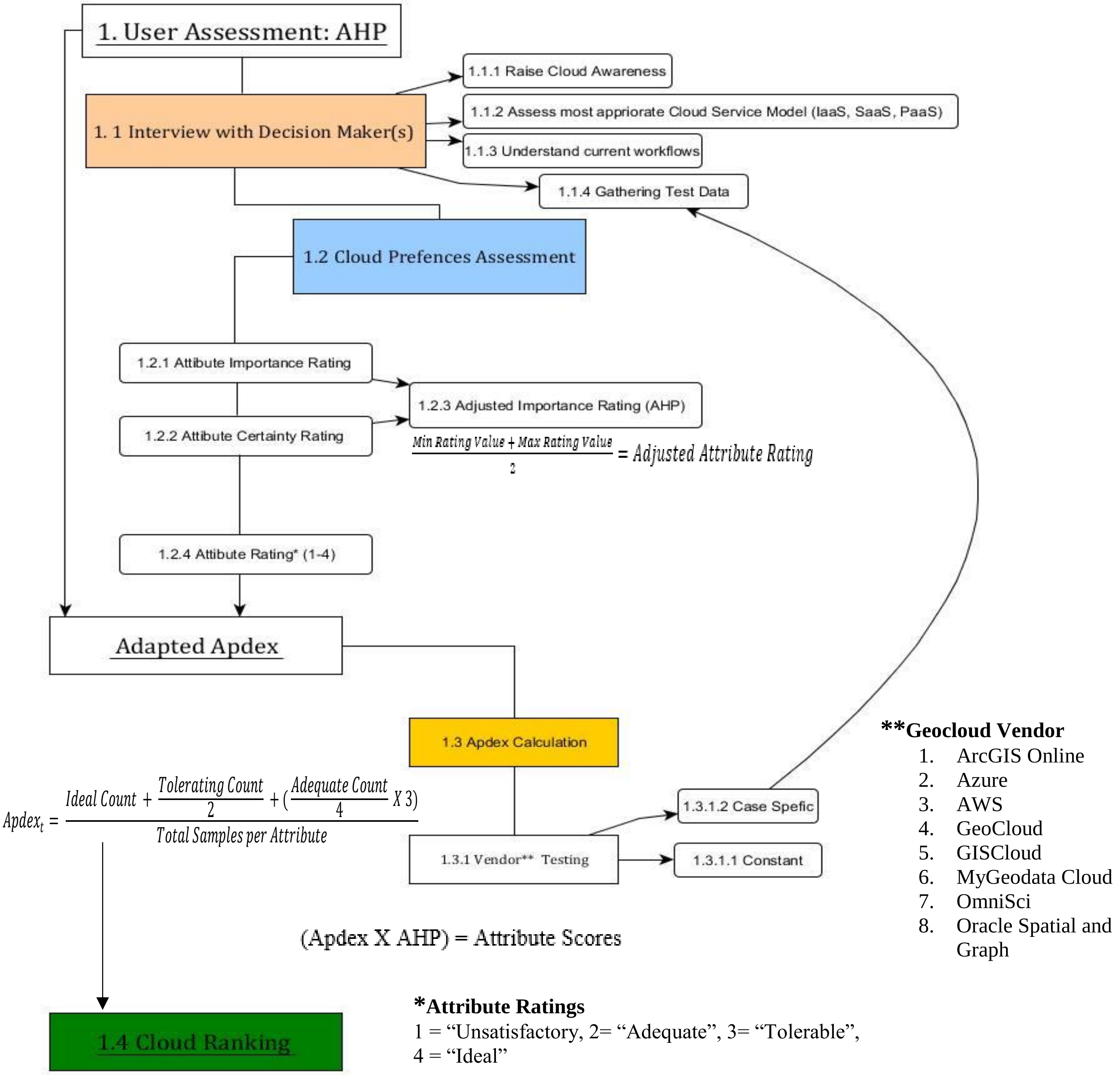


Figure 4.1 The Mixed Model Solution Design. Solution steps are described below.

4.1.1 Interview with Decision Maker(s)

Description: The first step of this model is a broad assessment of the organisation's geo-IT operations. There are a number of goals attached to this interview 1) gauging cloud awareness 2) assessing the desired or applicable cloud functionalities and 3) understanding current IT workflows. Additionally, data which is representative of those workflows (e.g. raster, vector,.gdb) is to be identified, which can be used in vendor testing.

Justification: While this research step is less rigorous and formal, it is key to understanding the cloud functionalities which may be applicable to an organisation (e.g. IaaS, SaaS or PaaS). Moreover, it provides necessary background information as to workflows and data types which will potentially be migrated to the cloud.

Implementation: In this work the interview was carried out by means of face-to-face or electronic screenshare presentations and discussions. It is intended that this process be carried out independently by decision makers outside of this research context.

The cloud briefing document is intended to lessen organisational issues such as the 'lack of IT skills' and 'lack of cloud awareness' in GI SMEs.

4.1.2 Cloud Preference Assessment

There are several components to the cloud preference assessment namely the attribute importance ratings and attribute preference ratings. The attributes are described in detail in RQ 2 and 3. An example of the Cloud Preference Assessment is provided in Appendix B.

4.1.2.1 Attribute Importance Rating

Description: This component of the model allows users to place greater or lesser importance on different cloud attributes (e.g. Cloud Security is more important than Customer Support). This data, together with 4.1.2.2 and 4.2.2.3 form the basis for the AHP of cloud attributes.

Justification: Attribute Importance Rating is a key component of MCDA evaluation approaches (e.g. Abdel Basset et al., 2018; Liu et al., 2016), however, it is largely neglected in quantitative approaches. The inclusion of this rating allows the priorities of GI SMEs to come across in the evaluation model. For example, it has been seen that "Customer Support" was very important to the micro-organisation GSD (see figure 5.2). As a result, geocloud offerings with better customer support will be more favourable in the analysis. This rationale can also be applied in different contexts (e.g. companies with sensitive data can place greater importance on cloud security).

Implementation: Attribute importance ratings were measured on a Likert scale of 1 to 10 following this question;

*"Compared with the other cloud characteristics how important would you rate *cloud* attribute* *on a scale of 1 to 10? 1 being unimportant and 10 being the most important".*

Attribute importance ratings were purposefully positioned after the preference ratings so that decision makers have a better idea of what is involved in each cloud attribute.

4.1.2.2 Attribute Certainty Rating

Description: Ratings such as 4.1.2.1 are subjective and vary depending on the previous cloud knowledge of the decision maker. Additional measures are needed to improve the reliability of the measures.

Justification: Previous cloud evaluation approaches have highlighted the subjectivity of decision maker judgements (e.g. Kahraman et al., 2015). Statistically complex 'Fuzzy AHP' or MAGM approaches have previously been applied to try to reduce the error attached to decision maker judgement (e.g. Abdel Basset et al., 2018). Such approaches are time consuming and require expertise which is likely to be beyond the resources of many GI SMEs. For this reason, a certainty question accompanies each attribute importance rating.

Implementation: Attribute certainty ratings can be measured on a Likert scale of 1 to 10 following the question below. This question immediately followed the attribute importance ratings (4.1.2.1)

"On a scale of 1 to 10 how sure are you of your answer to the previous question? 1 being certain, 10 being completely unsure"

4.1.2.3 Adjusted Importance Rating

Description and Justification: Garnering a more reliable measure of attribute importance involves combining attribute importance ratings and attribute certainty ratings by weighing importance relative to certainty.

Implementation: The formula below was utilized to adjust the attribute ratings relative to decision maker certainty.

$$\text{Adjusted Ratings} = \frac{Attribute\ Importance\ Rating}{100}\ X\ Uncertainty\ Percentage$$

For example, if the attribute importance rating of "9" was given to the 'customer services' and the certainty level was also 9. Therefore;

$$\text{Adjusted Rating} = \frac{9}{100}\ x\ 90 = 8.1$$

This produces a measure of relative certainty. Importantly, adjusted uncertainty values do not account for positive uncertainty but instead penalise attribute importance ratings based on their level of uncertainty. This way, the cloud attributes which decision makers are more certain about will have a more favourable weighing.

Additional Weighing: In two cases within the model, additional weighing was necessary. Within the 'cost' attribute budget was given a 75% importance weighing and other features (e.g. payment method etc.) were given a combined weighing of 25%. The desirability of cloud offerings were also weighed relative to decision makers interests in either IaaS, SaaS or PaaS, which they rated as a percentage during the assessment.

4.1.2.4 Attribute Preference Rating

Description: A review of the most prominent features of the geocloud vendors was carried out and the different features were turned into cloud option questions. “Attribute Preference Ratings” ask decision makers to rate how favourable each of these features are on a scale of 1 to 4.

Justification: Attribute Preference Ratings allow decision makers to choose which cloud features are favourable for their IT processes, similarly to MCDA, this will be combined with quantitative measures in the Apdex formula.

Implementation: Below is an example of an attribute importance rating question;

How would you like to be able to upload data to the cloud?

By means of an online user-friendly interface
By means of a File Transfer Protocol (FTP)
By means of command line prompts

Doesn’t matter
Don’t Know

“Doesn’t Matter” describes a case in which the decision maker feels the question is irrelevant and “Don’t Know” describes a situation in which the decision maker feels that they do not have enough knowledge to give a preference. In this case don’t know answers were answered by the author and responses were justified. Doesn’t matter answers were judged to be an automatic “4”. Multiple rating questions were asked regarding to each cloud attribute.

4.1.3 Apdex Calculation

Description: Calculating Apdex involves inputs from the cloud preferences (above) and vendor testing (below) in order to quantify the appropriateness of cloud offerings.

Justification: Apdex was chosen in the current design for two reasons. Firstly, the Apdex formula is well suited to a mixed methodology as user preferences can be assessed relative to vendor testing and secondly because this formula is easy to employ and will be accessible to GI SMEs.

Implementation: Typically, the Apdex formula has only three categories “Satisfied”, “Tolerable” and “Unsatisfied”. For the purposes of this research however, four categories were adopted 1) Unsatisfactory 2) Tolerable 3) Adequate and 4) Ideal as it was thought that greater categorisation would help to more finely rank different geocloud platforms. The adapted Apdex Formula here is;

$$Apdex_t = \frac{Ideal\ Count + \frac{Tolerating\ Count}{2} + (\frac{Adequate\ Count}{4}\ X\ 3)}{Total\ Samples\ per\ Attribute}$$

Description: In order to garner the data for 4.1.3 (above). The Attribute Preference Ratings need to be compared with the features of the geocloud vendors. Vendor testing can be split into two types 'Constant' and 'Case Specific' testing. Constant testing are features which do not vary day-to-day (e.g. legal framework). In contrast 'Case Specific' features will change frequently (e.g. customer service response time).

Justification: Assessing the 9 cloud offerings above in terms of how they perform relative to user preferences is key to providing reliable model results. Assessing both 'constant' and 'case specific' features add additional reliability to the approach.

4.1.3.1.1 Testing Constant Features

Implementation: Testing 'Constant' features was done by comparing all 9 cloud offerings the to attribute ratings.

4.1.3.1.1.2 Testing Case Specific Performance

Description: Performance tests were carried out on representative test data for each organisation (see Appendix A), Performance tests have been divided into three categories;

1) **Platform Testing**

Platform testing relates to the experiences of an administrative user with the cloud vendor console or user interface. Three platform features were tested in this research;

- **i)** **Customer Service Response Time:** was tested by recording the response time from vendor support for general inquiries during business hours (in minutes).
- **ii)** **Responsiveness of cloud console/user interface:** The responsiveness of the user interface was tested using Google Chrome's performance module.
- **iii)** **Set-Up Time:** The set-up time for the proposed cloud services was recorded once by the author (in minutes).

2) Functionality Testing

Functionality testing relates to how compatible the proposed cloud services are for the data types and functions which are desired by the organisation. Three functionality aspects were tested in the current research;

- i) **File Format Compatibility:** The native compatibility of the proposed cloud services with the file formats typically used by each organisation should be tested and recorded. In cases in which typical file formats weren't natively supported, the Geospatial Data Abstraction Library (GDAL) can be used to manipulate file format. PaaS language compatibilities (e.g. Python etc.) can also be recorded from the vendor website.
- ii) **Spatial Indexing:** Specific to IaaS services the implementation of relevant spatial indices was tested.
- iii) **Topology:** Specific to vector data in IaaS the possibility to validate topology using Db extensions in different vendors was recorded.

3) **Load Testing**

Load testing relates to the capacity of the IaaS to serve multiple clients effectively. These tests will endeavour to assess the performance of the IaaS in isolation.

i) **Import Time;** It is intended that the import time be noted across several vendors (in minutes).
ii) **Queries;** It is intended that typical queries be performed and the return speed be recorded (in seconds)
iii) **Multiple Client Testing;** It is intended that the performance of the IaaS be tested by running several queries at the same time.

Justification: 'Case specific' testing assesses the variability in performance for desired features/ (geo)-functions across cloud platforms. Specifically, platform testing assesses organisational factors and functionality and load testing assess the variability in providing the desired infrastructural features across several cloud platforms.

Implementation: The tests described above are to be carried out on a run environment of a typical personal laptop. Both functionality testing and load testing are to be carried out with spatial data which is representative of the desired end product. Descriptions on the run environments (RE) are available in appendix D and descriptions of the test datasets are available in appendix A.

4.1.4 Cloud Ranking

Description: Cloud ranking involves ranking different cloud offerings relative to performance and attribute importance.

Justification: This is a necessary calculation to complete the mixed AHP/Apdex approach.

Implementation: This is done by multiplying the AHP results with the averaged Apdex rating per cloud attribute;

(Apdex X AHP) = Attribute Scores

Individual attributes scores are then summed to get an overall cloud ranking value.

4.2 *RQ 2* What are the most important infrastructural attributes to be included in a geocloud evaluation model for GI SMEs?

The decision process involved in answering 'infrastructural' and 'organisational' sub-questions' is justified in detail below. Infrastructural attributes relate to the features and functionalities of a cloud platform. Based on vendor review, one novel infrastructural attribute is proposed in this work:

1. Spatial Functionality: Spatial infrastructure relates to the geo-functionality which can be provided in a cloud environment. Re-iterating section 3.1 spatial infrastructures involve storage, interaction and display features. Spatial storage infrastructures ought to be assessed in terms of its interoperability with existing work flows (e.g. spatial file formats). Spatial data interactions such as conversions, projections and queries and display (e.g. raster or vector interfaces) are all key considerations for GI SME decision makers.

Four generic cloud attributes were also chosen for inclusion in this geocloud evaluation model. These four attributes have been successfully assessed in previous work (e.g. Liu et al., 2016; Abdel Bassett et al., 2018).

2. Cloud Security: Security infrastructure relates to the features put in place by the cloud provider to ensure authorised data access only (e.g. password protection), proper use of data (e.g. access levels) and the protection of data against breaches (e.g. firewalls, SSH keys). In the literature, cloud security and vulnerability is considered to be the most prominent risk related to cloud migration.

3. Cloud Accessibility: Cloud accessibility is one of the key cloud advantages. Accessibility infrastructures relate to the cloud platform's user capacity (single or multiple use). Accessibility infrastructure also encompasses the operating systems (e.g. Windows, Mac or Linux) and devices (e.g. Smartphone, iPhone, Tablet) with which the cloud services are available.

4. Cloud Performance: The performance of cloud infrastructures (e.g. servers) relates to the functions performed, reliability and speed of IT tasks in a (geo)cloud environment. Typically, expected cloud performance will be formally laid out by cloud providers by means of SLAs. Performance is considered in previous research to be a key stakeholder consideration (e.g. Abdel Basset et al., 2018).

5. Cloud Architecture: Cloud architecture is the physical infrastructure which hosts any cloud environment. Different cloud vendors may employ different architectures, which has different ramifications for decision makers (see cloud briefing).

   Additionally, to vendor subscription, two other options are available to decision makers 1) Utilise Existing Infrastructure and 2) Build a Self-Cloud. Utilising Existing Infrastructure involves the incorporation of additional functionalities into servers already in use (e.g. for a company website). Self-Cloud options involve purchasing and setting up a proprietary server to host cloud functions.

4.3 *RQ 3* What are the most important organisational attributes to be included in a geocloud evaluation model for GI SMEs?

Organisational attributes describe the practicalities of implementing a cloud platform (cost, IT skills etc.). Taking the key organisational constraints among (GI) SMEs into account, three organisational attributes will be assessed in this geocloud evaluation model. All three of these attributes have been successfully incorporated in previous cloud evaluation models (e.g. Abdel Basset et al., 2018; Liu, 2016).

6. Cost: Cost is the key consideration for decision makers, migrating to the cloud. Several cost considerations need to be taken into account during the migration process including budget, pricing model (e.g. pay-per-use), payment method (e.g. electronic transfer, top-up etc.). Cloud budget is particularly relevant to decision makers in GI SMEs, who are more likely to have more limited financial resources than larger enterprises.

7. Legal Framework: Legalities are important to SME decision makers for two primary reasons. Firstly, the legal jurisdictions of the data centre's location applies to the data therein. For tax and data regulation purposes utilising a data centre in a less taxed or regulated area may be cost or time saving (AWS, 2018).

8. Customer Support: Customer support is the provision of assistance in cloud use by individuals employed by the cloud provider. This cloud attribute is particularly relevant to (GI) SMEs, who may have limited time and/or IT Skills.

Please see sections 1.3 and 4.1 of the cloud briefing document for a full review of the concepts referenced in RQs 1 and 2.

4.4 *RQ 4* How can the reliability of evaluation model be assessed on a whole?

Discussion: The advantages and disadvantages of the model, in the view of the author, will be discussed in the thesis.

Diverse Company Participation: Diverse GI SMEs who are engaged in different types of geo-work is favourable for testing this model.

Different Company Size: GI SMEs that are different sizes (e.g. 'Micro', 'Small' and Medium) is favourable for testing this model.

Follow-up Surveys/Discussions: It is intended that a follow up survey assessing decision maker satisfaction will be carried out after the brunt of this research has been completed.

5. Demonstration

Three GI SMEs with an interest in migrating to cloud infrastructures for IT operations were identified and willing to participate in this research. Section 5.1 (below) provides an overview of these enterprises and how they are looking to the cloud for (geo) IT solutions.

5.1 Overview of participating GI SMEs

1) **GeoSmart Decisions (GSD)**, GSD is a micro GIS consultancy, based near Aberystwyth in Wales. GSD typically carries out environmental mapping and has worked on projects related to oil and gas, renewable energies, land management and conservation. Recently GSD, completed a Space Assets for Monitoring of Habitats (SAMoH) project which involved building an online repository for satellite imagery, cloud processing and online visualisation. The source code for this project is currently hosted on Github.

   For future projects GSD, is looking to assess the spatial capabilities of IaaS, SaaS and PaaS, to guide future cloud use.

2) **Vicrea Solutions (Vicrea)** is a small IT company based in Amersfoort in the Netherlands. Vicrea specialises largely in 'smart data' applications for municipalities and other organisations within the areas of mobility, energy, infrastructure and construction. Solutions contribute to challenges in the areas of: governance, economic development, mobility, infrastructure, environment, people, safety and energy.

   Vicrea is now investigating, where possible, to migrate elements of their 'Neuron Stroomlijn' application to a cloud environment.

3) **Nelen & Schuurmans (N&S**) is a medium sized mapping consultancy based in Utrecht. N&S largely specialises in geo-applications related to water management, which are sold business to business in the Netherlands and abroad. N&S products includes 'Lizard' which integrates raster and temporal data and '3DI' a 3D analysis tool for flood management.

   Currently N&S are provisioning their software, on premise, and wish to investigate what cloud options they have for temporal raster data.

Both Vicrea and N&S have similar user needs in that they are both looking to investigate whether (parts of) their applications can be migrated to the cloud and how favourable that would be. In contrast GSD, more openly, is interested in what cloud platforms might be more favourable for future map hosting or geo-application development.

5.1.1 Size of Participating GI SMEs

Figure 5.1 (below) displays the size of participating enterprises, which ranges from 'micro' (<10 FTEs) to 'Medium' (50 -250 FTEs).

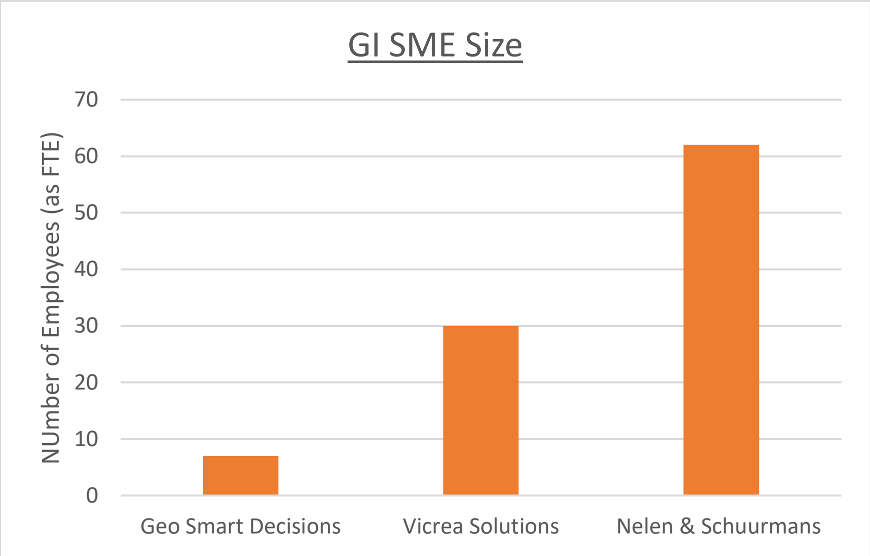


Figure 5.1. The number of employees in each of the participating GI SMEs in 2018 as FTE.

This sample of GI SMEs will provide a cross section of an organisation's needs irrespective of company size.

5.2Geo Smart Decisions

5.2.1 GSD Background

An interview was carried out with GSD assessing their current workflows and cloud needs. GSD typically uses raster data (65%) and vector data (35%) to provide deliverables to clients in the private (80%) and public (20%) sectors. The deliverables produced by the consultancy are typically map products and geo-databases using open (70%) and proprietary (30%) data. Recently, with the SAMoH project GSD has worked on developing a web-portal for viewing and interacting with satellite imagery.

GSD has a general interest in IaaS, SaaS and PaaS. See appendix A.

5.2.2 Cloud Preference Assessment

The 'user needs' cloud preference assessment (see Appendix B) was carried out with two decision makers in GSD. This assessment presented decision makers with 81 questions asking them to rate the favourability of different cloud features. Features were grouped into eight 'cloud attributes' (see Appendix B) and decision makers were also asked to rate the importance of each attribute on a linguistic scale of 1 to 10. These results are presented below;

GSD's Cloud Requirements

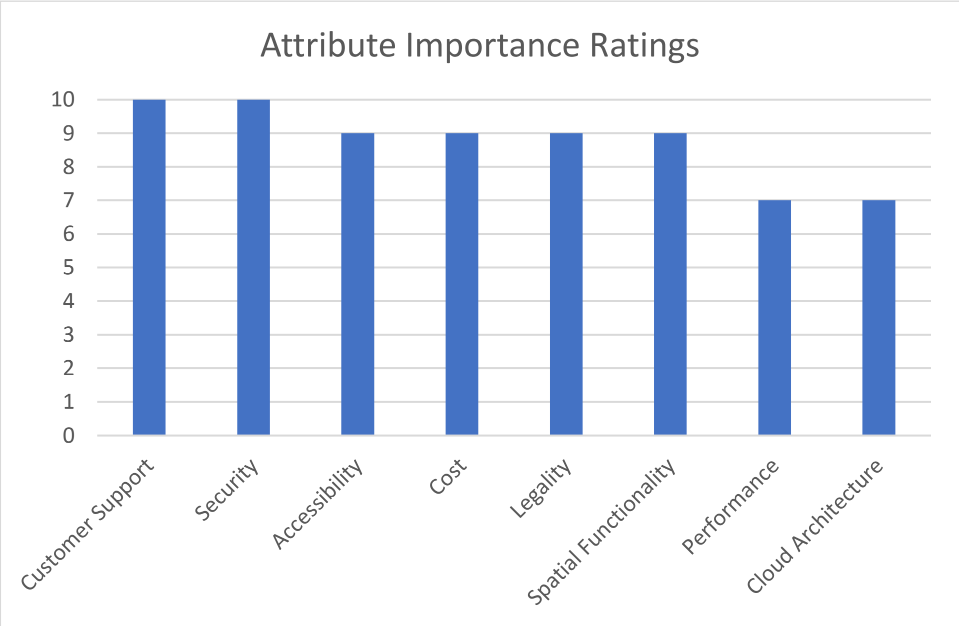


Figure 5.2.1. **Initial Attribute Importance Ratings** *Response from decision makers in GSD when asked "Compared with the other cloud characteristics how important would you rate *cloud* attribute* *on a scale of 1 to 10? 1 being unimportant and 10 being the most important*".

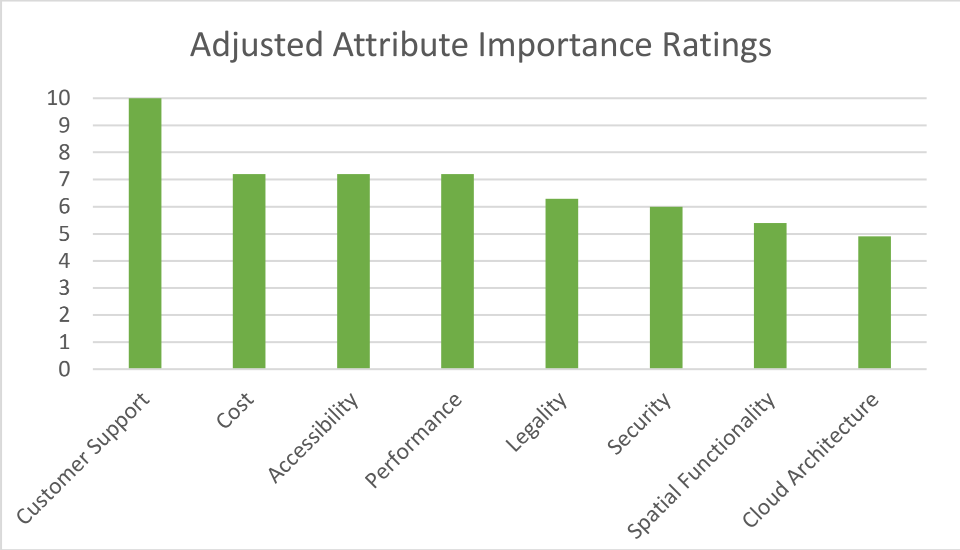


Figure 5.2.2 Adjusted cloud attribute importance ratings. *Response from decision makers in GSD when asked "Compared with the other cloud characteristics how important would you rate *cloud* attribute* *on a scale of 1 to 10? 1 being unimportant and 10 being the most important***".**

IaaS/PaaS vs SaaS

GSD showed an interest in IaaS (10%), SaaS (45%) and PaaS (45%). As such, all three types of cloud services were included in the current evaluation. Apdex scores were also weighed relative to I/S/PaaS importance.

I/PaaS Scenarios

IaaS and PaaS are typically used together for application development and for this reason several cloud I/PaaS 'Scenarios' are evaluated in this research. These 'scenarios' consisted of three elements: 1) Cloud object storage (static item storage), 2) A scalable Db with PostGIS or Oracle Spatial, and 3) A PaaS console to automate Db input/output or front-end development/deployment.

Three cloud vendors were included in the I/PaaS scenario evaluation: 1) AWS, 2) Azure, and 3) Oracle

Geo-SaaS

GSD also showed an interest in using geo-SaaS services. As such, five geo-SaaS platforms were also included in the present evaluation: 1)ArcGIS Online, 2) GeoCloud, 3) GISCloud, 4) My GeoData Cloud, and 5) OmniSci

5.2.3 Compiling a Cloud Matrix

The 'constant features' of I/PaaS Scenarios or geo-SaaS offerings were reviewed and compiled in a cloud matrix for GSD (see appendix C). This matrix is the key reference data for calculating Apdex.

5.2.4 Case Specific Cloud Performance Testing

Case specific performance testing was carried out for GSD with the ancient woodland inventory shapefile and Welsh DTM file.

Platform Testing

Customer Service Response Time

Customer service was highlighted by GSD as the most important cloud attribute. Customer service response times of all I/PaaS Scenario and SaaS offerings were recorded. Microsoft Azure had the most favourable customer service response time of the I/PaaS scenarios (20 minutes), while GeoCloud and GIS Cloud had the most favourable geo-SaaS customer service response time of 20 and 28 minutes respectively.

Table 5.1.1 Customer Service Response Time **(i**n minutes**)**

	IaaS/ PaaS			**Geo-SaaS**				
	AWS	Azure	Oracle	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Test 1	40	2	2	No Response	26	12	120	5
Test 2	120	3	3	No Response	20	30	60	3
Test 3	20	5	5	No Response	30	37	57	178
Test 4	15	60	120	No Response	12	27	30	48
Test 5	30	30	30	No Response	10	32	15	2
Average (in Minutes)	45	20	32	**N**	20	28	56	47

Console Responsivity

The responsiveness of cloud offerings were tested using Google Chrome’s performance module. Results suggest that AWS and Azure consoles have similarly favourable responsivity (~7 seconds) and Oracle and OmniSci have a less favourable responsivity.

Table 5.1.2 Responsiveness of Cloud interface or console (in seconds**)**

* Testing was done on with Google Chrome's Network Performance Profiler ('Control + Shift + C, 'Network') times are full loading times

	IaaS			**SaaS**				
	AWS	Azure	Oracle	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Test 1	7.9	7.9	12.4	13.4	6.8	6.3	3.1	11.5
Test 2	8.9	8.6	9.4	13.7	6.7	9.9	6.7	10.6
Test 3	6.0	8.2	12.1	7.7	7.5	6.5	8.2	6.4
Test 4	8.5	7.1	13.0	13.1	7.8	7.5	8.4	10.8
Test 5	9.1	9.9	9.1	11.1	8.1	8.4	11.0	10.9
Average	8.1	8.3	11.2	11.8	7.4	7.7	7.5	10.0

Set -Up Time

The set-up time was observed to be ideal in terms of its favourability, with IaaS and SaaS platforms typically taking less than 1 hour to set up. The exception to this is Oracle Spatial which takes several hours to set up.

Table 5.1.3 Set Up Time (in minutes)								
	IaaS			**Geo-SaaS**				
	AWS S3 RDS	Azure Postgres	Oracle Spatial + PaaS	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Set-Up Time	40.00	31.0	311.0	NA	15.0	17.0	10.0	50.0
				* AWI Shapefile was too large				

Functionality Testing

File Format Compatibility

Of the desired file formats, it was observed that the geo-SaaS platforms MyGeoData Cloud and GISCloud were favourable. In contrast ArcGIS Online and OmniSci were less than favourable as they were only compatible with vector data

Table 5.1.4 File Format Compatibility											
	*the desired formats indicated in the cloud preference assessment were assessed										
	Vector File Formats	Raster File Formats							Text File Format		
	(Zipped) Shapefile	JPEG	Tiff	GeoTiff	PNG	IMG	JPEG2	GeoRaster	JSON	GeoJSON	KMZ
IaaS (Object Storage)											
AWS S3	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
Azure Blob Storage	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
Oracle Object Storage	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
IaaS											
AWS RDS (PostGIS)	Y*	Y*	Y*	Y*	Y*	Y*	Y*	N	Y***	Y***	Y***
Azure Db (PostGIS)	Y*	Y*	Y*	Y*	Y*	Y*	Y*	N	Y***	Y***	Y***
Oracle Spatial	Y*	Y**	Y**	Y**	Y**	Y**	Y**	N	Y***	Y***	Y***

	Vector File Formats	Raster File Formats							Text File Format		
SaaS	**(Zipped) Shapefile**	**JPEG**	**Tiff**	**GeoTiff**	**PNG**	**IMG**	**JPEG2**	**GeoRaster**	**JSON**	**GeoJSON**	**KMZ**
ArcGis Online	Y	N	N	N	N	N	N	N	N	Y	N
GeoCloud	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
GISCloud	Y	N	N	N	N	Y	Y	N	N	N	N
MyGeodata Cloud	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
OmniSci	Y	N	N	N	N	N	N	N	Y	Y	Y
PaaS		**Python**	**R**	**Javascript**	**Java**	**JavaScript**	**PHP**				
AWS Lambda/ Codestar		Y	N*	Y	Y	Y	Y	* R isn't directly supported but it may be possible to use as a python extension			
Azure Web Apps		Y	N	Y	Y	Y	Y				
Oracle PaaS		Y	N	Y	Y	Y	Y				

Y/N = Yes/No, Y* GDAL_Translate to GeoRaster necessary Y ogr2ogr or gdal translate or Block PLSQL statement necessary**

The majority of GSDs desired file formats had the capacity to be compatible with PostGIS after using GDAL translate, Raster/Shp2pgsql or the Ogr2Ogr function. All data file formats needed to be converted to Oracle's proprietary formats prior to importing them to Oracle Spatial.

Spatial Indices

The possibility to index the data to improve data retrieval was investigated in all cloud offerings AWS, Azure and Oracle Scenarios are favourable for GSD as raster and vector data can be indexed. Spatial indexing was not possible in the SaaS platforms reviewed.

Table 5.1.5 Spatial Indexing

	IaaS/PaaS			SaaS				
	AWS	Azure	Oracle	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Raster and Vector	Y	Y	Y	N	N	N	N	N
Indices Commands		PostGIS:CREATE INDEX idx_geomcolumn_geom_gist ON schema_name.raster USING gist))						
		Oracle Spatial: CREATE INDEX rastertable_idx ON rastertable (territory_geom)INDEXTYPE IS MDSYS.SPATIAL_INDEX						

Topology

The possibility to validate, create or check topologies was investigated in all of the cloud offerings. Again AWS, Azure and Oracle are favourable in this regard as such functions can be used with these platforms

Table 5.1.6. Topological Rules

	IaaS/PaaS			**SaaS**				
	AWS	Azure	Oracle	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
AWI shapefile	Y	Y	Y	N	N	N	N	N
Topology Commands	Postgis: CREATE topology (edge, node, face)							
	Oracle Spatial: SDO_Topo.Create_Topology							

Load Testing

Import Time

Import time was tested on all cloud offerings. Geo-SaaS platforms were generally favourable for GSD (under 20 minutes). Whereas IaaS offerings were less favourable with vector imports taking between 37 minutes (Oracle) and 2 hours 25 minutes (AWS) and Azure 2 hours 12 minutes. Import syntaxes where applicable are in the appendices.

Table 5.1.7 Import Time (in minutes)

	IaaS/PaaS			Geo-SaaS				
Time (minutes)	AWS	Azure	Oracle	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Ancient Woodland Inventory	145	132	36	Did not load	6.0	10.0	8.0	19.0
Welsh DTM	364	354	12	Did not load	19	10	30	32

Five test queries were written and run on AWS, Azure and Oracle IaaS and return times were recorded. These queries were thought to be representative of functionalities desired by GSD. The PostGIS syntaxes will be described and discussed here. The Oracle syntaxes can be found in appendix E. The queries were run on QGIS (PostGIS) and SQL Developer (Oracle).

Vector Queries (Ancient Woodland Inventory)

Query 1

SELECT gid, ST_ISVALID (geom), ST_Summary(geom) from ancient_woodland_inventory

This query returned validation and descriptive information about the dataset. Its return speeds were less than ideal when run on the whole dataset on AWS and Azure (18.50 and 20.88 seconds respectively). Notably oracle was considerably faster (10.60 seconds).

Query 2

The following query returns the area of the largest woodland where the category name is equal to ‘Restored Ancient Woodland Site’.

SELECT gid, ST_Area(geom) from ancient_woodland_inventory

WHERE cat_name = 'Restored Ancient Woodland Site'

Query 3

The following query simply returns the largest areas of ancient woodland categorized by types in descending orders. This query has an ideal return time on all three IaaS platforms with AWS, Azure and Oracle all returning results in under .3 of a second.

CREATE TABLE GEOM1 as (SELECT gid, geom, MAX (hectares) AS BIGWOOD FROM ancient_woodland_inventory

GROUP BY GID, GEOM

ORDER BY BIGWOOD DESC

LIMIT 1)

Query 4

The following query returns a boolean statement assessing whether or not the largest part of Welsh woodland is touched by other wooded areas. This query has an ideal return time on all three IaaS platforms with AWS, Azure and Oracle all returning results in under .3 of a second.

```
SELECT ST_Touches (ancient woodland_inventory.geom,geom1.geom) FROM ancient_woodland_inventory INNER JOIN geom1 ON ancient_woodland_inventory.gid = geom1.gid
```

Query 5

The final vector data query produces a buffer around the largest area of Welsh woodland and then writes the buffer as an SVG which may be particularly useful in the development of an application frontend for interacting with vector data. The return time was favourable for GSD on Azure (0.10 seconds) and AWS (0.15 seconds). A rendering time of roughly 1.5 seconds for this buffer was also observed with QGIS.

```
WITH Buffer AS (SELECT ST_BUFFER(geom,80.0) as woodlandbuff from ancient_woodland_inventory WHERE gid = 45)

SELECT ST_asSVG (woodlandbuff) from Buffer
```

Raster Queries (Welsh JPEG)

Query 1

The following query summarizes the pixel values (mean, standard deviation etc.) for each band of the composite DTM test file. This query yielded unfavourable return times in AWS (14.8 seconds and Azure (14.2 seconds). Notably the response time with Oracle was significantly faster (7.7 Seconds).

```
SELECT rid, band, (stats) *

FROM (SELECT rid, band, ST_Summary Stats (rast, band) As stats

   FROM jpgtest CROSS JOIN generate_series(1,3) As band

    WHERE rid=1) As foo;
```

Query 2

The following query returns the value of each pixel across the three bands of the dataset. This query yielded a favourable response time in AWS (0.43 Seconds), Azure (0.45 seconds) and in Oracle (0.31 Seconds).

```
SELECT rid, ST_Value(rast, 1, 1, 1) As band1,

   ST_Value(rast, 2, 1, 1) As band2, ST_Value(rast, 3, 1, 1) As band3

FROM jpgtest
```

Query 3

The following query simply re-orders the data by the highest values in each band. This query again yielded favourable return times in AWS (0.46 Seconds), Azure (0.51 Seconds) and in Oracle (0.31 Seconds).

```
SELECT rid, ST_Value(rast, 1, 1, 1) As band1,
   ST_Value(rast, 2, 1, 1) As band2, ST_Value(rast, 3, 1, 1) As band3
FROM jpgtest
ORDER BY band1, band2, band3 DESC
```

Query 4

The following query gathers the pixel count from the dataset. It yielded a favourable return time with AWS (1.5 seconds) Azure (0.60 seconds) and Oracle (0.3 seconds).

```
SELECT (pxlcount)*
FROM (SELECT ST_ValueCount(rast) as pxlcount from jpgtest) As foo
   ORDER BY (pxlcount).value DESC
```

Query 5

The final raster data query for GSD returns pxlvalues in a certain range. This query again yielded favourable return times in AWS (0.7 seconds), Azure (0.5 seconds) and Oracle (0.3 seconds).

```
CREATE TABLE public.rangetest as
(SELECT rid, ST_Value(rast, 4) as pxlval from jpgtest )
ALTER TABLE rangetest ALTER COLUMN pxlval TYPE int USING pxlvalint;
SELECT rid, pxlval FROM rangetest
WHERE pxlval between 0 and 50
```

Table 5.1.7 Summary of Query Response Times (in seconds)

	Welsh DTM			Ancient Woodland Inventory		
	AWS	**Azure**	**Oracle**	**AWS**	**Azure**	**Oracle**
Query:						
Query 1	14.8	14.2	7.7	18.50	20.88	10.60
Query 2	0.42	0.45	0.3	1.90	3.09	0.26
Query 3	0.46	0.5	0.3	0.20	0.30	0.13
Query 4	1.5	0.6	0.3	0.40	0.15	0.14
Query 5	0.7	0.5	0.3	0.15	0.10	NA

Multiple Client Testing

The above queries were run simultaneously on two clients to more accurately assess how well each IaaS deals with load stress. Results (below) suggest, that while the vector queries run within a range which is favourable to GSD, the raster queries in PostGIS were very negatively affected.

5.1.8 Query Response time with Multiple Clients (in seconds)						
* Queries 1 to 5 (above) were carried out simultaneously with two clients. RE = Run Environment. See appendix D.						
Welsh DTM	**I/PaaS**					
	AWS	**AWS**	**Azure**	**Azure**	**Oracle**	**Oracle**
Query	RE 1	RE 2	RE 1	RE 2	RE1	RE2
Query 1	31.36	19.56	16.09	21.6	0.09	0.1
Query 2	7.7	4.48	0.4	0.32	0.07	0.11
Query 3	0.865	0.876	0.41	0.5	0.123	0.334
Query 4	1.5	1.82	0.71	0.79	0.057	0.079
Query 5	1.012	1.014	1.1	1.012	NA	NA
Ancient Woodland Inventory	**AWS**	**AWS**	**Azure**	**Azure**	**Oracle**	**Oracle**
Query	**RE 1**	**RE 2**	**RE 1**	**RE 2**	**RE 1**	**RE 2**
Query 1	0.39	0.09	22.19	13.7	0.52	0.4
Query 2	0.4	0.5	5.19	4.23	0.286	0.676
Query 3	0.04	0.01	0.11	0.312	0.3	0.0458
Query 4	0.1	0.4	0.154	0.264	0.141	0.2144
Query 5	2.4	2.5	0.95	0.102	0.0351	0.412

5.2.5 Calculating Apdex

Having completed the cloud preference assessment and case-specific vendor testing, Apdex scores were then calculated for each attribute of each scenario. Apdex results are displayed as radar graphs on the next pages.

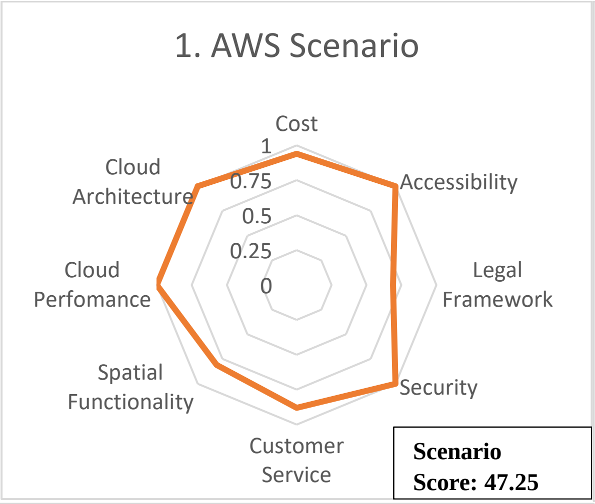
5.2.6 Ranking Cloud Scenarios

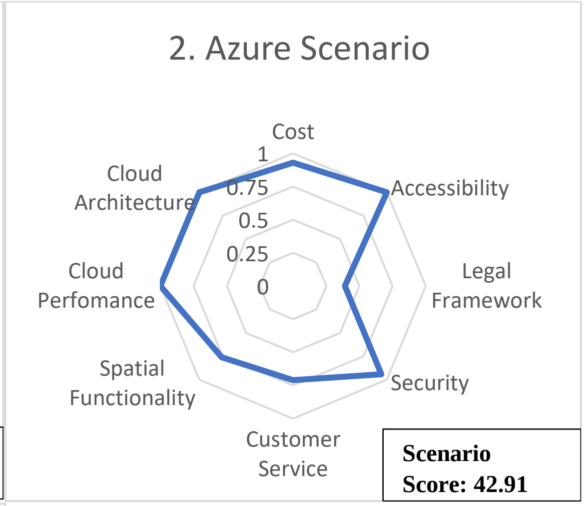
Final scenario rankings were calculated by multiplying the Apdex scores of each attribute by the adjusted importance ratings and summing them. Ranking results are also displayed on the next pages. Apdex and ranking calculations are demonstrated in Appendix F.

5.2.7 GSD Results

IaaS and PaaS Scenarios

The strengths of the proposed IaaS and PaaS scenarios are shown in the radar graphs below which have also been ranked.





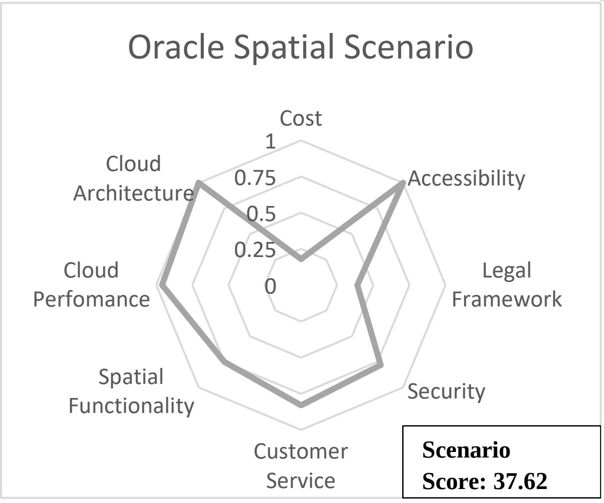


Figure 5.2.2 Favourability of I/PaaS scenarios.

Results indicate that AWS is the most favourable scenario (score: 47.35) followed by Azure (score: 42.91) and Oracle Spatial (score:37.62). Radar charts show how AWS is more appropriate to GSD's needs with customer services and spatial functionality outperforming that of Azure. In contrast, Oracle Spatial falls back in the ratings largely due to cost.

Geo-SaaS

The strengths of geo-SaaS platforms are shown in the radar graphs below which have also been ranked.

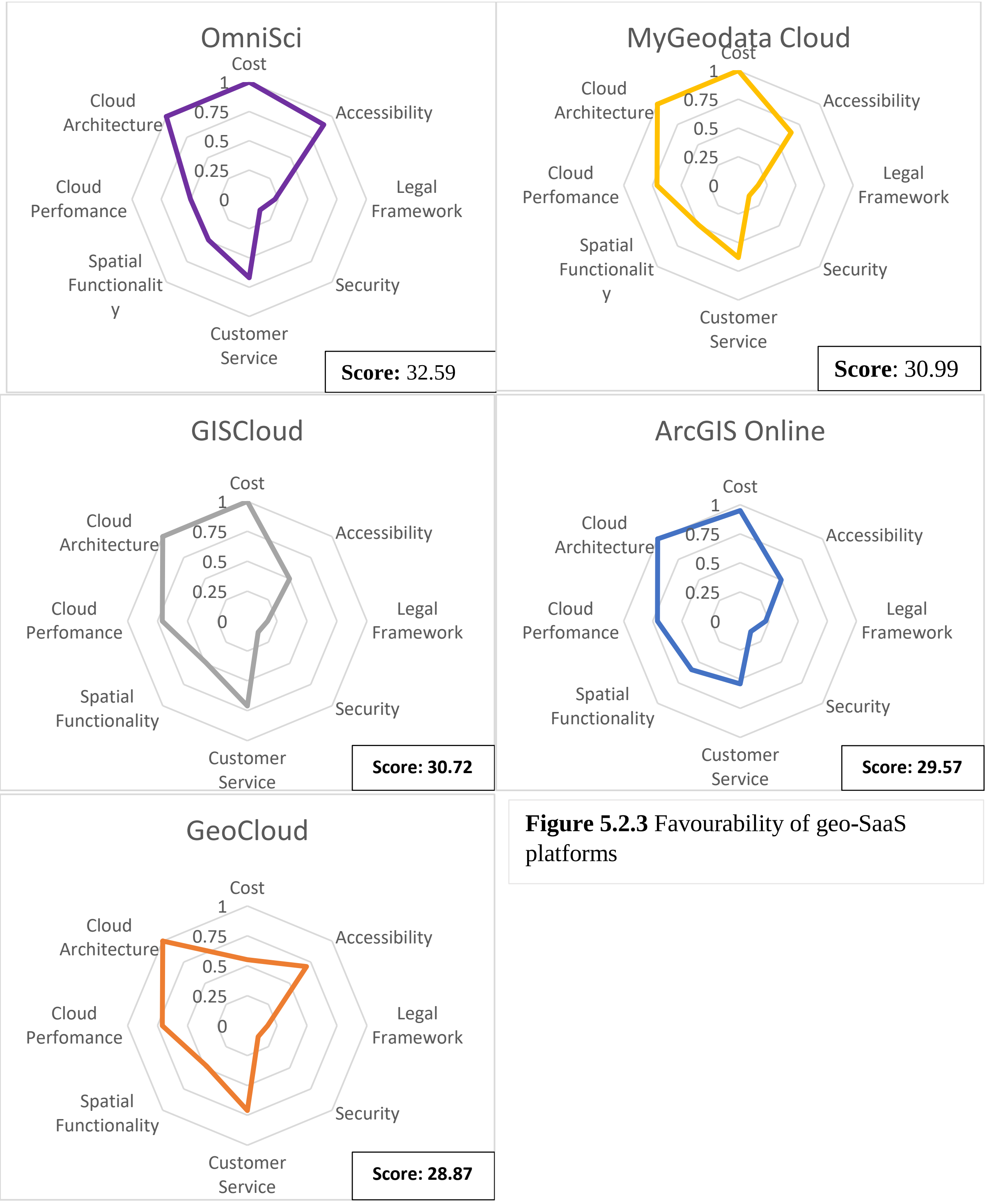


Figure 5.2.3 Favourability of geo-SaaS platforms

Results indicated that OmniSci is the most favourable geo-SaaS platform (score: 32.59) for GSD, followed by My GeoDataDrive (score: 30.99), GIS Cloud (30.72), ArcGIS Online (29.57) and GeoCloud (Score: 28.87).

5.3 Vicrea

5.3.1 Vicrea Background

An interview was carried out with a decision maker from Vicrea to assess their current workflow and cloud needs. Vicrea provides geo-applications to the public sector (100%) and is interested in migrating the Neuron Stroomlijn application to a cloud environment. Neuron Stroomlijn currently integrates a desktop application with vector data, stored in an on-premises Oracle Db. The information stored in the Db contains personal information such as names or addresses (50%), is privately owned (13%), or does not contain personal information (37%) (see appendix A).

Vicrea, more and more, is being asked by their customers to take on the responsibility of maintaining their on-premises infrastructure and they are looking for possible solutions.

5.3.2 Cloud Preference Assessment

The 'user needs', cloud preference assessment (see appendix B) was carried out with a decision maker in Vicrea. This assessment presented the decision maker with 81 questions asking them to rate the favourability of different cloud features. Features were grouped into eight 'cloud attributes' (see sections 4.2 and 4.3) and the decision maker was also asked to rate the importance of each attribute on a linguistic scale of 1 to 10. These results are presented below;

Vicrea's Cloud Requirements

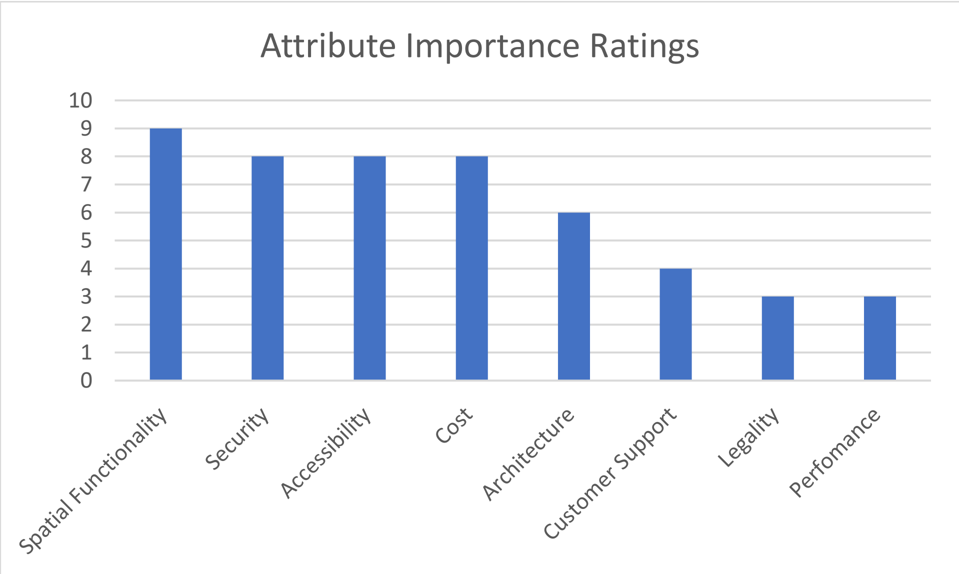


Figure 5.3.1. **Initial Attribute Importance Ratings** *Response from decision makers in Vicrea when asked "Compared with the other cloud characteristics, how important would you rate *cloud* attribute* *on a scale of 1 to 10? 1 being unimportant and 10 being the most important*"**.**

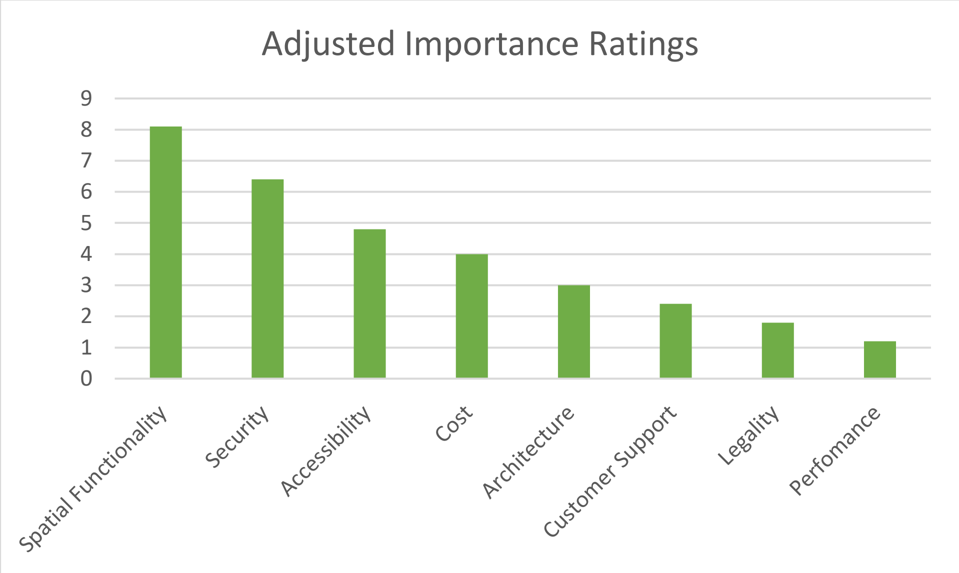


Figure 5.3.2 Adjusted cloud attribute importance ratings. *Response from decision makers in Vicrea when asked "Compared with the other cloud characteristics how important would you rate *cloud* attribute* *on a scale of 1 to 10? 1 being unimportant and 10 being the most important****".***

IaaS and SaaS

Vicrea showed an interest in IaaS (90%) and SaaS (10%). As such only IaaS and SaaS types of cloud services were included in Vicrea's cloud evaluation. Apdex scores were also weighed relative to IaaS and SaaS interest.

IaaS

Vicrea is primarily interested in outsourcing the infrastructure for the Neuron Stroomlijn Db (90%). As such IaaS services which have the following features were included in Vicrea's evaluation: 1) ISO security standards, and 2) native vector data capabilities.

The three cloud vendors that were included in the IaaS evaluation were: 1) AWS, 2) Azure, and 3) Oracle.

Geo-SaaS

Vicrea also showed an interest in using geo-SaaS services (10%). As such five geo-SaaS platforms were also included in Vicrea's evaluation: 1) ArcGIS Online, 2)GeoCloud, 3)GISCloud, 4)My geodata Cloud, 5)OmniSci.

5.3.3 Compiling a Cloud Matrix

The features of relevant IaaS and SaaS offerings were reviewed and compiled in a cloud matrix (see appendix C). This matrix served as the key reference data for calculating Apdex.

5.3.4 Case Specific Performance Testing

Case specific performance testing was carried out on all cloud offerings, the Assen Shapefiles were used as test data for this element of the research (see appendix A).

Platform Testing

Customer Service Response Time

Tests show that all cloud platforms had an ideal customer service response time (<1 hour) for Vicrea's needs. The most favourable IaaS platform was Microsoft Azure with an average response time of 20 minutes, followed by Oracle (32 minutes) and AWS (45 minutes). GeoCloud and GIS Cloud had the most favourable geo-SaaS customer service response times of 20 and 28 minutes respectively.

Table 5.2.1 Customer Service Response Time (in minutes)

	IaaS/ PaaS			Geo-SaaS				
	AWS	Azure	Oracle	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Test 1	40	2	2	No Response	26	12	120	5
Test 2	120	3	3	No Response	20	30	60	3
Test 3	20	5	5	No Response	30	37	57	178
Test 4	15	60	120	No Response	12	27	30	48
Test 5	30	30	30	No Response	10	32	15	2
Average	45	20	32	NA	20	28	56	47

Console Responsivity

The responsiveness of cloud offerings was tested using Google Chrome's performance module. Results suggest that AWS and Azure consoles have similarly favourable responsivity (~7 seconds) for Vicrea and Oracle and OmniSci have less favourable responsivity (> 10 seconds).

Table 5.2.2 Responsiveness of Cloud Interface or Console (in seconds)

	* Testing was done on with Google Chrome's Network Performance Profiler ('Control + Shift + C, 'Network') times are full loading times							
	IaaS			Geo-SaaS				
	AWS	Azure	Oracle	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Test 1	7.9	7.9	12.4	13.4	6.8	6.3	3.1	11.5
Test 2	8.9	8.6	9.4	13.7	6.7	9.9	6.7	10.6
Test 3	6.0	8.2	12.1	7.7	7.5	6.5	8.2	6.4
Test 4	8.5	7.1	13.0	13.1	7.8	7.5	8.4	10.8
Test 5	9.1	9.9	9.1	11.1	8.1	8.4	11.0	10.9
Average	8.1	8.3	11.2	11.8	7.4	7.7	7.5	10.0

Set -Up Time

The set-up time was observed to be ideal in terms of its favourability, for Vicrea, with IaaS and SaaS platforms typically taking less than 1 hour to set up. The exception to this is Oracle Spatial which takes several hours to set up.

Table 5.2.3 Set-up Time (in minutes)								
	* Times were tested only once with relevant files							
	IaaS			**Geo-SaaS**				
	AWS S3 RDS	Azure Postgres	Oracle Spatial + PaaS	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Set-Up Time (In Minutes)	40.00	31.0	311.0	NA	15.0	17.0	10.0	50.0
				* Assen Shapefile was too large				

Functionality Testing

File Format Compatibility

It was observed that the majority of vector and text file formats desired by Vicrea were supported directly or after data translation by IaaS and SaaS platforms. All desired formats were supported by all IaaS platforms after translations.

Table 5.2.4 File Format Combability					
	Vector File Formats	Text File Formats			
	Zipped Shapefile	SQL	.XLS	.CSV	.XML
IaaS (Object Storage)					
AWS S3	Y	Y	Y	Y	Y
Azure Blob Storage	Y	Y	Y	Y	Y
Oracle Object Storage	Y	Y	Y	Y	Y
IaaS					
AWS RDS (PostGIS)	Y*	Y	Y	Y	Y**
Azure Db (PostGIS)	Y*	Y	Y	Y	Y**
Oracle Spatial	Y*	Y	Y	Y	Y**
SaaS					
ArcGis Online	Y	N	N	Y	N
GeoCloud	Y	Y	Y	Y	Y
GISCloud	Y	N	Y	Y	N
MyGeodata Cloud	Y	Y	Y	Y	Y
OmniSci	Y	Y	Y	Y	Y

	Languages		IDEs
Supported Connection Strings	**Java-Script**	**C#**	**Visual S (.NET or Node.js)**
AWS RDS	Y	Y	Y
Azure	Y	Y	Y
Oracle PaaS	Y	Y	Y

Y/N = Yes/No, Y* GDAL_Translate to GeoRaster necessary Y ogr2ogr or gdal translate or Block PLSQL statement necessary**

Spatial Indices

The possibility to index the data to improve data retrieval was investigated in all cloud offerings AWS, Azure and Oracle scenarios are favourable for Vicrea as vector data can be indexed. Spatial Indexing was not possible in the SaaS platforms reviewed.

Table 5.2.5 Spatial Indexing

	IaaS/PaaS			SaaS				
	AWS	Azure	Oracle	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Raster and Vector	Y	Y	Y	N	N	N	N	N
Indices Commands		PostGIS:CREATE INDEX idx_geomcolumn_geom_gist ON schema_name.raster USING gist))						
		Oracle Spatial: CREATE INDEX rastertable_idx ON rastertable (territory_geom) INDEXTYPE IS MDSYS.SPATIAL_INDEX						

Topology

The possibility to validate, create or check topologies was investigated in all of the cloud offerings. Again AWS, Azure and Oracle are favourable in this regard as such functions can be used with these platforms.

Table 5.2.6 Topological Rules

	IaaS/PaaS			**Geo-SaaS**				
	AWS	Azure	Oracle	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
AWI shapefile	Y	Y	Y	N	N	N	N	N
Topology Commands	Postgis: CREATE topology (edge, node, face)							
	Oracle Spatial: SDO_Topo.Create_Topology							

Load Testing

Import Time

Import time was tested on all cloud offerings. Geo-Saas platforms were generally favourable (under 20 minutes). Tested with the Assen shapefile however, IaaS offerings show larger discrepancies in import time. Oracle loaded the file the fastest (37 minutes), whereas both Azure and AWS both took roughly two hours to load the file.

Table 5.2.7 Import Time (in minutes)

	IaaS/PaaS			Geo-SaaS				
	AWS	Azure	Oracle	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Assen Shapefile Import Time	122	110	37	Did not load	13	6	9	15

Query Response Time

Five test queries were written and run on AWS, Azure and Oracle IaaS and return times were recorded. These queries were thought to be representative of the functionalities desired by Vicrea in the Neuron Stroomlijn application. The PostGIS syntaxes will be described and discussed here. The Import and Oracle syntaxes can be found in Appendix E. The queries were run on QGIS (PostGIS) and SQL Developer (Oracle Spatial).

Query 1

The following query simply returns the information attached to buildings which were constructed before the year 1700. This query had a favourable return time of under 0.3 seconds in AWS, Azure and Oracle.

```
SELECT gid, bouwjaar, geom FROM assenpoly

WHERE bouwjaar < 1700
```

Query 2

This query introduces the spatial ST_Area function which will simply return the area of the oldest buildings in Assen. Such a query had a favourable response time in AWS (0.045 seconds), Oracle (0.07seconds) and Azure (0.35 seconds).

```
With oldestblds as (SELECT gid, bouwjaar, geom FROM assenpoly

WHERE bouwjaar < 1700

Select gid, ST_Area (geom) from oldestblds
```

Query 3

This query will generate a buffer of a given distance around the oldest building in Assen. The query had a return time of 0.069 seconds with AWS RDS 0.35 seconds in an Azure Db and 0.8 seconds with Oracle Spatial.

With bufferpoint as (select geom, MIN (bouwjaar) as oldestbld FROM assenpoly

GROUP BY gid

ORDER BY oldestbld DESC

LIMIT 1)

SELECT ST_Buffer(GEOM, 1) FROM bufferpoint AS oldbuffer

Query 4

Creating a temporary table from the query above, the format of the geometry can then be altered to another format for visualisation in the front end of the application. Here, the time taken to alter the buffer to Scalable Vector Graphics (SVG) format was measured. Similar times were recorded with AWS (0.083) and Azure (0.090).

SELECT ST_asSVG(st_buffer) from bufftab

Query 5

A query which returned the id, year of construction and postcode of the oldest buildings in Assen was carried out, joining the polygon layer with the semantic fields of the points layer. This query across joined tables returned favourable times with AWS (0.063), Azure (0.069) and Oracle (0.3seconds).

With oldestblds as (SELECT gid, bouwjaar, geom FROM assenpoly

WHERE bouwjaar < 1700)

SELECT oldestblds.gid, bouwjaar, postcode FROM oldestblds INNER JOIN assen_points ON oldestblds.gid = assen_points.gid

Table 5.2.8 Query Response Time (in seconds)

	IaaS/PaaS			**Geo-SaaS**				
	AWS	Azure	Oracle	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Query:								
Query 1	0.18	0.32	0.3	NA	NA	NA	NA	NA
Query 2	0.045	0.35	0.07	NA	NA	NA	NA	NA
Query 3	0.069	0.35	0.8	NA	NA	NA	NA	NA
Query 4	0.083	0.09	NA	NA	NA	NA	NA	NA
Query 5	0.067	0.63	0.3	NA	NA	NA	NA	NA

Multiple Client Testing

The above queries were run simultaneously on two clients to more accurately assess how well each IaaS deals with load stress. Results (below) suggest that the return speed of test queries did not deteriorate significantly when serving two clients simultaneously.

Table 5.2.9 Query Response Time with Multiple Clients (in seconds)

Testing was done simultaneously with two clients

	AWS	AWS	Azure	Azure	Oracle	Oracle
Query;	RE 1	RE 2	RE 1	RE 2	RE 1	RE 2
Query 1	0.27	0.05	0.34	0.1	0.08	0.1
Query 2	0.2	0.05	0.435	0.369	0.078	0.084
Query 3	0.07	0.44	0.398	0.412	0.406	0.61
Query 4	0.08	0.09	0.09	0.112	N	N
Query 5	0.05	0.055	0.063	0.068	0.077	0.087

Details of the run environments are provided in appendix D. Screenshots of Case Specific Performance Testing are provided in Appendix G.

5.3.5 Calculating Apdex

Having completed the cloud preference assessment and case specific vendor testing, Apdex scores were then calculated for each attribute of each scenario. Apdex results are displayed as radar graphs on the next pages.

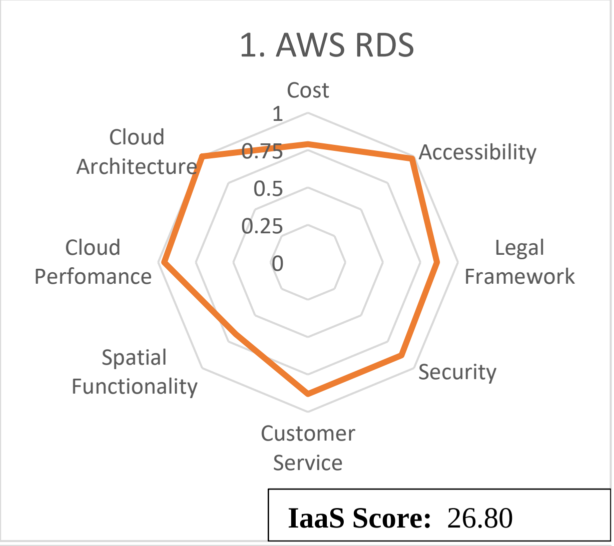
5.3.6 Ranking Cloud Scenarios

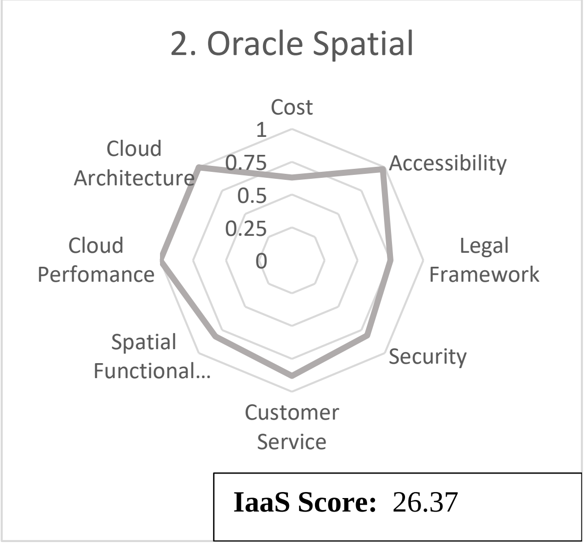
Final scenario rankings were calculated by multiplying the Apdex scores of each attribute by the adjusted importance rankings and summing them. Ranking results are also displayed on the next pages. Apdex and ranking calculation are demonstrated in Appendix F.

5.3.7 Vicrea Results

IaaS

The strengths of the proposed IaaS scenarios are shown in the radar graphs below which have also been ranked.





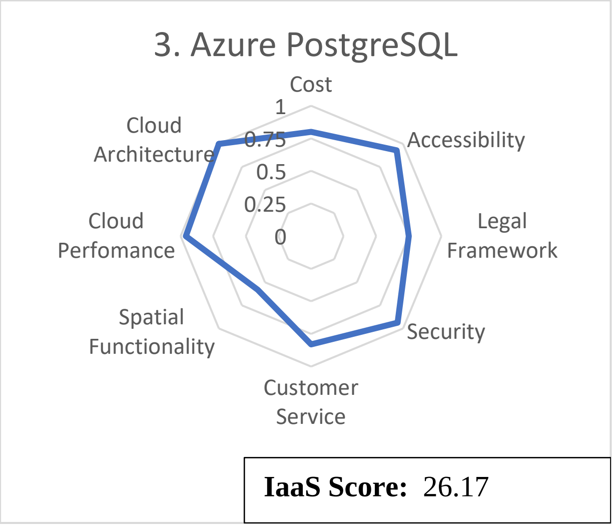
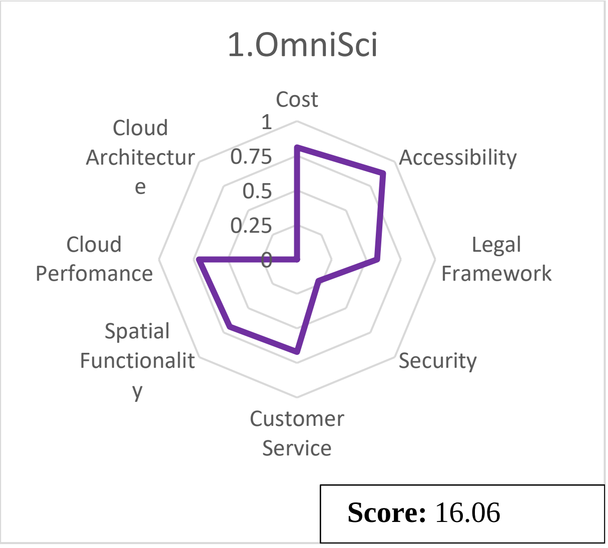


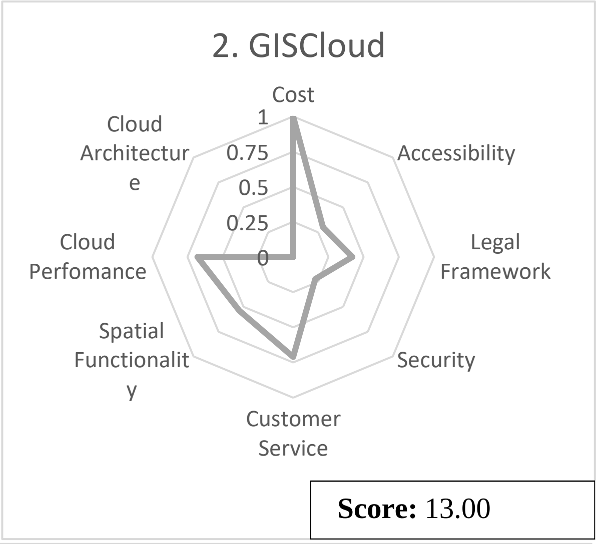
Figure 5.3.6 Favourability of IaaS services

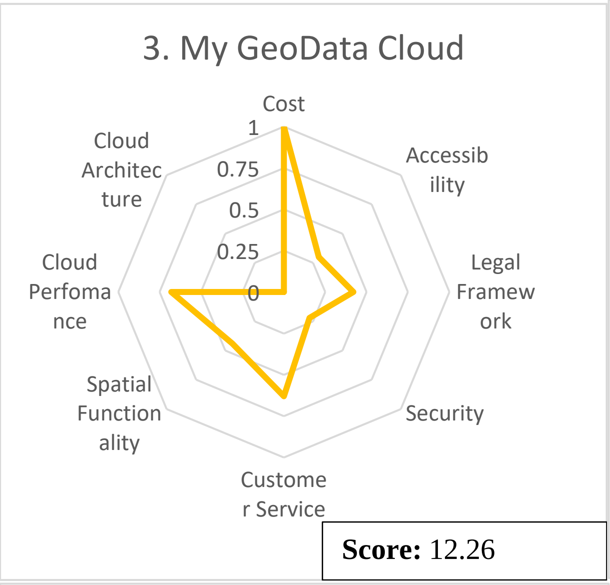
Results indicate that AWS RDS is the most favourable IaaS (score: 26.80) followed by Oracle Spatial (score: 26.37) and Azure PostgreSQL (score: 26.17).

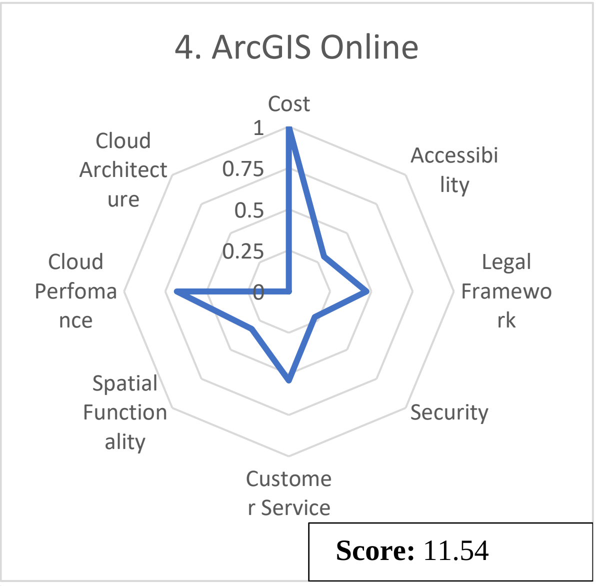
Geo-SaaS

The strengths of common geo-SaaS platforms are shown in the radar graphs below which have also been ranked.









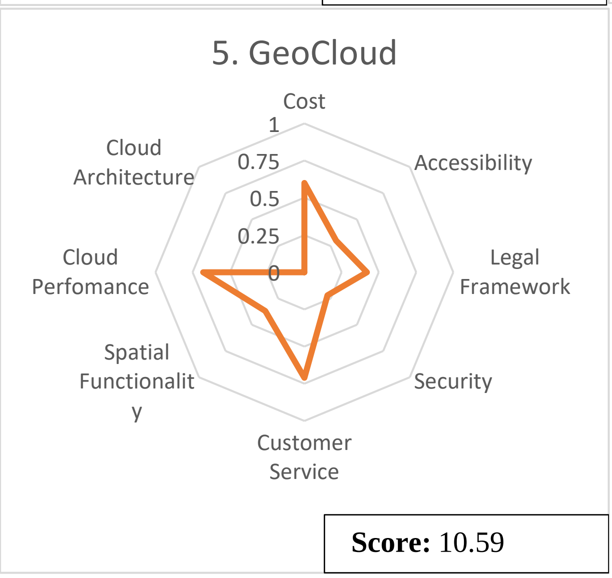


Figure 5.3.6 Favourability of geo-SaaS platforms

Results indicate that OmniSci is the most favourable geo-SaaS platform (score: 16.06) for Vicrea, followed by GIS Cloud (score: 13.00), My GeoData Cloud (12.26), ArcGIS Online (11.54) and GeoCloud (Score: 10.59).

5.4 Nelen & Schuurmans

5.4.1 N&S Background

A presentation/ group interview was carried out with several decision makers from N&S to assess their current workflows and cloud needs. N&S provides 'business-to-business' geo-applications to the public (80%) and private (20%) sectors. N&S typically uses both open public data (50%) and privately-owned data (50%) in their applications (see appendix A).

N&S is primarily interested in investigating what cloud infrastructures may be appropriate for spatio-temporal raster data.

5.4.2 Cloud Preference Assessment

The 'user needs' cloud preference assessment (see appendix B) was completed by decision makers in N & S. This assessment presented decision makers with 82 questions asking them to rate the favourability of different cloud features. Features were grouped into eight 'cloud attributes' (see sections 4.2 and 4.3) and decision makers were also asked to rate the importance of each attribute on a linguistic scale of 1 to 10. These results are presented below:

N&S's Cloud Requirements

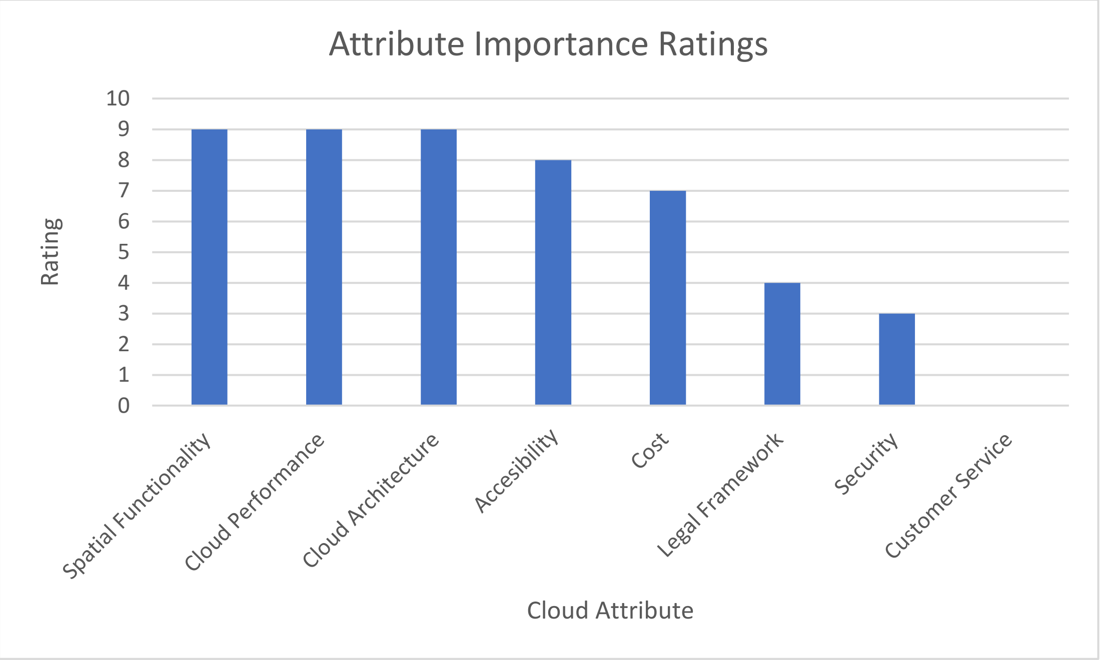


Figure 5.4.1. **Initial Attribute Importance Ratings** *Response from decision makers in N&S when asked "Compared with the other cloud characteristics how important would you rate *cloud* attribute* *on a scale of 1 to 10? 1 being unimportant and 10 being the most important***".**

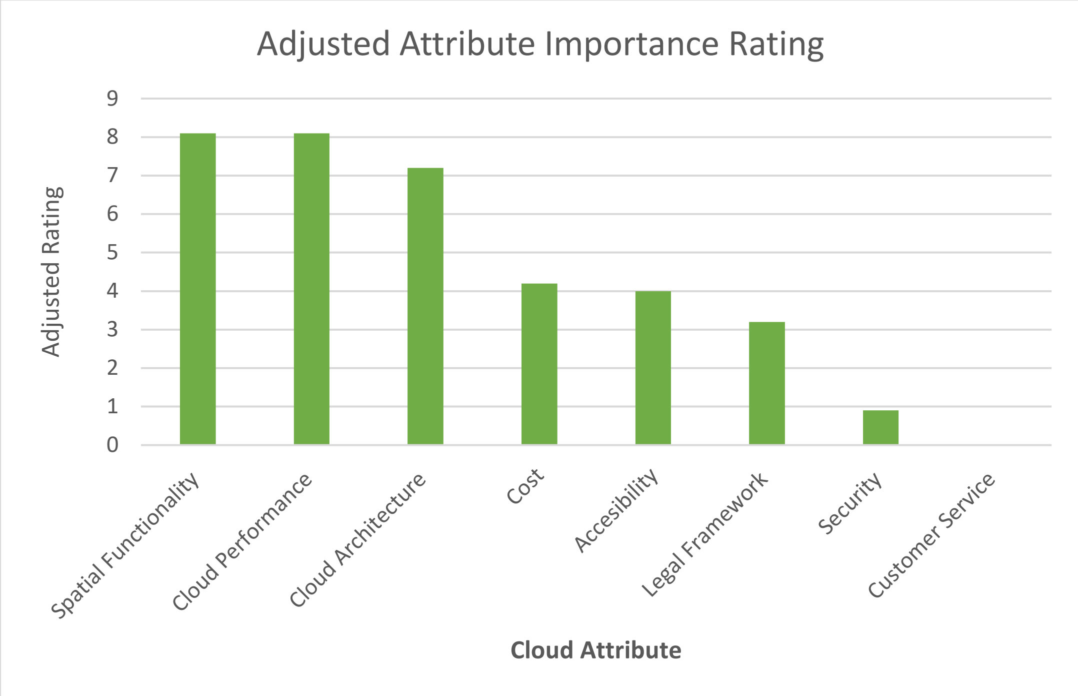


Figure 5.4.2 Adjusted cloud attribute importance ratings. *Response from decision makers in N&S when asked "Compared with the other cloud characteristics how important would you rate *cloud* attribute* *on a scale of 1 to 10? 1 being unimportant and 10 being the most important***".**

Results indicated that spatial functionality, cloud performance and architecture are the most important cloud considerations for N&S. Customer service was not rated as an important consideration by N&S decision makers and has not been considered further in this analysis.

I/PaaS Scenarios

N&S were interested in IaaS (80%) and PaaS (20%) and as such IaaS and PaaS 'scenarios' were researched as input into the current evaluation model. I/PaaS scenarios were chosen which 1) had a capacity to handle raster data, 2) had ISO Security Standards, 3) had the capacity to develop and deploy scripts in an online environment.

The three cloud vendors which were included in the I/PaaS evaluation were: 1) AWS, 2) Azure, and 3) Oracle Spatial.

Uniquely in the case of N & S, I/PaaS scenarios across two cloud vendors were analysed. This 'combined scenario' involved provisioning an Oracle Spatial Db in an AWS environment, which allows developers to use AWS's PaaS services.

5.4.3 Creating a Cloud Matrix for Constant Features

The features of relevant IaaS and PaaS offerings were reviewed and compiled in a cloud matrix (see appendix C). This matrix served as the key reference data for calculating Apdex.

5.4.4 Case Specific Performance Testing

Case specific performance testing was carried out on all cloud offerings, the Bangladesh NDVI timeseries was used as test data for this element of the research (see appendix A).

Platform Testing

Console Responsivity

The responsiveness of cloud offerings was tested using Google Chrome's performance module. Results suggest that AWS and Azure consoles have similarly favourable responsivity (~7 seconds) for N&S and Oracle and OmniSci have less favourable responsivity (> 10 seconds).

Table 5.3.1 Responsiveness of Cloud Interface or Console (in seconds)			
	* Testing was done on with Google Chrome's Network Performance Profiler ('Control + Shift + C, 'Network') times are full loading times		
	I/PaaS Scenario		
	AWS	Azure	Oracle
Test 1	7.9	7.9	12.4
Test 2	8.9	8.6	9.4
Test 3	6.0	8.2	12.1
Test 4	8.5	7.1	13.0
Test 5	9.1	9.9	9.1
Average	8.1	8.3	11.2

Set -Up Time

The set-up time was observed to be ideal for N&S's needs with AWS, RDS or Azure Postgres Db (< 1 hour). Setting up an Oracle Spatial instance was significantly slower, taking several hours. Set-up time for a combined Oracle Spatial and AWS PaaS scenario was untested, due to licensing restrictions but it is likely to be somewhat slower than setting up an Oracle spatial instance alone.

Table 5.3.2 Set-Up Time **(**in minutes**)**				
	I/PaaS Scenarios			
	AWS RDS	Azure Postgres	Oracle Spatial + PaaS	Oracle Spatial and AWS
Set-Up Time (In Minutes)	40.00	31.0	311.0	Untested

Functionality Testing

File Format Compatibility

It was noted in N&S's cloud preference assessment that a Db infrastructure which could handle a broad range of data formats was favourable. Here, the compatibility of a range of data formats has been assessed. It was found that the majority of file formats are compatible with the cloud offerings reviewed.

Tables 5.3.3 File Format Compatibility								
	Vector File Formats	Raster File Formats						
	Zipped Shapefile	JPEG	Tiff	GeoTiff	PNG	IMG	JPEG2	GeoRaster
IaaS (Object Storage)								
AWS S3	Y	Y	Y	Y	Y	Y	Y	N
Azure Blob Storage	Y	Y	Y	Y	Y	Y	Y	N
Oracle Object Storage	Y	Y	Y	Y	Y	Y	Y	Y
IaaS								
AWS RDS (PostGIS)	Y*	Y*	Y*	Y*	Y*	Y*	Y*	N
Azure Db (PostGIS)	Y*	Y*	Y*	Y*	Y*	Y*	Y*	N
Oracle Spatial	Y**	Y**	Y**	Y**	Y**	Y**	Y**	Y

	Text File Formats						
	JSON	GeoJSON	KMZ	SQL	.XLS	.CSV	.XML
IaaS (Object Storage)							
AWS S3	Y	Y	Y	Y	Y	Y	Y
Azure Blob Storage	Y	Y	Y	Y	Y	Y	Y
Oracle Object Storage	Y	Y	Y	Y	Y	Y	Y
IaaS							
AWS RDS (PostGIS)	Y***	Y***	Y***	Y	Y	Y	Y***
Azure Db (PostGIS)	Y***	Y***	Y***	Y	Y	Y	Y***
Oracle Spatial	Y***	Y***	Y***	Y*	Y*	Y*	Y***

PaaS Support	Languages	
	Python	Python
AWS Lambda/ Codestar	Y	Y
Azure Web Apps	Y	Y
Oracle PaaS	Y	Y

Y/N = Yes/No, Y* GDAL_Translate to GeoRaster necessary Y* ogr2ogr or gdal translate or Block PLSQL statement necessary**

Spatial Indexing

The capacity to index the data was investigated. It was found that, favourably, it is possible to index spatial data on all of the included cloud scenarios.

Table 5.3.4 Spatial Indexing							
	IaaS/PaaS Scenarios						
	AWS RDS		**Azure Db**		**Oracle Spatial**		**Oracle Spatial + AWS**
Result	Y		Y		Y		Y
Indices Commands	PostGIS:CREATE INDEX idx_rastercolumn_rast_gist ON schema_name.raster USING gist (ST_ConvexHull(rast))						
	Oracle Spatial: CREATE INDEX bndvi_idx ON territories (bndvi_geom) INDEXTYPE IS MDSYS.SPATIAL_INDEX						

Load Testing

Import Times

A significant increase in the import time of the Bangladesh NDVI file package was observed, compared to the file imports carried out heretofore. Notably the import of the NDVI package was significantly faster with Oracle (roughly 10 hours), than AWS (23 hours) or Azure (27 hours).

Table 5. 3. 5 Import Time (in hours)				
	AWS	Azure	Oracle	Oracle Spatial + AWS
Time	23	27	10	Untested

Query Response Time

Five test queries were written and run on AWS, Azure and Oracle IaaS and return times were recorded. These queries were thought to be representative of the functionalities desired by N&S in the ‘Lizard’ application. The PostGIS syntaxes will be described and discussed here. The Oracle syntaxes and python script can be found in Appendix E. The queries were run on QGIS (PostGIS) and SQL Developer (Oracle Spatial).

There are several ways to design an Oracle or PostGIS database for raster data. If importing untiled data, PostGIS will store the data in one table, in which there is a text-based raster string in each row. This approach, however, was found to be quite slow and as such the Bangladesh NDVI files were tiled (50x50) and imported into a PostGIS database where one tile was stored per row.

A ‘filename’ column is automatically produced by PostGIS when importing tiled data. Here this autogenerated column was modified from a text to an integer type, so that it can be used to mimic temporal queries. A python script was written to rename all the Bangladesh images with a number and as such each raster image which was imported to PostGIS had a pseudo timestamp.

Oracle was able to handle individual raster images well in a single row and an additional timestamp (integer) column was additionally added to assess temporal query capacities.

Query 1

The first query simply validated each instance in the raster column. This query had an unfavourable return time for N&S with AWS, Azure and Oracle all returning the results in roughly 10.5 seconds.

```
SELECT Rid, (ST_IsValid(rast, 1, FALSE)).* FROM bndvi

WHERE tmstp between 1 and 2

ORDER BY rid
```

Query 2

The second query returned descriptive statistics of the NDVI band. This query had tolerable response times in AWS (4.3 seconds) and Azure (4.2 seconds). Oracle spatial had an ideal response time of 2.2 seconds.

```
SELECT (ST_SummaryStats(bndvi.rast)).* FROM public.bndvi WHERE  tmstp

 BETWEEN 1 and 5
```

Query 3

The third query returned the complete Bangladesh NDVI data at an individual ‘time’ period. This was a slow query to complete on PostGIS platforms. AWS’s return time was severely unfavourable (840 seconds), while Azure was significantly faster but still unfavourable (351.1 seconds) and Oracle (in which the data was stored in one row) returned a favourable time of 0.4 seconds.

```
SELECT rast FROM bndvi WHERE tmstp = 1
```

Query 4

The fourth query returned pixel values in a given time period. Such a query again returned an ideal speed with Oracle Spatial (2.1 seconds) and a tolerable return speed with both AWS (5.4 seconds) and Azure (5.2 seconds).

```
SELECT  ST_Value(rast, 1, 1, 1, False) as pxlval from bndvi

WHERE tmstp between 1 and 4
```

Query 5

The final query tested here returned a count numeric of pixels at different time intervals. This query ran quicker on AWS and Azure (0.4 and 0.5 seconds) than Oracle Spatial (1.6 seconds), although the return time was favourable in all scenarios.

```
SELECT tmstp, st_valuecount (rast) as count FROM bndvi

WHERE tmstp between 0 and 5

ORDER by tmstp
```

Table 5.3.6 Summary of Query Response Times (in seconds)				
	IaaS/PaaS Scenarios			
	AWS	Azure	Oracle	Oracle Spatial + AWS
Query:				
Query 1	10.1	10.3	10.3	10.3
Query 2	4.2	4.3	2.1	2.1
Query 3	840	351.1	0.4	0.4
Query 4	5.4	5.1	2.1	2.1
Query 5	0.4	0.5	1.6	1.6
Average	172.0	74.3	3.3	3.3

Multiple Client Testing

The above queries were run simultaneously on two clients to more accurately assess how well each IaaS deals with load stress. Results (below) suggest that return times are generally negatively affected when serving multiple clients. Query 1 is particularly negatively affected in Azure and AWS. (+ 3 and + 16 seconds). Query 3 is also significantly negatively affected. It is observed that Oracle Spatial is the least negatively affected by multiple query loads.

Table 5.3.7 Query Response Time with Multiple Clients (in seconds)						
	IaaS/PaaS Scenarios					
	AWS	AWS	Azure	Azure	Oracle	Oracle
Query	RE1	RE2	RE1	RE2	RE1	RE 2
Query 1	14.50	16.20	31.0	22.0	3.2	3.4
Query 2	4.2	4.5	4.8	5.1	0.067	0.215
Query 3	950	1200	368	411	0.532	0.6824
Query 4	1.9	1.7	1.62	1.7	1.59	1.2
Query 5	1.5	1.2	1.1	1.5	0.9125	1.14

Details of the local run environments (RE) are provided in appendix D. Screenshots of Case Specific Performance Testing are provided in Appendix G.

5.4.5 Calculating Apdex

Having completed the cloud preference assessment and case specific vendor testing, Apdex scores were then calculated for each attribute of each scenario. Apdex results are displayed as radar graphs on the next page.

5.4.6 Ranking Cloud Scenarios

Final scenario rankings were calculated by multiplying the Apdex scores of each attribute by the adjusted importance rankings and summing them. Ranking results are also displayed on the next page. Apdex and ranking calculations are demonstrated in Appendix F.

5.4.7 N&S Results

IaaS/PaaS Scenarios

The strengths of the proposed IaaS and PaaS scenarios are shown in the radar graphs below which have also been ranked.

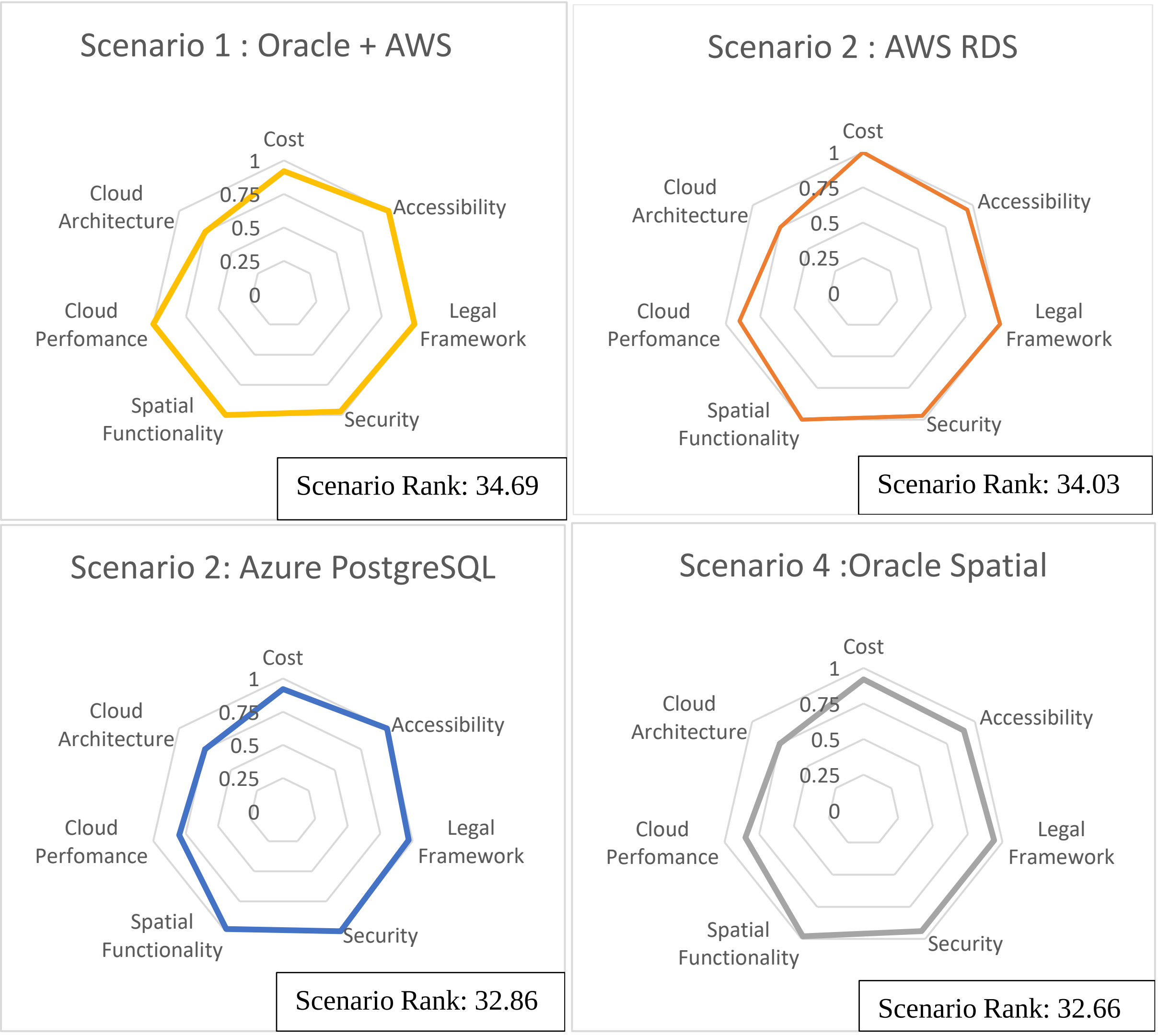


Figure 5.4.3 Favourability of I/PaaS scenarios.

Results indicate that and Oracle Spatial IaaS and an AWS PaaS is the most favourable scenario (score: 34.69) followed by an AWS I/PaaS Scenario (score: 34.03), an Azure I/PaaS Scenario (score: 32.86) and an Oracle Spatial Scenario (score: 32.66).

6. Evaluation

A literature review identified that Small to Medium Enterprises (SMEs) face issues such as lack of IT knowledge, financial or personnel resources when making decisions about cloud migration. Furthermore, previous cloud evaluation techniques do not take spatial data considerations into account.

This thesis adopted a combined Application Performance Index (Apdex) and Analytical Hierarchy approach (AHP) to evaluate the favourability of geocloud services for GI SMEs. This approach was designed to address the aforementioned challenges and its practicality was demonstrated in three relevant GI SMEs. The merit of the components of this approach will be evaluated in this chapter also taking into account feedback from participating decision makers.

6.1 Apdex

For each of the eight cloud attributes assessed in this approach, the features of relevant cloud vendors were assessed within a matrix. Decision makers were then asked to rate the favourability of 81 cloud feature scenarios in the preference assessment. An Apdex formula, which included four tolerance levels rather than the three (traditionally used) was used here. This adjusted formula could more accurately represent the diversity of cloud features.

When asked to rate the success of this element of the evaluation approach decision makers responded with moderate positivity;

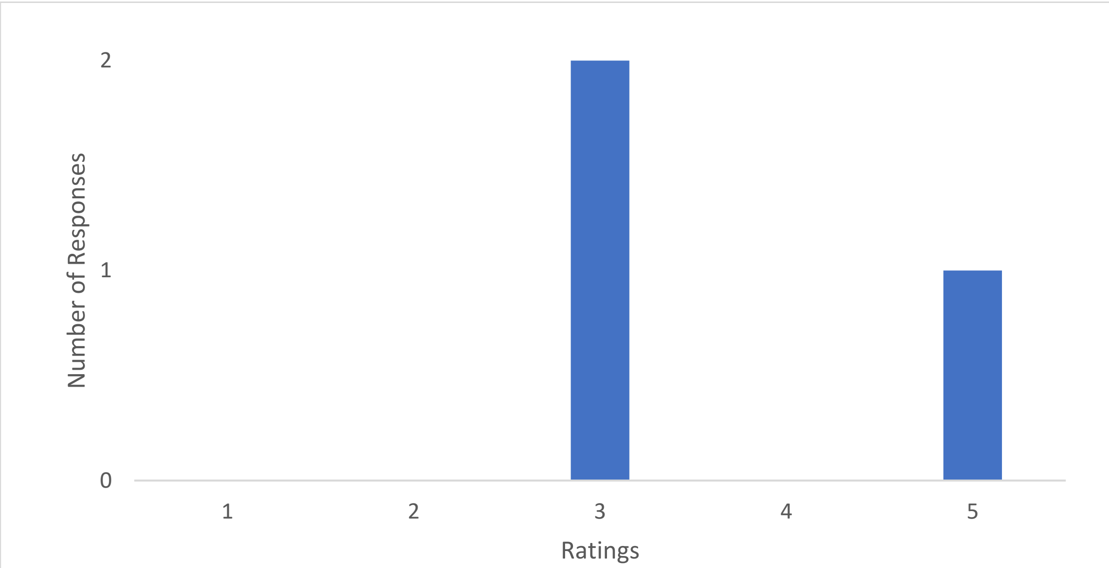


Figure 6.1 Responses of participating decision makers when asked "The cloud evaluation approach adopted by this research used an Apdex approach to weigh cloud feature between 0 and 1. How would you rate this element of the research, on a scale of 1 to 5, 1 being useless 5 being very useful".

Decision makers hesitancy towards the Apdex approach is most likely due to the types of questions which were asked during the cloud preference assessment. The questions asked during the cloud preference assessment were often lacking the specificity needed to guide decision makers, particularly, in the case of IaaS and PaaS scenarios. For example, the cloud preference assessment asked question such as;

How many users (clients and collaborators) would you like to have access to your cloud services?

Rating

> 10 users

5 – 10 users

3 – 5 users

1 – 3 users

1 user

This question is more applicable to geo-SaaS packages with a defined number of users and access privileges. In the case of IaaS for example the following scenario would have been more appropriate;

What level of Input/Output (I/O) would you expect from your application's database?

Rating

1 GB/1 GB (I/O) per week

2 GB/2 GB (I/O) per week

5 GB/ 5GB (I/O) per week

10 GB/ 10GB (I/O) per week

Other, please specify I/O

Similarly, other questions in the cloud preference assessment are also directed towards evaluating geo-SaaS. For example;

What do you think would be an appropriate server response time for cloud services?

Rating

1 to 3 seconds

3 to 5 seconds

5 to 10 seconds

> 10 seconds

In this case more information is necessary to trace user requirements from IaaS to the final digital product.

For example;

Please provide an example of a function (e.g. query) carried out by your application?

What do you think would be an appropriate wait time for end users to get the results of this function?

Rating

1 to 3 seconds

3 to 5 seconds

5 to 10 seconds

> 10 seconds

The second example more specifically, addresses the situation where the server response time is important (e.g. in the front-end user-interface).

Apdex results were calculated after carrying out the preference assessment and performance testing. Apdex scored each cloud attribute as an averaged score of between 0 and 1 and these scores were visualised in radar graphs. In turn, these calculations were then weighed, relative to the attribute importance ratings (discussed below). Within the scope of the current research, comparative differences between the favourability of different cloud platforms/scenarios were assessed as percentages only. It is noted that t-tests could be applied to Apdex scoring in future versions of this evaluation model, to improve statistical robustness.

Conclusion for Apdex

In summary, the usage of an adapted Apdex approach in the current research was moderately successful. Overly generalised questions in the cloud preference assessment detracted considerably from the successful demonstration of this approach. Nonetheless, the Apdex framework itself proved to be a useful method in quantifying complex migrational considerations for decision makers in GI SMEs.

6.2 AHP

In the current evaluation approach, several key 'organisational' and 'infrastructural' cloud attributes were identified (e.g. cost, security, spatial functionality etc.). Decision makers were then asked to prioritise each of these attributes on a linguistic scale of 1 to 10. Decision makers were also asked to weigh their level of certainty surrounding each attribute. Adjusted cloud attribute scores could then be calculated and used to weigh the Apdex scores accordingly.

This approach worked well in the cases of Vicrea and Nelen & Schuurmans where a wider spread of the importance ratings was observed. This allows for an enterprise's priorities to be emphasised in the model. In contrast GSD's attribute importance ratings were largely positive (between 7 and 10), which may have homogenised the weighing of different cloud attributes. This issue could be negated by asking decision makers to rank cloud attribute importance on a relative scale (e.g. as a percentage out of 100%).

When asked to rate the success of this element of the evaluation approach, decision makers responded positively.

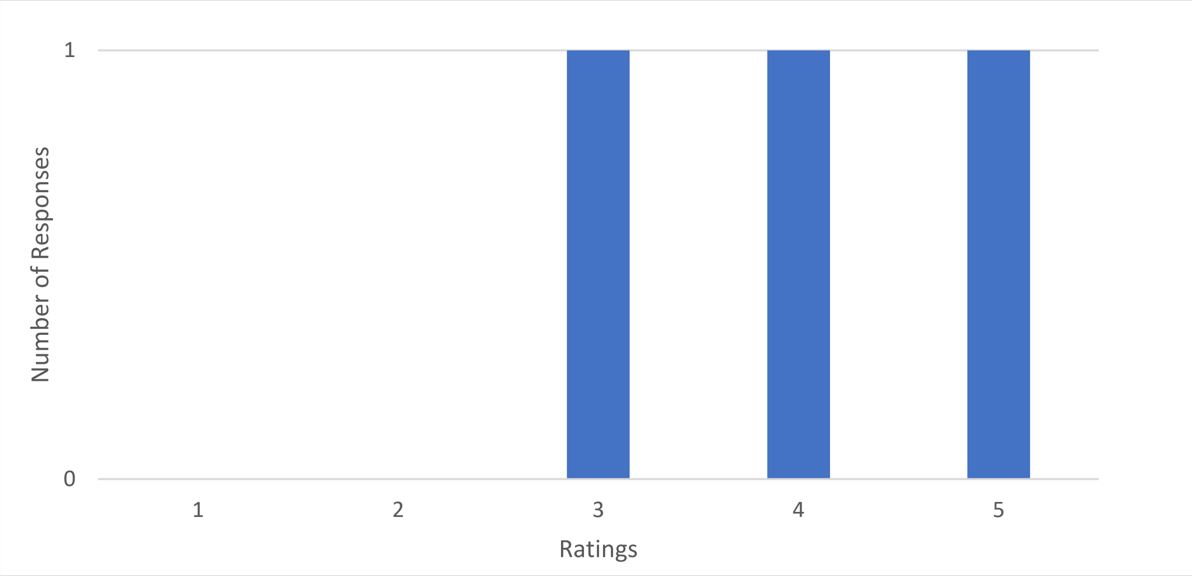


Figure 6.2 Responses of participating decision makers when asked "The cloud evaluation approach adopted by this research used attribute importance ratings to weigh the importance of different cloud attributes. How would you rate this element of the research, on a scale of 1 to 5, 1 being useless 5 being very useful.

Providing qualitative feedback on the AHP method, one decision maker stated the difficulty in ranking cloud attribute importance and emphasised the necessity for, and merit of, adjusting these ratings relative to decision maker certainty.

Conclusion for AHP

It was observed that each of the three participating GI SMEs attached very different levels of importance to different cloud attributes. No cloud attribute (s) were consistently highly or poorly rated in the current research. Although further study is needed, the lack of a consensus as to the most important cloud attributes, further emphasises the need for enterprise- specific approaches to (geo)cloud evaluation. The AHP method demonstrated in the current research successfully weighed enterprise priorities with Apdex and was well received by decision makers.

6.3 Case specific performance testing

In order to assess variable cloud features, the current approach paired certain questions in the cloud preference assessment with quantitative testing of geo-SaaS or I/PaaS offerings.

The import time into IaaS and SaaS offerings, console responsivity, and single and multiple-client query response times were among the variable features tested, with case specific data. In a non-demonstrative scenario such load testing would be carried out directly from the application's front-end. For demonstrative purposes, in this research, the queries were carried out in QGIS (PostGIS) and SQL Developer and Map Builder (Oracle Spatial). The realism of the case specific performance testing values would be improved outside of the current research context as load and functionality testing could be carried out directly from an application's front-end.

6.4 Model Usability

Geo-SaaS

In the cases of Vicrea and GSD, the current approach evaluated several geo-SaaS offerings. Comparatively assessing the overall SaaS rankings for Vicrea, it was observed that the most favourable SaaS was quantitively between 18% and 30% more favourable than other geo-SaaS options. Similarly, although less pronounced, the most favourable geo-SaaS option for GSD was, quantitatively, between 3 and 10% more favourable than other SaaS options. This demonstrates, at least, that there is a spread in terms of the favourability of geo-SaaS options available to GI SME decision makers. The validation of these figures will be discussed together with that of I/PaaS scenarios later in this chapter.

Iaas/PaaS Scenarios

The current results indicated the biggest difference in terms of I/PaaS cloud favourability for the micro organisation ‘Geo Smart Decisions’. Comparatively assessing the overall cloud rankings for I/PaaS scenarios in GSD, show that AWS was 9% more favourable than Azure and roughly 20% more favourable than Oracle.

In contrast, Vicrea’s preferred IaaS scenario was quantitively only 0.02% more favourable than the second highest scoring result and 0.03% higher than the third highest scoring IaaS scenario. Similarly, N&S’s highest scoring I/PaaS scenario was quantitively only 0.02% more preferable than the scenario with the second highest rating and 0.06% more favourable than the lowest scoring I/PaaS scenario.

The receipt of such homogenous results (e.g. that certain scenarios are similarly favourable or unfavourable) in two companies is likely to have occurred due to a number of factors. Firstly, the IaaS vendors reviewed offer very similar infrastructural services (e.g. PostGIS on a remote machine), which are not necessarily comparatively favourable or unfavourable.

Secondly, the difference in performance observed with case specific performance testing, did not necessarily come to the fore in the overall scenario weighing. Sizeable differences were observed in the import time, query response time and multiple client response time between AWS, Azure and Oracle offerings, however if not highly rated in terms of importance, these discrepancies did not heavily influence the overall ranking.

Thirdly, it was observed that decision makers from GSD used a wider spread of the available feature ratings in the cloud preference assessment, whereas both Vicrea and N&S tended to use only ’ideal’ or ‘unsatisfactory’ ratings (1 or 4 respectively) in the cloud preference assessment. This is likely due to the greater specificity of the desired end product by both Vicrea and N&S compared to GSD but may also be related to time pressure when completing the assessment.

To summarize it was observed that the present cloud evaluation approach can highlight significant differences in the perceived favourability of different geo-SaaS platforms. However, it was demonstrated that this approach poorly handles the complexity of I/PaaS scenarios.

6.5 Validation of Model Results

The ranking values presented in section 6.4 (above) have been analysed as percentages only. In terms of model validation, these figures remain unchecked.

The validation of the current ranking scores would ideally be achieved studying SME satisfaction post migration to the platforms or scenarios recommended in the current research. In fact, as noted by Adam and Musah (2015), the longitudinal study of cloud migration outcomes is absent from cloud evaluation techniques in general.

Such a long-term assessment of cloud migration outcomes was beyond what was feasible in the time frame of the current thesis. However, feedback from the participating decision makers provides some initial insights into the reliability of this approach.

When asked “how likely are you to use the results of the current analysis in future cloud projects?”, decision maker responses were mixed. Such results may reflect the need for model improvements (outlined below) and validation.

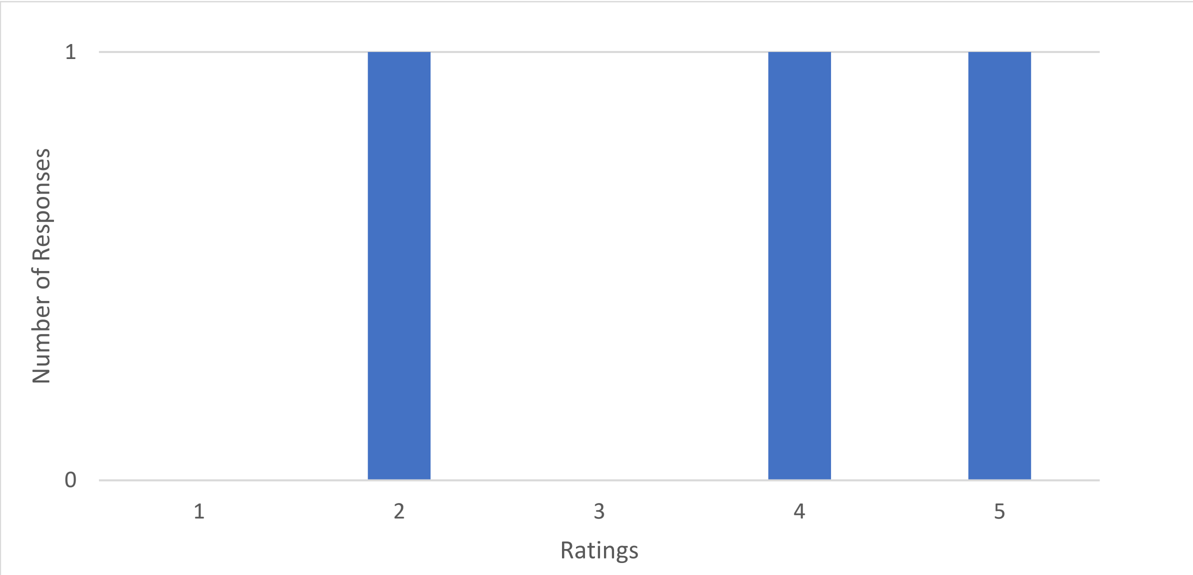


Figure 6.3 Responses of participating decision makers when asked; “How likely are you to use the results of the research to guide future cloud projects?” 1 being very unlikely and 5 being very likely.

6.6 Future Model Development

PostGIS vs Oracle Spatial

PostGIS and Oracle Spatial were identified as the key geo-Db offerings. Broadly, PostGIS and Oracle Spatial have very similar functionalities. Both Db platforms can handle transformed vector and raster data. PostGIS uses the Geographic Data Abstraction Library (GDAL) for its data transformations. Oracle Spatial, in contrast, uses GDAL with proprietary geometry and ‘georaster’ data formats to store spatial data. Oracle provides object-oriented (vertical) spatial data storage whereas PostGIS offers relational (horizontal) storage.

Across all four test datasets, Oracle outperformed PostGIS in terms of its averaged query return times. These trends favouring Oracle Spatial, were more pronounced in raster than in vector datasets.

However, Oracle Spatial is licenced and only accessible with Oracle’s ‘High’ or ‘Extreme’ performance packages. In contrast, PostGIS is open source and could be employed without licensing and may be more suitable for smaller scale projects. The need for further research comparatively quantifying the performance of PostGIS and Oracle Spatial is highlighted in this work. Future comparative research of these two Db platforms could be integrated with good effect to a geocloud evaluation model.

The complexity of I/PaaS scenarios

One of the key challenges facing this research was the diversity of available as-a-service offerings (object storage, geo-SaaS, IaaS and PaaS). The establishment of cloud matrices presented in this research, goes some way to quantifying the merits of these offerings. Similar matrices which evaluate the features of all relevant cloud offerings in a standardised or indexed fashion ought to be established.

Such a long-term goal would be best achieved by a consortium of individuals working with geo-IT scenarios. Cloud evaluation for geospatial purposes would benefit greatly if a 'geocloud services' working group could be set up within the Cloud Services Measurement Initiative Consortium (CSMIC). The current evaluation approach could be used as a template for geocloud evaluation by such a group.

The separate evaluation of scenario components

After the establishment of standardised evaluation matrices for (geo) cloud products, the current evaluation approach would be improved if the complexity of cloud scenarios was ‘filtered’ in the cloud preference assessment. This could be easily achieved by simply asking GI SME decision makers what type of remote infrastructures (e.g object storage, IaaS, SaaS or PaaS) are necessary for their project.

As a result, the favourability of each individual infrastructural component to geocloud migration could be compared across vendors in a standardised fashion. This was carried out, to some extent in the current research. However, scenarios were evaluated “on a whole” rather than by their individual components.

6.7 Conclusion of Evaluation

The geocloud evaluation model presented in the current thesis, provides GI SME decision makers with a framework, with which they can quantify complex decision-making processes related to cloud migration.

Findings suggest that this methodology could be applied effectively by GI SMEs in evaluating geo-SaaS offerings. The presented framework, however, is less effective at comparatively evaluating the favourability of more complex I/PaaS scenarios. This shortcoming could be addressed in future work by improving the questions presented to decision makers in the cloud preference assessment (see Appendix B).

Future iterations of the current approach would benefit greatly from the establishment of standardised cloud evaluation matrices (modelled in this work) for each standalone component of a desired geo-I/PaaS scenario. In such a case, the favourability of each individual scenario component could be calculated, rather than the favourability of the scenario as a whole. This would also give the model the advantage of being able to evaluate I/PaaS components across different vendors (e.g. Azure PostgreSQL and AWS Codestar), more easily. The potential benefit of establishing a spatial working group within the CSMIC and further quantifying the performance of PostGIS and Oracle Spatial is also highlighted in this research.

Model validation ought also to take a central role in future research. In the current work, decision maker feedback was utilized to provide initial insights into the reliability of the present approach. In this case decision makers rated the Apdex and AHP components of the current approach positively or with moderate positivity. Further validation is needed in future work. Ideally, outcome satisfaction would be measured longitudinally following the migration of GI SMEs to the platforms/scenarios recommended in the current research. Such a long-term analysis was not feasible within the time frame of the current thesis.

The validity of the case specific performance testing will also improve outside of the current research context, as queries and load testing can be carried out directly from an application's frontend by decision makers.

Based on the demonstrated practicality of the current approach within GI SMEs and subsequent decision maker feedback, it can be concluded that the current approach is worth future investigation, improvement and use.

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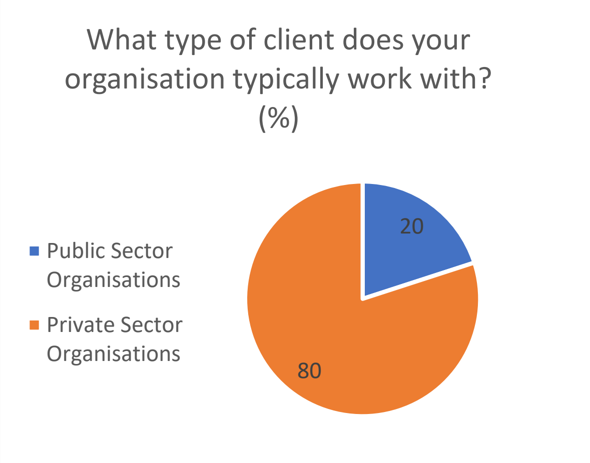
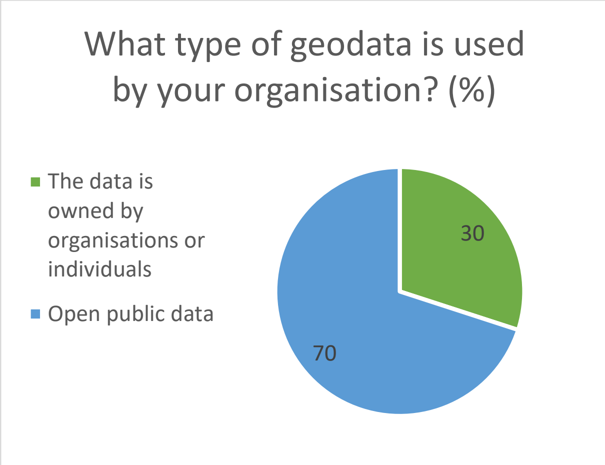
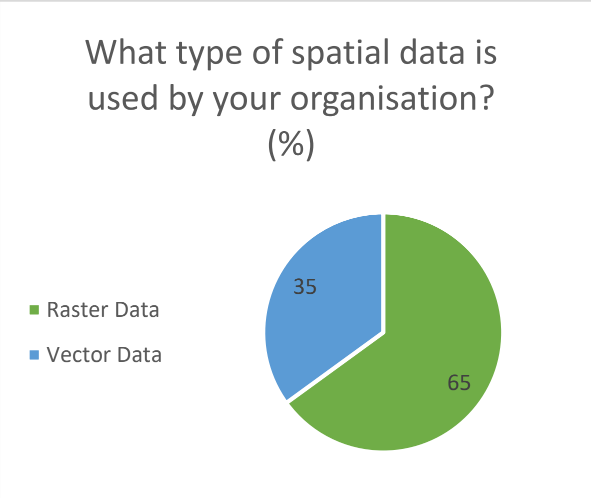
Appendices

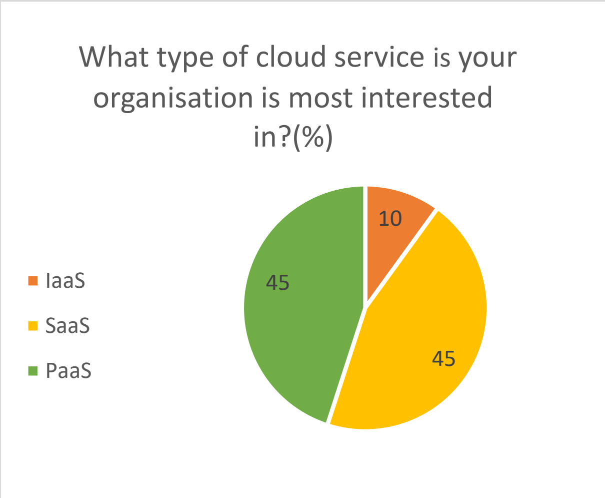
Appendix A: Company Background and Test Data

GSD







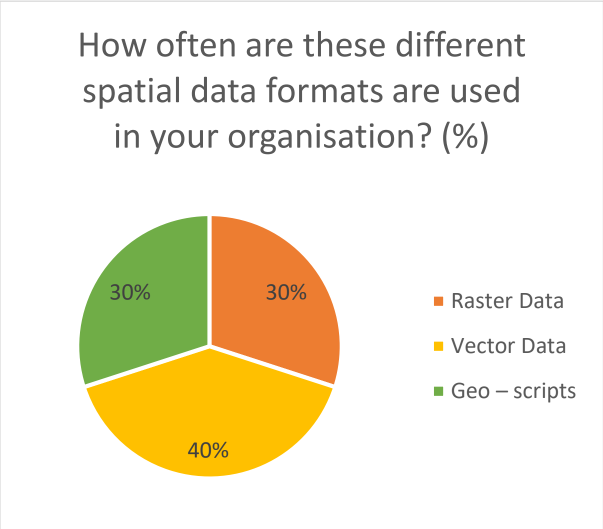


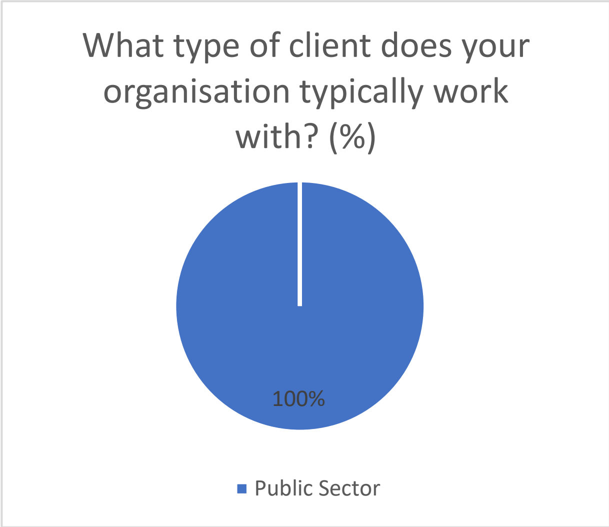
Test Data

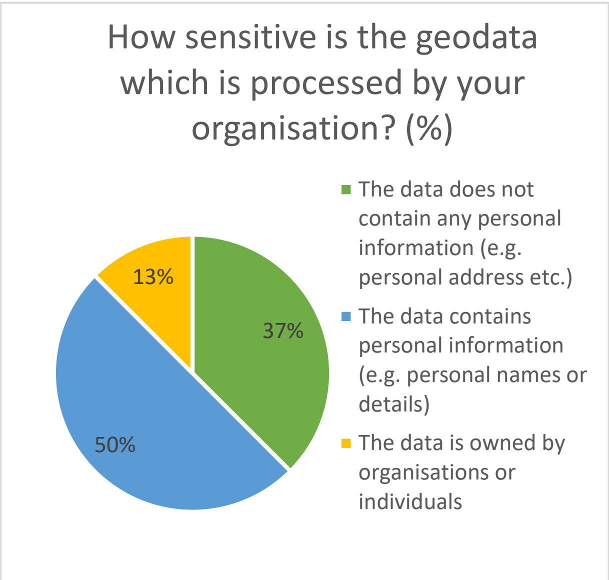
Ancient_Woodland_Inventory	
Description: An Ancient Woodland Inventory (AWI) shapefile of vegetation cover in Wales was used as representative vector data for Geo Smart Decisions. The shapefile contains information about the status, categorization and size of forested areas in Wales.1	
Folder Size: 89.9 MB File Format: ESRI Shapefile Coverage: Wales	SRID: “EPSG 27700”

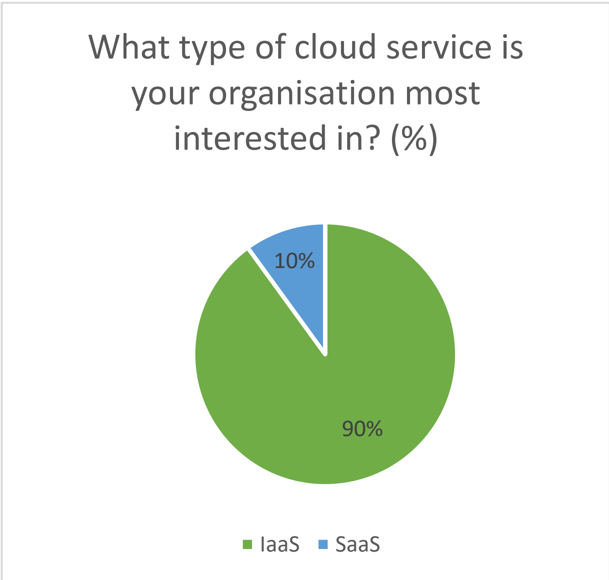
SN68_2M_RES	
Description: Some tiles from a Digital Terrain Model (DTM) of North Western Wales was used as representative raster data for Geo Smart Decisions. These files had a resolution of 2 meters.	
Folder Size: 7 MB File Format: JPG, JPGW Size: 500 x 500	Datum: None Projection: None 4 Bands (R,G,B) and Height
Coverage: Various uniform coverages in within SN60 (North-Western Wales).	

Vicrea





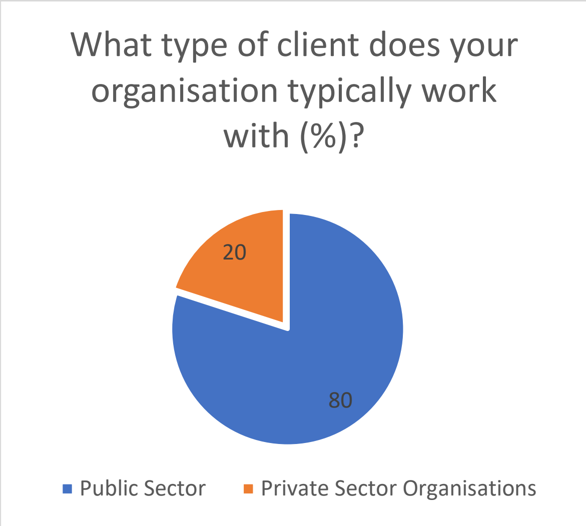


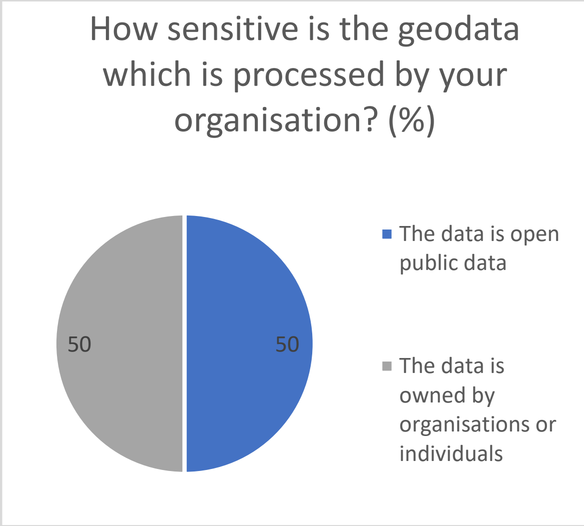


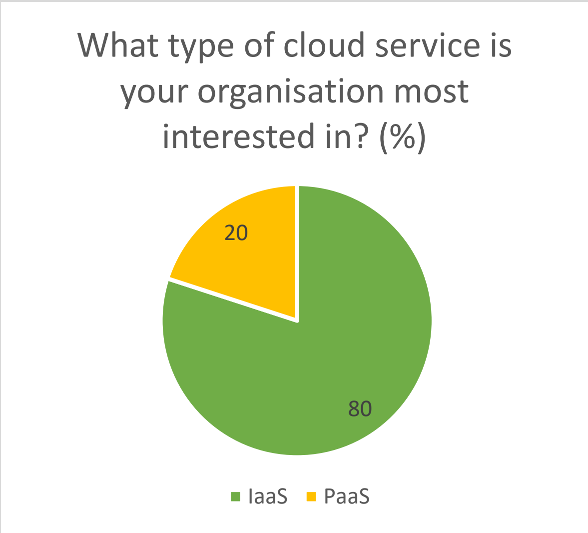
Test Data

Shapefiles of Assen	
Description: Vicrea shared a shapefile package containing building information and geometric points in the city of Assen (Netherlands), for the purposes of this research. The package consisted of two shapefiles, one containing polygon data (e.g. buildings) and attached sematic data (e.g. building age) and one containing point data for geometric construction.	
Folder Size: 80 MB File Format: ESRI Shapefile Coverage: Assen Urban Area	SRID: “EPSG 28992”

N & S







Test Data

Bangladesh NDVI	
Description: Nelen and Schuurmans shared a 7 day series of NVDI images of Bangladesh, for the purposes of this research. This series of images consisted of 46 files, which were roughly 1.86 MB in size.	
Folder Size: 108 MB File Format: Geotiff Individual File Size: ~1.86MB	Datum: WGS 1984 Projection: 3106 (Bangladesh) 1 Band Displayed (Type 16 Int)
Coverage: Upper Left (83.8640382, 26.9833333) (83d51'50.54"E, 26d59' 0.00"N) Lower Left (83.8640382, 20.4091146) (83d51'50.54"E, 20d24'32.81"N) Upper Right (97.3844235, 26.9833333) (97d23' 3.92"E, 26d59' 0.00"N) Lower Right (97.3844235, 20.4091146) (97d23' 3.92"E, 20d24'32.81"N)	

Appendix B: Cloud Preference Assessment

Introduction

Dear participant, welcome to the user assessment for my research.

Questions have been grouped into 8 general topics. The first 5 topics - 1) Cost 2) Accessiblity, 3) Legality 4) Security ,and 5) Customer Service, will assess your preferences for general cloud characteristics.

The remaining three topics - 6) Spatial Functionality 7) Cloud Performance and 8) Architecture assess how best cloud services might be established for Geo Smart Decisions. After each topic you will be asked to rate how important you think each attribute is. At the end of the assessment there is also a small section asking you for details of your existing hardware and how your existing website has been set up.

If you have not already, please watch this instructional video about how to respond to the questions. A key is also provided below this text to help you. > https://drive.google.com/file/d/1qfjojKFEnRHPW5JnRBt9GmkIOqYPF3qY/view?usp=sharing

This assessment will take roughly 45 minutes to complete. Please answer these questions together and come to a consensus about what the most appropriate answers are.

If you have any questions about the assessment please don't hesitate to contact me. I will be available after 2pm everyday this week and can be contacted via Whatsapp at +353 87 4588017.

Thank you for taking the time to complete the assessment!

Assessment Key

Ratings

1 = "Unsatisfactory" - the option is not preferable

2 = "Tolerable" - the option is mildly preferable

3 = "Adequate " - the option is moderately preferable

4 = "Satisfactory" - the option is preferable

Checkboxes (X)

"Does not Matter" - Any of the presented options would suffice

"Do not Know" -I do not have sufficient knowledge to give a preference

Attribute Importance Ratings

1 - The attribute is less important than all of the other attributes

5 - The attribute is of middling importance compared to the other attributes

10 - The attribute is the most important attribute compared to the other attributes

Attribute Certainty Ratings

1 - I am completely unsure about the rating which I have given

5 - I am neither sure nor unsure of the attribute rating which I have given	
10 - I am certain about the attribute rating which I have given	
Percentages	
0%- this format is unused	
30% this format is used roughly on third of the time	
90% this format is used nearly all of the time	
Section 1: Cost	
Typically cloud vendors adopt a “pay per use” pricing model. This means that pricing is dependent on hours of use and what online infrastructures you engage with. Thus, the estimates in this section are based on the average monthly usage of generic services.	
1.1What is the budget for cloud services?	
	Answer (X)
Negligible or none	
<£15 per month	
£15 - 30 per month	
£30 – 50 per month	
£50 – 100 per month	
£100 - £300 per month	
£300 - £500 per month	
>£500 per month	
I have a more specific budget (please describe)	
1.2 How would you like to pay for cloud services?	
	Rating (1-4)
Pay per use	
A flat monthly rate	
Topping up cloud credits as needed	
Doesn’t Matter	
Don’t Know	
1.3 Would you like there to be cost capping* on your cloud services?	

*Cost capping is the stopping of cloud services once the cost reaches a certain threshold.	Answer (X)
Yes	
No	
Doesn't Matter	
Don't Know	
1.4 How would you like your cloud provider to communicate with you about cloud costs?	
	Rating (1-4)
By providing cost breakdowns and sending my alerts when cloud cost exceed certain thresholds	
By providing me with a breakdown of cost only	
By provided usage and cost guidelines	
Communication about cost doesn't matter	
Doesn't Matter	
Don't know	
1.5 Would you like your clients/collaborators to have to pay for software licencing (e.g. ArcGIS), while working in the cloud?	
	Answer (X)
Yes	
No	
Doesn't Matter	
Don't Know	
1.6 Would you like your cloud provider to send you alerts if you accidentally leave a virtual machine (VM)* running when not in use?	
* A VM is server owned by the cloud provider	
	Answer (X)
Yes	
No	

Doesn't Matter											
Don't Know											
Attribute Importance Rating											
Compared with the other cloud characteristics, how important would you rate cloud cost on a scale of 1 to 10?*											
* 1 being of the least important and 10 being of most important											
Rating		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Answer											
On a scale of 1 to 10 how sure are you or your answer to the previous question?											
* 1 being completely uncertain 10 being completely certain											
Rating		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Answer											

Do you have any additional comments regarding cloud cost?	
Comment:	
Section 2: Cloud Accessibility	
2.1 How many users (clients and collaborators) would you like to have access to your cloud services?	
	Rating (1 -4)
>10 users	
5 – 10 users	
3 – 5 users	
1 to 3 users	
1 user only	
Don't Know	
2.2 Would you like multiple users to be able to login to your cloud services at the same time?	

	Answer (X)
Yes	
No	
Doesn’t Matter	
Don’t Know	
2.3 How many users would you like to be able to the simultaneous access to your cloud services?	
	Rating (1 -4)
More than 5 users	
5 users	
3 users	
2 users	
Doesn't Matter	
Don’t Know	
2.4 How would you like users to be able to access your cloud services?	
	Rating (1 -4)
On all PCs and laptops and most mobile devices (android, IOs, windows)	
On all PCs and laptops and windows smartphones	
On any windows, Linux or IOS PC or laptop	
On any windows PC or laptop	
On all PCs in the office	
On one office PC only	
Don’t Know	
2.5 How would you like your cloud services to be shared with clients and collaborators?	
	Rating (1 -4)
Via an invite link with unique login credentials	
Access via a generic (non-unique) username and password	
Manually downloading and sharing the data	

Doesn’t Matter	
Don’t Know	
2.6 Would you like to have the possibility of making your cloud services publicly available on the web?	
	Rating (1 -4)
Yes	
No	
Doesn’t Matter	
Don’t Know	
2.7 Would you like to have access to software packages which will aid the migration of offline data/services to the cloud?	
	Rating (1 -4)
Yes	
No	
Doesn’t Matter	
Don’t Know	
2.8 How would you like your data in the cloud to be shared with clients and collaborators?	
	Rating (1 -4)
Via login credentials which will automatically change every 72 hours	
Via an invite link with unique login credentials	
Access via a generic (non-unique) username and password	
Manually downloading and sharing the data	
Doesn’t Matter	
Don’t Know	
2.9 How would you like your clients and collaborators to be able to interact with versions of your data/services?	
	Rating (1 -4)

I would like to be able to set unique download/upload restrictions for each project.											
I would like them to be able to both download and upload without restriction											
I would like them to be able download only											
I would like them to be able to edit and upload data to the cloud only											
I would like them to be able view the data/cloud service only											
Doesn’t Matter											
Don’t Know											
2.10 Would you like to be able to give clients and collaborators access to information backed up by your cloud provider?											
	Answer (X)										
Yes											
No											
Doesn’t Matter											
Don’t Know											
Attribute Importance Rating											
Compared with the other cloud characteristics how important would you rate cloud accessibility on a scale of 1 to 10?*											
* 1 being of the least important and 10 being of most important											
Rating		1	2	3	4	5	6	7	8	9	10
Answer											
On a scale of 1 to 10 how sure are you or your answer to the previous question?											
* 1 being completely uncertain 10 being completely certain											
Rating		1	2	3	4	5	6	7	8	9	10
Answer											
Do you have any additional comments regarding cloud accessibility?											
Comment:											

Section 3: Cloud Legal Frameworks	
Data and services in the cloud should be subject to a binding legal contract and also the data protection laws of the location of the cloud provider's datacenter.	
3.1 Would you like your cloud provider to provide you with information regarding SLAs* and the legalities of their cloud services?	
*Service Level Agreements (SLAs) are commitments which cloud providers can make as to the level of reliability which can be expected from their cloud offerings.	
	Answer (X)
Yes	
No	
Doesn't Matter	
Don’t Know	
3.2 What uptime* SLA would you consider to be favourable?	
Uptime is the amount hours where your remote services are available. The industry standard is 99.99% uptime.	
	Rating (1-4)
An uptime percentage of greater 99.99% for cloud services	
An uptime percentage of 99.99% and the receipt or service credits when uptime falls sort of this percentage	
Less than 99%	
Doesn’t Matter	
Don’t know	
3.3 Where would you like your data centre to be based?	
	Answer (X)
In the same legal jurisdiction as your operations (e.g. Europe)	
In a jurisdiction with less data regulation (e.g. in the U.S or Canada)	

Doesn’t Matter		
Don’t Know		
3.4 What legal contractual arrangement would you like to have with your cloud provider?		
	Answer(X)	
The cloud provider will take responsibility for losses of data, cloud failures etc.		
Your company will take responsibility for the loss or misuse of data, cloud failures etc.		
Doesn't Matter		
Don't Know		
None		
3.5 How would you like the legal agreement between your organisation and the cloud provider to be presented to you?		
	Rate (1-4)	
By email		
Within your cloud console/dashboard		
Published somewhere on the cloud providers website		
Doesn’t Matter		
Don’t Know		
3.6 Who you like to take legal responsibility for “disaster scenarios” such as data breach or the loss of data?		
	Rating (1-4)	
You		
The Cloud Provider		
Third Party Insurance		
Doesn’t Matter		
Don’t Know		
3.7 If you choose to terminate your contract with your cloud provider, what agreement is acceptable?		
	Rating (1-4)	
You can end y		

our contract instantly if termination is by cause or choice.	
You can end your contract instantly if there is cause.	
You must give your cloud provider 30 days notice before ending the contract	
Doesn’t Matter	
Don’t Know	
3.8 How would you like to be notified of any changes to your cloud providers SLAs?	
	Answer (X)
By personal email, alert or text.	
Notification is not necessary I will find the changes on the cloud providers websites	
Doesn’t Matter	
Don’t Know	
3.9 Would you like to be able manage the area in which your cloud services are registered for tax purposes	
	Answer (X)
Yes	
No	
Doesn't Matter	
Don’t Know	
Attribute Importance Rating	
Compared with the other cloud characteristics how important would you rate cloud legalities on a scale of 1 to 10?*	
* 1 being of the least important and 10 being of most important	

Rating		1	2	3	4	5	6	7	8	9	10
Answer											
On a scale of 1 to 10 how sure are you or your answer to the previous question?											
* 1 being completely uncertain 10 being completely certain											
Rating		1	2	3	4	5	6	7	8	9	10
Answer											
Do you have any additional comments regarding cloud legality?											
Comment:											

Section 4: Cloud Security	
Cloud security is the protection of data and cloud services from unauthorized access or misuse.	
**	
A “Firewall” is a network security infrastructure	
“Multi-Factor Authentication” is the use of two security barriers, for example a password and security access code.	
“Key Pairs” are passwords or codes known by two individual and must be entered at the same time to gain access.	
**	
4.1 What type of security would be ideal for you, your clients and collaborators?	
	Rating (1-4)
Firewall and Password Protection	
Password Protection Only	
Firewall Protection Only	
Multi-Factor Authentication	
Cloud Front Key Pairs	

Access via an office computer only	
Doesn’t Matter	
Don’t Know	
4.2 How robust would you like your cloud service to be?	
	Rating (1-4)
Resistant against low level attacks such as password cracking	
Resistant and higher- level attacks such as network attacks	
Resistant against almost all attacks	
Security isn’t a major concern	
Doesn't Matter	
Don’t know	
4.3 Would you like your cloud vendor to monitor your data/service for potential security issues?	
	Answer (X)
Yes	
No	
Doesn't Matter	
Don’t Know	
4.4 How would you like your cloud provider to notify you regarding security issues?	
	Rating (1-4)
By providing you with security alerts, recommendations and metrics	
By providing you with security alerts only	
By providing you with recommendations and metrics only	
No communication is necessary	
Doesn’t Matter	
Don’t Know	

4.5 How would you like the security settings for your cloud service to be managed?	
	Rating (1-4)
I would like to be able to configure the security settings myself with security guidance from my cloud provider	
I would like to be able to configure the security settings myself (allowing for easier access for etc.)	
I would like my cloud vendor to manage security settings	
Security settings don't matter	
Doesn't Matter	
Don't Know	
4.6 Would you like to be able to set a customized security policy for secondary cloud users?	
e.g. give greater access to certain collaborators/clients	Answer (X)
Yes	
No	
Doesn't Matter	
Don't Know	
4.7 Would you like to be able to customize the password requirements for collaborators and clients?	
	Answer (X)
Yes	
No	
Doesn't Matter	
Don't Know	
4.8 How would you like your cloud vendor to monitor the activities of secondary users within your cloud?	
	Rating (1-4)
I would like my cloud vendor to discreetly monitor the activities of secondary users and notify me if any security issues arise.	
I would like my cloud vendor to monitor the activities of secondary user and to restrict the access of secondary users when necessary.	

I don't want my cloud vendor to monitor the activity of secondary users.											
Doesn't Matter											
Don't know											
Attribute Importance Rating											
Compared with the other cloud characteristics, how important would you rate cloud security on a scale of 1 to 10?*											
* 1 being of the least important and 10 being of most important											
Rating		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Answer											
On a scale of 1 to 10 how sure are you or your answer to the previous question?											
* 1 being completely uncertain 10 being completely certain											
Rating		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Answer											
Do you have any additional comments regarding cloud security?											

Section 5: Customer Service	
Cloud support is valuable. Cloud providers offer customer support in different forms. This section assesses your cloud support preferences.	
5.1 What types of customer service/support would you like your cloud provider to provide?	
	Rating (1-4)
Live chat in desktop	
Over the phone support	
Support via e-mail	
Support by means of forums and FAQs	
Doesn't matter	
Don't know	

5.2 What customer support hours would be ideal for you?	
	Rating (1-4)
.24/7	
.24/5	
9pm to 5pm Monday to Friday	
Irregular weekday hours	
Doesn’t Matter	
Don’t Know	
5.3 Would you like to have a designated support person assigned to you?	
	Answer (X)
Yes	
No	
Doesn’t Matter	
Don’t Know	
5.4 Would you consider paying extra for basic technical support?	
	Answer (X)
Yes	
No	
Doesn't Matter	
Don’t Know	
5.5 Where would you like your support team to be based?	
	Rating (1-4)
In your base country	
In an English-speaking country	
In any country worldwide	
Doesn’t Matter	

Don't Know											
5.6 What do you think is an acceptable wait time for a response from a support representative from your cloud provider?											
	Rating (1-4)										
Less than 5 minutes											
Between 5 and 10 minutes											
Between 10 minutes and 30 minutes											
Between 30 minutes and 1 hours											
>1 hour											
>3 hour											
>1 day											
Doesn't Matter											
Don't Know											
Attribute Importance Rating											
Compared with the other cloud characteristics how important would you rate customer service on a scale of 1 to 10?*											
* 1 being of the least important and 10 being of most important											
Rating		1	2	3	4	5	6	7	8	9	10
Answer											
On a scale of 1 to 10 how sure are you or your answer to the previous question?											
* 1 being completely uncertain 10 being completely certain											
Rating		1	2	3	4	5	6	7	8	9	10
Answer											
Do you have any additional comments regarding customer service?											
Comment:											

Section 6: Spatial Functionality

We have finished the assessing general cloud characteristics. The follow section will more specifically assess how best a cloud service can serve GSD.	
Please rate as a percentage adding up to 100, how often these different spatial data formats are used in your organisation.	
	Answer (%)
Raster Data	
Vector Data	
Geo – scripts	
Other (Please describe) Not sure what is meant by geo- scripts	
What spatial cloud functionalities are most important for your organisation.	
	Answer (1-4)
Storing and Retrieving Spatial Data	
Processing and collaborative work with vector data	
Visualising and sharing vector data products	
Processing and collaborative work with raster data	
Visualising and sharing raster data products	
Writing and collaborating on scripts	
Other please describe…	

Infrastructure-as-a-Service (IaaS)

IaaS is related to the storage and retrieval of data from the cloud. As before please rate the options on a scale of 1 to 4.	
How would you like to be able to upload data to your cloud provider?	
	Rating (1-4)
By means of an online user-friendly interface	
By means of a File Transfer Protocol (FTP)	
By means of command line prompts	
Doesn't matter	
Don't Matter	
In which file formats would you like to be able to upload data to your cloud provider for IaaS and SaaS services?	

	Rating (1- 4)
ESRI shapefile or .shp	
jpeg, tiff, png	
json	
Geoson	
.xls file types	
xml file types	
sql file types	
.gdb file types	
.db file types	
.rdf and graph file types	
other file types (please rate also) 'geotiff', kmz, kea, jpeg2, img	
Ideally how would you like to be able to upload spatial data to the cloud?	
	Rating (1-4)
As a complete file in its original format (e.g. shapefile, Tiff image)	
As a complete file in its original format which is automatically converted to meet upload requirements	
As a transformed image or datafile to fit the cloud storage requirements (e.g. shapefile to CSV, Tiff to JPEG etc.)	
As a file which is only partially stored in the cloud	
Doesn't Matter	
Don't Know	
Ideally how would you like your spatial data to be stored from the cloud?	
	Rating (1-4)
As a complete file in its original format (e.g. shapefile, Tiff image) with SQL attribute data	
As a complete file in its original format (e.g. shapefile, Tiff image) only	
As SQL attribute data only	
As a transformed image or datafile to fit the cloud storage requirements (e.g. shapefile to CSV, Tiff to JPEG)	
As a file which is only partially stored in the cloud	
Doesn't Matter	
Don't Know	

How would you like to be able to retrieve your spatial data from the cloud?	
	Rating (1-4)
In the same format in which you entered it	
In a different format from that in which you entered it	
I would like to be able to convert it to multiple formats, projections etc.	
Doesn’t Matter	
Don’t Know	
If the capacity to query a database is important to you what query capacities would you like to have?	
	Rating (1-4)
The capacity to carry out SQL queries and with spatial extensions (e.g. PostGIS)	
The capacity to carry out SQL queries	
The capacity to filter the data to some extent	
Running queries on the data is not important	
Doesn't Matter	
Don’t know	
What type of additional data storage features would you like from your cloud provider?	
	Rating (1-4)
Access API Keys	
Data Analytics	
Data Metrics	
All of the above	
None	
Doesn’t Matter	
Don’t Know	
How would you like your spatial data to be backed up?	
	Rating (1-4)

I would like it to be back up as per customized settings which I set (e.g. frequency etc.)	
I would like my cloud provider to automatically back up my data for me	
I don't need my data backed up	
Doesn't Matter	
Don't Know	
Would you like to have free access to other spatial data from your cloud provider?	
	Answer (X)
Yes	
No	
Doesn't Matter	
Don't Know	
Software-as-a-Service	
On most cloud platforms, IaaS must be established in order to utilize higher level cloud services such as SaaS and PaaS. SaaS, particularly spatial SaaS, is the remote provision of geo software which can be used without writing code. Examples of geo SaaS is remote access to Arc GIS on Microsoft Azure and AWS. Other Cloud providers such as My GeoData Cloud and OmniSci, however, have built their own online SaaS.	
What type of data would you like to be able to visualise on a cloud platform?	
	Rating (1-4)
Raster and Vector Data	
Raster Data	
Vector Data	
Graph Triples	
Doesn't Matter	
I don't need to visualise data	
What additional features would you like to have in when visualising spatial data	
	Rating (1-4)
The ability to pan/ zoom in and out	

The capacity to explore the attribute data/cell values	
The ability to run basic analyses on the data	
The ability to interact with the data (e.g. produce proportional symbols, choropleths etc.)	
The ability to query the data itself	
The ability to convert and transform the dataset	
Providing multiple data visualisations in a dashboard	
All of the above	
Doesn't Matter	
Don't Know	
Would you like to be able to work with ArcGIS and in your cloud platform?	
	Answer (X)
Yes	
No	
Doesn't Matter	
Don't Know	
Would you like to be able to host projects created in ArcGIS in your cloud platform?	
	Answer (x)
Yes	
No	
Doesn't Matter	
Don't Know	
Would you like to have access to SaaS which enables the development of Virtual Reality or Augmented Reality Applications?	
	Answer (x)
Yes	
No	
Doesn't Matter	

Don’t Know	
Would you like to have access to an SaaS which automates to analysis of statics and video imagery?	
	Answer (X)
Yes	
No	
Doesn't Matter	
Don’t Know	
Would you like to have access to SaaS which facilitates the Internet of Things (IoT)	
	Answer (X)
Yes	
No	
Doesn't Matter	
Don’t Know	

Platform-as-a-Service (PaaS)

PaaS is the provision of an online environment where developers can build and employ application or scripts related to data processing.

What programming language would be optimal for your purposes?	
	Rating (1-4)
Python	
Mathlab	
R	
Java	
C	
C++	
PHP	
JavaScript	
Java	
Other, please rate also	

What integrated development environments (IDEs) would you like your cloud PaaS to be compatible with?	
	Rating (1-4)
Visual Studio	
Net Beans	
PyCharm	
Eclipse	
.NET	
Other, please rate also	
I don't need my cloud PaaS to be compatible with an IDE	
Don't know	
How would you like your PaaS to be set up?	
	Rating (1-4)
I and other collaborators would have easy access to the platform for app/script development as well as the possibility of easy deployment.	
I would like to have easy access to a PaaS as well as the possibility of easy PaaS deployment.	
Doesn't Matter	
Don't Know	
How would you like your collaborators/clients to have access to your scripts/applications?	
	Rating (1-4)
Giving them access to the build on the cloud platform	
By setting up API keys	
URL or QR code access	
Doesn't Matter	
Don't Know	
How would you like your cloud provider to assist you in developing applications?	
	Rating (1-4)

By giving me access to “project templates” which provide me with much of the necessary code for my application.		
By giving me access to a “code library” where I can find blocks of pre-written code which may be useful		
By guiding me with tutorials about application development		
By pointing me in the direction of resources freely available online		
Doesn’t Matter		
Don’t Know		
How would you like to source the compute power for your application or scripts?		
	Answer (X)	
From any computer or server		
From the servers of the cloud provider only		
Doesn’t Matter		
Don’t Know		
How would you like to be able to customise your PaaS environment?		
	Rating (1-4)	
Change code settings and customize ownership and work responsibilities		
Change certain code settings (e.g. languages, use default code blocks etc.)		
A PaaS environment where I can write and share code before deploying it.		
Doesn’t matter		
Don’t Know		
How would you like to be able to disseminate finished versions built with PaaS?		
	Rating (1-4)	
Deploying them publicly online (no restrictions of access)		
Deploying them to certain individuals with login credentials online		
Allowing access via download only		
Deploying them publicly only and allowing download		
Deploying them to certain individuals online who will also have download capacities.		

Doesn’t Matter	
Don’t Know	
If you update scripts or applications, would you like your cloud provider to automatically update any version already deployed?	
	Answer (X)
Yes	
No	
Doesn't Matter	
Don’t Know	
What type of PaaS monitoring would you expect from your cloud provider?	
	Rating (1-4)
By means of collaboration metrics (e.g. code commit and access logging)	
By means of performance metrics (e.g. code testing, computer speed etc.)	
Both of the above	
PaaS monitoring doesn’t matter	
Don’t know	
How would you like your PaaS environment to be monitored?	
	Rating (1-4)
It would like performance metrics to be carried out automatically and for roles and responsibility to be outlined with inbuilt software.	
I would like performance metrics to be carried automatically	
I would like tasks, roles and responsibilities to be out outlined with an inbuilt software.	
Doesn’t Matter	
Don’t Know	

Attribute Importance Rating	
Compared with the other cloud characteristics how important would you rate spatial functionality on a scale of 1 to 10?*	
* 1 being of the least important and 10 being of most important	

Rating		1	2	3	4	5	6	7	8	9	10
Answer											
On a scale of 1 to 10 how sure are you of your answer to the previous question?											
* 1 being completely uncertain 10 being completely certain											
Rating		1	2	3	4	5	6	7	8	9	10
Answer											
Please rate as a percentage adding up to 100, what cloud service is your organisation is most interested in?											
	Answer (%)										
IaaS											
SaaS											
PaaS											
Do you have any additional comments regarding spatial functionality?											

Section 7: Cloud Performance

Cloud vendors utilize remote desktop protocols (RDP) to provide online services. How would you like your RDP interface to be set up?	
	Rating (1-4)
I would like to be able to access my RDP and cloud storage easily using pre-built interfaces	
I would to access my RDP after manually configurating the settings	
I would like to access my RDP after setting it up with the command line.	
Doesn’t Matter	
Don’t Know	
How would you like your RDP interface to be?	
	Rating (1-4)

To have all of my applications pre-installed and guidelines about how to use them.	
To have guidelines about how to install my applications	
Remote computer access only, I can install applications myself	
Doesn’t Matter	
Don’t Know	
What information would you like to have about the server where your data is stored?	
	Rating (1-4)
Live updates on disk operations per second, bytes uploaded download per second, processing speed etc.	
Service Status only; Running well, slow, down etc	
Server Location only	
Doesn't Matter	
Don’t know.	
What do you think would be an appropriate server response time for your cloud services?	
	Rating (1-4)
1 to 3 seconds	
3 to 5 seconds	
5 to 10 seconds	
>10 seconds	
Don’t Know	
Doesn’t Matter	
What level of internet connectivity would you expect from your cloud provider?	
	Rating (1-4)
4 or 5 bars nearly all of the time	
3 or 4 bars nearly all of the time	
Over 3 bars nearly all of the time	
1 or 2 bars is enough	

Don't Know	
Doesn't Matter	
What scalability would you expect from your provider?	
	Rating (1-4)
I would like to be able to increase or decrease the size of my operations manifold (x2 – x10).	
I would like to be able to quadruple or reduce the size of my operations by four.	
I would like to be able to treble or reduce the size of the operations by three.	
I would like to be able to easily double or half the size of my operations.	
Doesn't Matter	
Don't Know	
What amount of time would you consider to be ideal for setting up a IaaS, SaaS or PaaS to the point where you can start working on it?	
	Rating (1-4)
Less than 5 minutes	
Between 5 and 10 minutes	
Between 10 minutes and 30 minutes	
Between 30 minutes and 1 hour	
>1 hour	
Doesn't Matter	
Don't Know	

Attribute Importance Rating

Compared with the other cloud characteristics how important would you rate cloud performance on a scale of 1 to 10?*										
* 1 being of the least important and 10 being of most important										
Rating	1	2	3	4	5	6	7	8	9	10
Answer										
On a scale of 1 to 10 how sure are you or your answer to the previous question?										

* 1 being completely uncertain 10 being completely certain										
Rating	1	2	3	4	5	6	7	8	9	10
Answer										
Do you have any additional comments regarding cloud performance?										
Comment:										

Section 8: Cloud Architecture

Cloud services can be constructed in different ways, which are useful for different scenarios. This section will assess what cloud architectures are ideal in your case.	
What type of client does your organisation typically work with?	
	Answer (%)
Public Sector Organisations	
Private Sector Organisations	
Individuals	
Other (please also include percentage)	
How sensitive is the geodata which is processed by your organisation?	
	Answer (%)
The data does not contain any personal information (e.g. personal address etc.)	
The data contains personal information (e.g. personal names or details)	
The data is owned by organisations or individuals	
The data is open public data	
The data is public data with copy or publishing restrictions.	
Other (please also include percentage)	
Please read the short descriptions of cloud architectures below and answer the questions thereafter	
Public cloud architectures give you access to generic cloud services built and maintained by cloud providers. Typically, public cloud architectures provide easy access to sophisticated data services at lowest possible price. Data within “public” cloud architectures can be protected by the security measures described above.	

However, within a public cloud architecture you do not have total control over your geodata or applications which may be stored in formats proprietary to the cloud provider.

Private cloud architectures are cloud services exclusively built for your needs. Private cloud services give you greater control over your data, allowing you to format and store the data as suits your organisation. Private cloud architectures are considerably more expensive to build and are unlikely to have the same user friendliness.

Hybrid cloud architectures combine elements of both public and private cloud architectures. This may be particularly useful if you have unique or valuable data process which you would like to keep total control over while also taking advantage of publicly available IaaS, SaaS or PaaS. Hybrid cloud architecture are more expensive than either employing either public or private architectures.

Community cloud architecture involve the collaborative building of cloud services by several organisations which have similar IT needs. The primary advantage of a community cloud is that that infrastructural, build and maintenance costs are distributed and the control is maintained over your data. However, a community cloud is not often feasible.

Having read the descriptions above how would you rate the cloud deployment model, as before?	
	Rating (1-4)
Public Cloud	
Private Cloud	
Hybrid Cloud	
Community Cloud	
Don’t Know	
Do you have any additional comments, with regards to cloud architecture?	

Attribute Importance Rating

Compared with the other cloud characteristics how important would you rate cloud performance on a scale of 1 to 10?*										
* 1 being of the least important and 10 being of most important										
Rating	1	2	3	4	5	6	7	8	9	10
Answer										
On a scale of 1 to 10 how sure are you or your answer to the previous question?										

* 1 being completely uncertain 10 being completely certain										
Rating	1	2	3	4	5	6	7	8	9	10
Answer										
Do you have any additional comments regarding cloud performance?										
Comment:										

Appendix C: Cloud Evaluation Matrix (GSD Example)

Cloud Vendor	Cost	Q1.1 What is your budget for cloud services?	Q1.2 How would you like to pay for cloud services?	Q1.3 Would you like there to be cost capping* on your cloud services?	Q1.4 How would you like your cloud provider to communicate with you about cloud costs?	Q1.5 Would you like your clients/collaborators to have to pay for software licencing (e.g. ArcGIS), while working in the cloud?	Q1.6 Would you like your cloud provider to send you alerts if you accidentally leave a virtual machine (VM)* running when not in use?
IaaS and PaaS							
1. AWS RDS and Lambda			PPU	Y	CB + Alerts	Y	N
2. Azure Db for Postgres + Web apps			PPU	N	CB	Y	N
3. Oracle Spatial + Oracle PaaS			PPU	N	CB	N	N
SaaS							
ArcGIS Online			FY	NA	NA	Y	N
GeoCloud			PPU	N	None	N	Y
GISCloud			FM	NA	NA	N	N
My GeoData Cloud			FM	NA	NA	N	N
OmniSci			FM	N	NA	N	N

Cloud Vendor	Cloud Accessibility	Q2.1 How many users (clients and/its and collaborators) would you like to have access to your cloud services?	Q2.2 Would you like a like multiple users to be able to login to your cloud services at the same time?	Q 2.3 How3 How many users would you like to be able to the simultaneous access to your cloud services?	
IaaS and PaaS					
1. AWS RDS and Lambda		>10	Y	>10	
2. Azure Db for Postgres + Web apps		>10	Y	>10	
3. Oracle Spatial + Oracle PaaS		>10	Y	>10	
SaaS					
ArcGIS Online		1.00	N	0.0	0.00
GeoCloud		>10	Y	>10	
GISCloud		1.00	N	0.0	0.00
My GeoData Cloud		1.00	N	0.0	0.00
OmniSci		<10	Y	10.0	10.00

Cloud Vendor	Q 2.4 How would you like users to be able to access your cloud services?	Q2.5 How would you like your cloud services to be shared with clients and collaborators?	Q2.6 Would you like to have the possibility of make your cloud services publicly available on the web?	Q2.7 Would you like to have access to software packages which will aid the migration of offlin…	Q2.8 How would you like your data in the cloud to be shared with clients and collab…	Q 2.9 How would you like your clients and collaborators to be able to …	Q2.10 Would you like to be able to give clients and colla…	Q2.11 Would you like to use the same cloud…	Q 2.12 Do your clients already u…	Legal
IaaS and PaaS										
1. AWS RDS and Lambda	PC + Mobile	IL	Y	Y	IL	UC +UDE	Y			
2. Azure Db for Postgres + Web apps	PC + Mobile	IL	Y	Y	IL	UC + UDE	Y			
3. Oracle Spatial + Oracle PaaS	PC + Mobile	IL	Y	N	IL	UC + UDE	Y			
SaaS										
ArcGIS Online	PC + Mobile	GL	Y	N	URL	U+D	N			
GeoCloud	PC	GL	N	N	None	U+D	N			
GISCloud	PC + Mobile	GL	Y	N	URL	U+D	N			
My GeoData Cloud	PC + Mobile	GL	N	N	IL	U+D	N			
OmniSci	PC + Mobile	API	s	N	IL	U+ D	N			

Key

IL=Invite Link
GL=Generic Link

**Is Case Specific

Access with APIs

UC = Unique Considerations
U/D/E = Upload/Download/Edit

... data/services to the cloud?
...orators?
...eract with versions of your data/services?
...orators access to information backed up by your cloud provider?
...platform as is already in use by some of your clients (e.g. Azure)?**
...e some of these cloud platforms?**
...:
...condary cloud users?
...quirements for collaborators and clients?
...monitor the activities of secondary users within your cloud?

Framework Q3.1 Would you like your cloud provider to provide you with information regarding SLAs* and the legalities of their cloud services?**	Q3.2 What uptime* SLA would you consider to be favourable?	Q3.3 Where would you like your data centre to be based?	Q3.4 What legal contractual arrangement would you like to have with your cloud provider?	Q3.5 How would you like the legal agreement between your organisation and the cloud provider to be pre	Q3.6 Who you like to take legal responsibility for "disaster scenarios" such as data breach o	Q3.7 If you choose to terminate your contract with your cloud provider, what ap	Q3.8 How would you like to be notified of any changes to your	Q3.9 Would you like to be able manage the area	Cloud Securi ce	Q. 4.1 Do	Q5.2 What customer support hours would be ideal for you?	Q5.3 Would you like to have a designated support person assigned to you?	Q5.4 Would you consider paying extra for basic technical support?	Q5.5 Where would you like your support team to be based?	Spatial Functionality	Q6.1 Geodata Types?	Q6.2 What spatial cloud functionalities are most important for your organisation?	IaaS	Q6.3 How would you like to be able to upload data to your cloud provider?	Q6.4 In which file formats would you like to be able to upload data to your cloud provider for IaaS and SaaS services?	Q6.5 Ideally how would you like to be able to upload spatial	Q6.6 Ideally how would you like your spatial	Q6.7 How would you like to be	Q6.8 If the cap	
Y	9990.00%	Global	Vend, Re	On Webs	Full Res	30 Days	On Webs	Y		Y	24\7 *	N	Y	Global					UF	SHP+ R + DB + PY+ SQL+ XML *	FULL	Same	Same	SP EXT	F
Y	99.99%	Global	Client Re	On Webs	Shared R	30 Days	On Webs	N		Y	BH	Y	Y	Global					UF	SQL+ XML + JSON + GeoSONd *	FULL	Altered	Altered	SP EXT	F
Y	99.9	Global	Client Re	On Webs	Low Res	30 days	On Webs	N		YL	24\7	Y	Y	Global					CL	SHP+R+G	FULL	Same	Same	SP EXT	F
N	99.99%	NA	NA	On Webs	NA	30 Days	On Webs	N		TP	BH	N	N	Global					UF	SHP	FULL	Same	Same	FILTER	N
N	NA	NA	NA	On Webs	NA	0-10 Days	On Webs	N		N	BH	N	N	Israel					UF	SHP+R +DB + PY+XML *	FULL	Same	Same	NA	N
N	NA	NA	NA	On Webs	NA	0 Days	On Webs	N		TP	BH	N	N	Croatia					UF	SHP	FULL	Altered	Altered	FILTER	N
N	NA	Oregon	NA	On Webs	NA	NA	On Webs	N		N	BH	N	N	Czech R					UF	SHP+RL	FULL	Same	Same + C	FILTER	N
N	'HA'	NA	Client Re	On Webs	Low Res	30 Days	On Webs	N		N	BH	N	N	USA					UF	SHP + SQL+ CSV *	FULL	Same	Same	SQL	A

* with enterprise or developmenet packages

*AWS S3/ Azure Cosmos DB/ Oracle Db

*for previous formats

Low/ Shared/ High Responsibility

TP = Uti

YL = Ye

Live Chat/ Email/Phone

UF/CL = User Friendly/ Command Line

Quoted as ' High Availability'

BH = Business Hours

SHP = shaple

R = image file formats

RL = image storage only

GDB = geodatabase

G= Graph

…for your organisation? …uld you like to be able to upload data to your cloud provider? Q6.4 In which file formats would you like to be able to upload data to your cloud provider for IaaS and SaaS services?	Q6.5 Ideally how would you like to be able to upload spatial data to the cloud?	Q6.6 Ideally how would you like your spatial data to be stored from the cloud?	Q6.7 How would you like to be able to retrieve your spatial data from the cloud?	Q6.8 If the capacity to query a database is important to you what query capacities would you like to have?	Q6.9 What type of additional data storage features would you like from your cloud provider?	Q6.10 How would you like your spatial data to be backed up?	Q6.11 Would you like to have free access to other spatial data from your cloud provider?		SaaS	Q6.12 What type of data would you like to be able to visualise on a cloud platform?	Q6.13 What additional features would you like to have in when visualising spatial data	Q6.14 Would you like to be able to work with ArcGIS and in your cloud platform?	Q6.15 Would you like to be able to host projects created in ArcGIS in your cloud platform?	Q6.16 Would you like to have access to SaaS which enables the development of Virtual Reality or Augmented Reality Applications?	Q6.17 Would you like to have access to an SaaS which automates to analysis of static and video imagery?	Q6.18 Would you like to have access to SaaS which facilitates the Internet of Things (IoT)
SHP+ R + DB + PY+ SQL+ XML *	FULL	Same	Same	SP EXT	FULL	AUTO or CUS	Y			SHP + R	BASIC	Y	Y	Y	Y	Y
SQL+ XML + JSON + GeoSONd *	FULL	Altered	Altered	SP EXT	FULL	AUTO or CUS	N			DB/JSON	BASIC	Y	Y	N	N	N
SHP+R+G	FULL	Same	Same	SP EXT	FULL	AUTO or CUS	N			SHP + R +	EXCELLEN	N	N	N	N	N
SHP	FULL	Same	Same	FILTER	Metrics	MANUAL	N			SHP	GOOD	Y	Y	N	N	N
SHP+R +DB + PY+XML *	FULL	Same	Same	NA	NA	None	N			NA	NA	N	N	N	N	N
SHP	FULL	Altered	Altered	FILTER	Metrics + APIs	AUTO	N			SHP	GOOD	Y	N	N	N	Y
SHP+RL	FULL	Same	Same + Co	FILTER	NA	None	Y			SHP	BASIC	N	N	N	N	N
SHP + SQL+ CSV *	FULL	Same	Same	SQL	APIs	None	Y			SHP	V GOOD	N	N	N	N	N
*AWS S3/ Azure Cosmos DB/ Oracle Db	*for previous formats															
er Friendly/ Command Line																
SHP = shaple						Auto = Automatic					BASIC = Zoom/ Pan					
R = image file formats						CUS = customisable					Good = Zoom/ Pan FILTER and analyse					
RL = image storage only											V Good = zoom pan filter analyse and query					
GDB = geodatabase											Excellent = zoom, pan, filter query analyse and visualise query					
G= Graph																

	PaaS	Q6.19 What programming language would be optimal for your purposes?	Q6.20 What integrated development environments (IDEs) would you like your cloud PaaS to be compatible with	Q6.21 How would you be your PaaS to be set up?	Q6.22 How would you like your collaborators/clients to have access to your scripts/application…	Q6.23 How would you like your cloud provider to assist you in developing appl…	Q6.24 How would you like to source the compute power f…	Q6.25 How would you like to be able to cu…	Q6.26 How would you like t…	Q6.27 If you…
		Python, P	Cloud9	FULL	Console o	Templates	Internal	EXCELLEN	Cred	Y
		Java, Ruby	PyCharm	FULL	Console o	Library	Internal	GOOD	Cred	Y
		Java, Nod	Netbean	FULL	Console o	Libray	Internal	GOOD	Cred	N
		NA	NA	NA	NA	NA	NA	NA	NA	N
		NA	NA	NA	NA	NA	NA	NA	NA	N
		HTML	NA	PARTIAL	Gen L	POOR	NA	POOR	Cred	N
		NA	NA	NA	NA	NA	NA	NA	NA	N
		NA	NA	NA	NA	NA	NA	NA	NA	N
		AWS CodeStar, Azure App Service,								
								EXCELLENT = collaboration + rol		
		Cloud 9 with Python, PHP and Javascript						GOOD= collaboration only		
								Poor = FAQs only		
					Gen L = Generic Login					

…d with PaaS?

…your cloud provider to automatically update any version already deployed?

…you expect from your cloud provider?

…your PaaS environment to be monitored?

Cloud Performance *	Q7.1Cloud vendors utilize remote desktop protocols (RDP) to provide online services. How would you like your RDP interface to…	Q7.2 What information would you like to have about the server where your data is stored?	Q7.5 What scalability would you expect from your provider?		Cloud Architecture	Q8.11 Having read the descriptions above how would…
	UF	FULL	*20 SC*			PUBLIC
	UF	FULL	*64SC *256SP			PUBLIC
	UF	FULL	*10 S *5 SP			PUBLIC
	UF	POOR	NA			PUBLIC
	UF	POOR	x400 SC			PUBLIC
	UF	POOR	NA			PUBLIC
	UF	POOR	x50 SC			PUBLIC
	UF	POOR	x12 dV			PUBLC
			*AWS scales in packages			

Appendix D: Run Environments

Main Computer for Cloud Testing (RE1)
Description: Was used for all testing, apart from the multiple client tests.
Device Type: Laptop Manufacturer: Toshiba Processor: Intel(r) Core (tm) i5 5200 CPU @ 2.20 GHz Installed RAM: 8 GB Operating System: Windows 10 Operating Type x64 but
Internet Connectivity: Type: Wireless Broadband Download Speed: 7 Mbps Upload Speed: 0.5 Mbps Db Engines: PostgreSQL 11.1 (AWS and Azure) Oracle 12.2.01c (Oracle) Query Environment QGIS Desktop 3.4.4 (Madeira) Map Builder 12.2.1 (Oracle Spatial Raster) SQL from Developers (Oracle Spatial Vector)

Secondary Computer for Cloud Testing (RE 2)
Description: Was used together with primary computer for multiple client testing
Device Type: Laptop Manufacturer: Toshiba Processor: Intel(r) Core (tm) i3 5200 CPU @ 2.20 GHz Installed RAM: 4 GB Operating System: Windows 10 Operating Type x32 bit
Internet Connectivity: Type: Wireless Broadband Download Speed: 7Mbps Upload Speed: 0.5 Mbps Db Engines: PostgreSQL 11.1 (AWS and Azure) Oracle 12.2.01c (Oracle) Query Environments: QGIS Desktop 3.4.4 (Madeira) Map Builder 12.2.1 (Oracle Spatial Raster) SQL for Developers (Oracle Spatial Vector)

Appendix E: Import and Oracle Query Syntaxes

GSD: Ancient Woodland Inventory

Import Syntax: import: Ancient_Woodland_Inventory>shp2pgsql -s27700 ancient_woodland_inventory.shp | psql - d AncientWoodlanddb -U User -h Endpoint -p 5432

Query 1

SELECT objectid, SDO_GEOM.VALIDATE_GEOMETRY (geometry) FROM ancient_woodland_inventory

Query 2

Select objectid, SDO_GEOM.SDO_AREA (geometry, 0.005)

from ancient_woodland_inventory

WHERE cat_name = 'Restored Ancient Woodland Site'

Query 3

SELECT sdo_touch(ancient_woodland_inventory.geometry, biggestwood.geometry)

FROM ancient_woodland_inventory INNER JOIN biggestwood ON ancient_woodland_inventory.objectid = biggestwood.objectid

Query 4

SELECT sdo_geom.sdo_buffer(geometry, 70)

FROM biggestwood
WHERE objectid = 1

Query 5

NA

GSD Raster Data

Sn6080 DTM

Import Syntax: for "%%f in (*.jpg) do raster2pgsql -t 250x250 -I -C -M -s 0 %%f %%~nf > %%~nf.sql"

for %%f in (*.sql) do psql -d AWdb -h Endpoint -f %%**f**

Query 1

SELECT sdo_geor.validateBlockMBR(georaster) FROM georaster_table

Query 2

```
SELECT georid,
      sdo_geor.getCellValue(georaster,0,1,1,0) bnd1,
      sdo_geor.getCellValue(georaster,0,1,2,0) bnd2,
      sdo_geor.getCellValue(georaster,0,1,3,0) bnd3
  FROM georaster_table WHERE georid=1;
```

Query 3

```
SELECT georid,
      sdo_geor.getCellValue(georaster,0,1,1,0) bnd1,
      sdo_geor.getCellValue(georaster,0,1,2,0) bnd2,
      sdo_geor.getCellValue(georaster,0,1,3,0) bnd3
  FROM georaster_table WHERE georid = 1
  ORDER BY bnd1, bnd2, bnd3 DESC
```

Query 4

```
SELECT georid, sdo_geor.getHistogram(georaster, 0) as pxlcount
FROM georaster_table
```

Query 5

```
Create table rangetest as (SELECT sdo_geor.getHistogram(georaster, 1) as pxlcount
 FROM georaster_table)

ALTER TABLE rangetest MODIFY pxlcount (int)
SELECT pxlcount FROM rangetest
WHERE pxlcount between 0 and 50
```

Vicrea: Assen Shapefiles

Import Syntax: Syntax for PostGIS import; %%f in (*.shp) do shp2pgsql - I -s 28992 > %%~nf.sql for %%f in (*.sql) do psql -d AWdb -h Endpoint -f %%f

Query 1

SELECT status_id, SDO_GEOM.VALIDATE_GEOMETRY (geom) FROM assenpoly where bouwjaar < 1700

Query 2
Select status_id, SDO_GEOM.SDO_AREA (geom) from assenpoly

where bouwjaar < 1700

Query 3
SELECT sdo_geom.sdo_buffer(geom,80)
FROM assenpoly

WHERE bouwjaar < 1500

Query 4

NA

Query 5

SELECT assenpoly.status_id,

.assenpoly.bouwjaar, basispoints. postcode, assenpoly.geom FROM assenpoly

INNER JOIN basispoints ON basispoints.id = assenpoly.status_id

WHERE bouwjaar < 1700

N&S: Bangladesh NDVI

Python Script for renaming files; import os

```
path = '/Users/Eoin/Desktop/TestC'

files = os.listdir(path)

i = 1

for file in files:

    os.rename(os.path.join(path, file), os.path.join(path, str(i)))

    i = i+1
```

Syntax for PostGIS import: raster2pgsql -I -s 4326 -C -M -F -t 50x50 * public.bndvi | psql -d Dbname -U -h Db endpoint - p

Oracle import was done with the Mapbuilder software.

Query 1

```
SELECT sdo_geor.validateBlockMBR(georaster) FROM bndvi_table
WHERE tmstp =1
```

Query 2

```
SELECT georaster FROM bndvi_table
WHERE tmstp =1
```

Query 3

```
SELECT  sdo_geor.getHistogram(georaster, 1) FROM georaster_table
WHERE georid between 1 and 5
```

Query 4

```
SELECT georid,
       sdo_geor.getCellValue(georaster,0,1,1,0) bnd1,
  FROM ndvi_table WHERE tmstp between 1 and 5;
  ORDER by bnd1 DESC
```

Query 5

```
Create table rangetest as (SELECT tmpstp, sdo_geor.getvaluecount(georaster, 1) as pxlcount
 FROM bndvi_table)
ALTER TABLE rangetest MODIFY pxlcount (int)
SELECT pxlcount FROM rangetest
WHERE pxlcount between 0 and 46
```

Appendix F: Apdex Calculations (GSD Example)

Adjusted Apdex Rating Values (e.g. Tolerable/2 etc)
0 rating = 0
1 rating = 0.5
2 rating = 0.75
4 rating = 1

IaaS and PaaS (Scenario)	**~ Monthly Cost (€)**	
S3 + RDS + Lambda	275.00	
Azure Blob + Az. PostgreSQL + Web Apps	322.00	
Oracle Spatial	870 - 900	* Within yearly contract

SaaS (Vendor)	**~ Monthly Cost (€)**	
OmniSci	329.00	* S1 package
GIS Cloud	83.35	* Portal package
My GeoData Cloud	34.00	* Premium
GeoCloud	500.00	* avg RDP cost
ArcGIS Online	43.00	* Creator Package

		IaaS/PaaS			**SaaS**					
Cloud Cost		AWS	Azure	Oracle Spatial and Graph	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci	
Q1,1 What is you monthly budget for cloud services?		1.00	1.00	0.00	1.00	0.50	1.00	1.00	1.00	
Q1.2 How would you like to pay for cloud services?		0.75	0.75	0.75	1.00	0.50	1.00	1.00	1.00	*Flat a Rates a ArcGIS GISClo MyGeo
Q 1.3 Would you like there to be cost capping* on your cloud services?		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Q1.4 How would you like your cloud provider to communicate with you about cloud costs?		1.00	0.75	0.75	1.00	0.00	1.00	1.00	1.00	

Q1.5 Would you like your clients/collaborators to have to pay for software licencing (e.g. ArcGIS), while working in the cloud?	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00
Q1.6 Would you like your cloud provider to send you alerts if you accidentally leave a virtual machine (VM)* running when not in use?	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00
Raw Apdex Score	0.94	0.93	0.18	0.95	0.55	1.00	1.00	1.00
Adjusted Attribute Importance Rating	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20
Total Attribute Rating	6.75	6.66	1.26	6.84	3.96	7.20	7.20	7.20
	IaaS/PaaS			**SaaS**				
	AWS	Azure	Oracle Spatial and Graph	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Cloud Accessibility								
Q2.1 How many users (clients and collaborators) would you like to have access to your cloud services?	1.00	1.00	1.00	0.00	1.00	0.00	1.00	1.00
Q2.2 Would you like multiple users to be able to login to your cloud services at the same time?	1.00	1.00	1.00	0.00	1.00	0.00	0.00	1.00
Q 2.3 How many users would you like to be able to the simultaneous access to your cloud services?	1.00	1.00	1.00	0.00	1.00	0.00	0.00	1.00
Q 2.4 How would you like users to be able to access your cloud services?	1.00	1.00	1.00	1.00	0.50	1.00	1.00	1.00
Q2.5 How would you like your cloud services to be shared with clients and collaborators?	1.00	1.00	1.00	0.50	0.50	0.50	0.50	1.00
Q2.6 Would you like to have the possibility of make your cloud services publicly available on the web?	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Q2.7 Would you like to have access to software packages which will aid the migration of offline data/services to the cloud?	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Q2.8 How would you like your data in the cloud to be shared with clients and collaborators?	1.00	1.00	1.00	0.50	0.00	0.50	1.00	1.00
Q 2.9 How would you like your clients and collaborators to be able to interact with versions of your data/services?	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Q2.10 Would you like to be able to give clients and collaborators access to information backed up by your cloud provider?	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Raw Apdex Score	1.00	1.00	1.00	0.50	0.70	0.50	0.65	0.90
Adjusted Attribute Importance Rating	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20
Total Attribute Rating	7.20	7.20	7.20	3.60	5.04	3.60	4.68	6.48
	IaaS/PaaS			**SaaS**				
	AWS	Azure	Oracle Spatial and Graph	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Legal Framework								
Q3.1 Would you like your cloud provider to provide you with information regarding SLAs* and	1.00	1.00	1.00	0.50	0.00	0.00	0.00	0.50

the legalities of their cloud services?									
Q3.2 What uptime* SLA would you consider to be favourable?		1.00	1.00	1.00	1.00	0.00	0.00	0.00	1.00
Q3.3 Where would you like your data centre to be based?		1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Q3.4 What legal contractual arrangement would you like to have with your cloud provider?		1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q3.5 How would you like the legal agreement between your organisation and the cloud provider to be presented to you?		0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Q3.6 Who you like to take legal responsibility for "disaster scenarios" such as data breach or the loss of data?		0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q3.7 If you choose to terminate your contract with your cloud provider, what agreement is acceptable?		0.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00
Q3.8 How would you like to be notified of any changes to your cloud providers SLAs?		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q3.9 Would you like to be able manage the area in which your cloud services are registered for tax purposes		1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Raw Apdex Score		0.69	0.39	0.39	0.22	0.17	0.17	0.17	0.22
Adjusted Attribute Importance Rating		6.30	6.30	6.30	6.30	6.30	6.30	6.30	6.30
Total Attribute Rating		4.38	2.45	2.45	1.40	1.05	1.05	1.05	1.40
Notes									
		IaaS/PaaS			**SaaS**				
		AWS	Azure	Oracle Spatial and Graph	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Cloud Security									
Q4.1 What type of security would be ideal for you, your clients and collaborators?		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Q4.2 How robust would you like your cloud service to be?		1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Q4.3 Would you like your cloud vendor to monitor your data/service for potential security issues?		1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Q4.4 How would you like your cloud provider to notify you regarding security issues?		1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Q 4.5 How would you like the security settings for your cloud service to be managed?		1.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00
Q 4.6 Would you like to be able to set a customized security policy for secondary cloud users?		1.00	1.00	0.75	0.00	0.00	0.00	0.00	0.00
Q 4.7 Would you like to be able to customize the password requirements for collaborators and clients?		1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Q 4.8 How would you like your cloud vendor to monitor the activities of secondary users within your cloud?		1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Raw Apdex Score		1.00	0.94	0.78	0.13	0.13	0.13	0.13	0.13
Adjusted Attribute Importance Rating		6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Total Attribute Rating		6.00	5.63	4.69	0.75	0.75	0.75	0.75	0.75
		IaaS/PaaS			**SaaS**				

		AWS	Oracle Spatial and Graph	Azure	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Customer Service									
Q5.1 What types of customer service/support would you like your cloud provider to provide?		1.00	0.75	1.00	0.75	1.00	1.00	0.75	1.00
Q5.2 What customer support hours would be ideal for you?		1.00	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Q5.3 Would you like to have a designated support person assigned to you?		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Q5.4 Would you consider paying extra for basic technical support?		1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Q5.5 Where would you like your support team to be based?		0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Q5.6 What do you think is an acceptable wait time for a response from a support representative from your cloud provider?		0.50	0.00	0.50	0.00	0.75	0.75	0.50	0.50
Raw Apdex Score		0.88	0.71	0.83	0.54	0.71	0.71	0.63	0.67
Adjusted Attribute Importance Rating		10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Total Attribute Rating		8.75	7.08	8.33	5.42	7.08	7.08	6.25	6.67
Notes									
Spatial Functionality		**IaaS/PaaS**			**SaaS**				
Q6.2 What spatial cloud functionalities are most important for your organisation?		Vendors were weighed relevant to functionalities offered. IaaS (10%), SaaS(45%), PaaS (45							
Iaas		AWS	Oracle Spatial and Graph	Azure	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Q6.3 How would you like to be able to upload data to your cloud provider?		1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00
Q6.4 In which file formats would you like to be able to upload data to your cloud provider for IaaS and SaaS services?		1.00	0.75	1.00	1.00	0.50	0.50	0.50	0.50
Q6.5 Ideally how would you like to be able to upload spatial data to the cloud?		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Q6.6 Ideally how would you like your spatial data to be stored from the cloud?		0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Q6.7 How would you like to be able to retrieve your spatial data from the cloud?		1.00	0.00	1.00	1.00	1.00	1.00	0.75	1.00
Q6.8 If the capacity to query a database is important to you what query capacities would you like to have?		1.00	1.00	1.00	0.50	0.00	0.50	0.00	0.75
Q6.9 What type of additional data storage features would you like from your cloud provider?		1.00	1.00	1.00	0.75	0.00	1.00	0.00	1.00
Q6.10 How would you like your spatial data to be backed up?		0.75	0.75	1.00	0.75	0.00	1.00	0.00	0.00
Q6.11 Would you like to have free access to other spatial data from your cloud provider?		1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Raw Apdex Score		0.86	0.61	0.67	0.67	0.39	0.67	0.58	0.58
Weighted Apdex Score		0.78	0.55	0.60	0.60	0.35	0.60	0.53	0.53

SaaS									
Q6.12 What type of data would you like to be able to visualise on a cloud platform?		1.00	1.00	1.00	0.00	1.00	0.00	0.00	0.00
Q6.13 What additional features would you like to have in when visualising spatial data		0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00
Q6.14 Would you like to be able to work with ArcGIS and in your cloud platform?		1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00
Q6.15Would you like to be able to host projects created in ArcGIS in your cloud platform?		1.00	1.00	1.00	0.50	0.00	0.00	0.00	0.00
Q6.16 Would you like to have access to SaaS which enables the development of Virtual Reality or Augmented Reality Applications?		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Q6.17 Would you like to have access to a SaaS which automates to analysis of statics and video imagery?		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Q6.18 Would you like to have access to SaaS which facilitates the Internet of Things (IoT)		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Score		0.86	0.86	0.86	0.79	0.71	0.57	0.57	0.57
Weighted Score		0.81	0.81	0.81	0.75	0.68	0.54	0.54	0.54
Paas									
Q6.19 What programming language would be optimal for your purposes?		1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Q6. 20 What integrated development environments (IDEs) would you like your cloud PaaS to be compatible with		0.00	1.00	0.50	0.00	0.00	0.00	0.00	0.00
Q6.21 How would you be your PaaS to be set up?		1.00	0.75	0.75	0.00	0.00	0.00	0.00	0.00
Q6.22 How would you like your collaborators/clients to have access to your scripts/applications?		1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
Q6.23 How would you like your cloud provider to assist you in developing applications?		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Q6.24 How would you like to source the compute power for your application or scripts?		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Q6.25 How would you like to be able to customise your PaaS environment?		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Q6.26 How would you like to be able to disseminate finished versions built with PaaS?		1.00	1.00	1.00	0.75	0.75	0.75	0.75	0.75
Q6.27 If you update scripts or applications, would you like your cloud provider to automatically update any version already deployed?		1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Q6.28 What type of PaaS monitoring would you expect from your cloud provider?		1.00	0.75	0.75	0.00	0.00	0.00	0.00	0.00
Q6.29 How would you like your PaaS environment to be monitored?		0.75	1.00	0.75	0.00	0.00	0.00	0.00	0.00
Apdex Score		0.89	0.95	0.89	0.43	0.43	0.34	0.43	0.43
Weighted Score		0.84	0.91	0.84	0.41	0.41	0.32	0.41	0.41
		IaaS/PaaS			**SaaS**				
		AWS	Azure	Azure	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Total Raw Apdex (IaaS, SaaS and PaaS)		0.81	0.76	0.75	0.59	0.48	0.49	0.49	0.49
Adjusted Attribute Importance Rating		5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40

Total Attribute Rating		4.38	4.09	4.06	3.16	2.59	2.64	2.66	2.66	
Notes										
		IaaS/PaaS			**SaaS**					
Cloud Performance		AWS	Azure	Oracle Spatial and Graph	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci	
Q7.1Cloud vendors utilize remote desktop protocols (RDP) to provide online services. How would you like your RDP interface to be set up?		1.00	1.00	0.75	1.00	1.00	1.00	1.00	1.00	
Q7.2 How would you like your RDP interface to be?		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Q7.3 What information would you like to have about the server where your data is stored?		1.00	1.00	1.00	0.00	0.00	0.50	0.50	0.50	
Q7.4 What do you think would be an appropriate server response time for your cloud services?		1.00	1.00	1.00	NA	NA	NA	NA	NA	
Q7.5 What level of internet connectivity would you expect from your cloud provider?		1.00	1.00	1.00	1.00	1.00	0.50	0.50	0.00	
Q7.6 What scalability would you expect from your provider?		1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	
Q7.7 What amount of time would you consider to be ideal for setting up an IaaS, SaaS or PaaS to the point where you can start working on it?		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Raw Apdex Score		1.00	1.00	0.96	0.71	0.71	0.71	0.71	0.50	
Ajusted Attribute Importance Rating		4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	
Total Attribute Rating		4.90	4.90	4.73	3.50	3.50	3.50	3.50	2.45	
		IaaS/PaaS			**SaaS**					
Cloud Architecture		AWS	Azure	Azure	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci	
Q8.1 Having read the descriptions above how would you rate the cloud deployment model, as before?		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	AWS, Azure and Oracle have public private capaci
Raw Apdex Score		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Attribute Importance Rating		4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	
Total Attribute Rating		4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	
Raw Apdex Scores										
	IaaS and Paas			**SaaS**						

	AWS	Azure	Oracle	ArcGis Online	GeoCloud	GISCloud	MyGeodata Cloud	OmniSci
Cost	0.94	0.93	0.18	0.95	0.55	1.00	1.00	1.00
Accessibility	1.00	1.00	1.00	0.50	0.70	0.50	0.65	0.90
Legal Framework	0.69	0.39	0.39	0.22	0.17	0.17	0.17	0.22
Security	1.00	0.94	0.78	0.13	0.13	0.13	0.13	0.13
Customer Service	0.88	0.71	0.83	0.54	0.71	0.71	0.63	0.67
Spatial Functionality	0.81	0.76	0.75	0.59	0.48	0.49	0.49	0.49
Cloud Perfomance	1.00	1.00	0.96	0.71	0.71	0.71	0.71	0.50
Cloud Architecture	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Cloud Ranking (Apdex x Importance Ratings)

	IaaS and PaaS			SaaS				
	AWS	**Azure**	**Oracle**	**ArcGis Online**	**GeoCloud**	**GISCloud**	**MyGeodata Cloud**	**OmniSci**
Cost	6.75	6.66	1.26	6.84	3.96	7.20	7.20	7.20
Accessibility	7.20	7.20	7.20	3.60	5.04	3.60	4.68	6.48
Legal Framework	4.38	2.45	2.45	1.40	1.05	1.05	1.05	1.40
Security	6.00	5.63	4.69	0.75	0.75	0.75	0.75	0.75
Customer Service	8.75	7.08	8.33	5.42	7.08	7.08	6.25	6.67
Spatial Functionality	4.38	4.09	4.06	3.16	2.59	2.64	2.66	2.66
Cloud Perfomance	4.90	4.90	4.73	3.50	3.50	3.50	3.50	2.45
Cloud Architecture	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
Sum	47.25	42.91	37.62	29.57	28.87	30.72	30.99	32.51

Final Rankings	
IaaS and PaaS	
1. AWS S3/RDS/Codestar	47.25
2. Azure PgSQL and WebApps	42.91
3. Oracle Spatial and Orcle PaaS	37.62
SaaS	
1. OmniSci	32.51
3. My geoData Cloud	30.99
3. GIS Cloud	30.72
4. ArcGIS	29.57
5. GeoCloud	28.87

0

Appendix G: Screenshots of Case Specific Performance Testing

In this appendix, screenshots of the case specific performance testing from across the three participating companies have been provided to help the reader follow the testing methodologies adopted in this research.

1. Platform Testing

Cloud Responsiveness

Platform Testing was done using google chrome's performance module which recorded the times taken for website pages to load, this was recorded on five common interfaces of each cloud vendor.

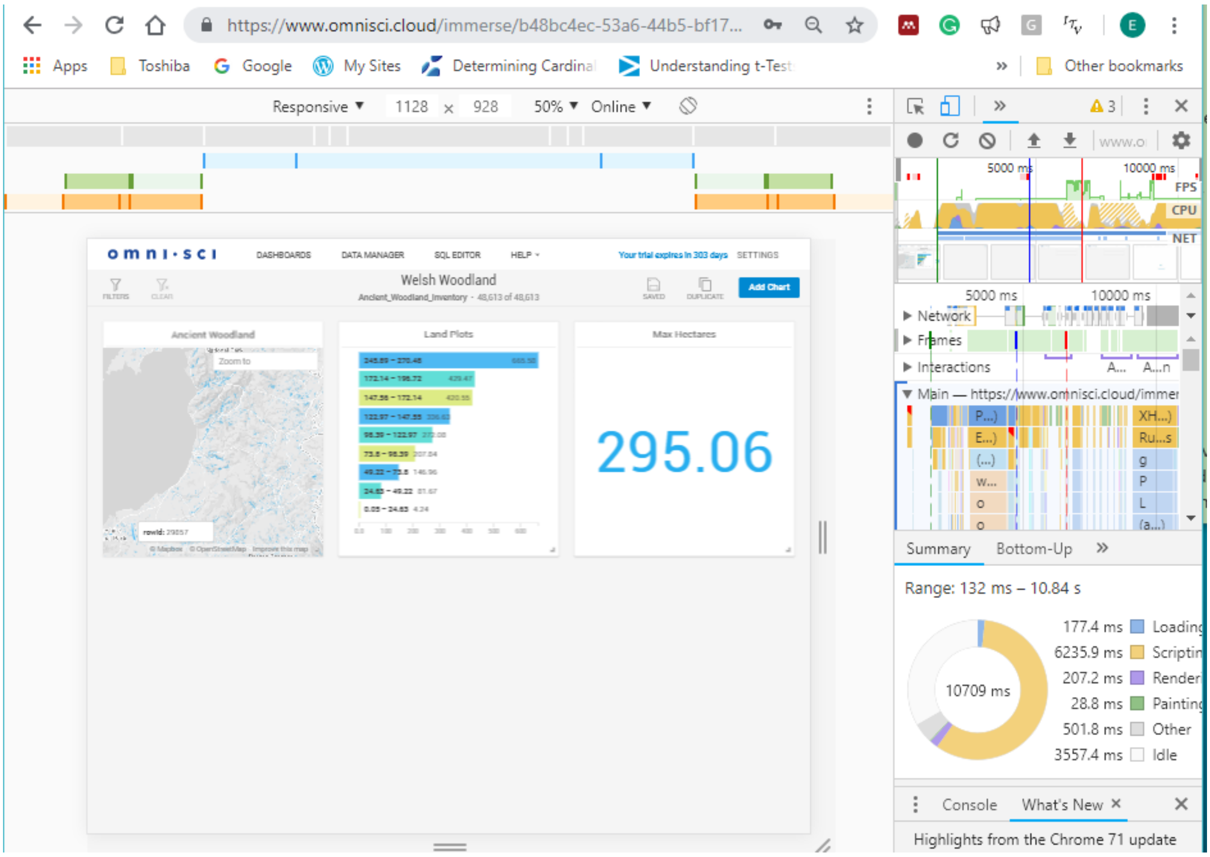


Figure 8.1. Testing the responsiveness of a dashboard created using OmniSci.

2. Functionality Testing

Native File format compatibility was tested by uploading data of the desired file format to different IaaS or SaaS. With SaaS this could be done with online import functions. With IaaS this was achieved with the 'GDAL Translate', 'Polygonize' or 'Ogr2Ogr functions'.

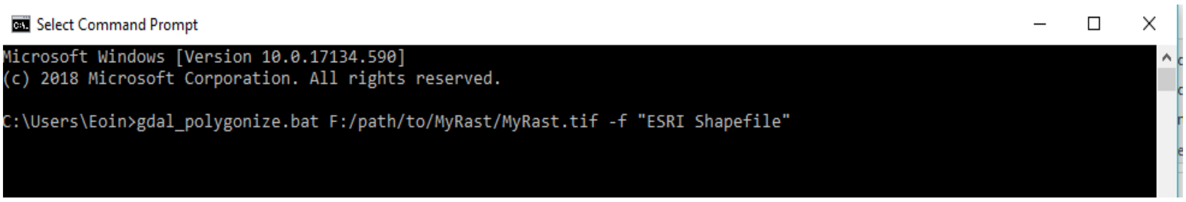


Figure 8.2 Example of a command to convert the raster Bangladesh NDVI to vector using GDAL

3.Load Testing

Import Testing

Import times were recorded for test datasets in IaaS and SaaS platforms. In IaaS platforms the data had to be manipulated using the Raster2pgsql or Shp2psql functions with PostGIS and the geometry or equivalent functions in Oracle. Appropriate data could then be piped into the database in the same command and the time recorded with the echo function.

Figure 8.3 Example of Windows command to import the Welsh composite DTM dataset.

Queries

Five queries which were thought to be representative of those which may be carried out in the front-end of an application such as Neuron Stroomlijn or Lizard were written and tested using either QGIS (PostGIS) or SQL Developer and Map Builder (Oracle). These softwares were used as proxies for the front-end of an application.

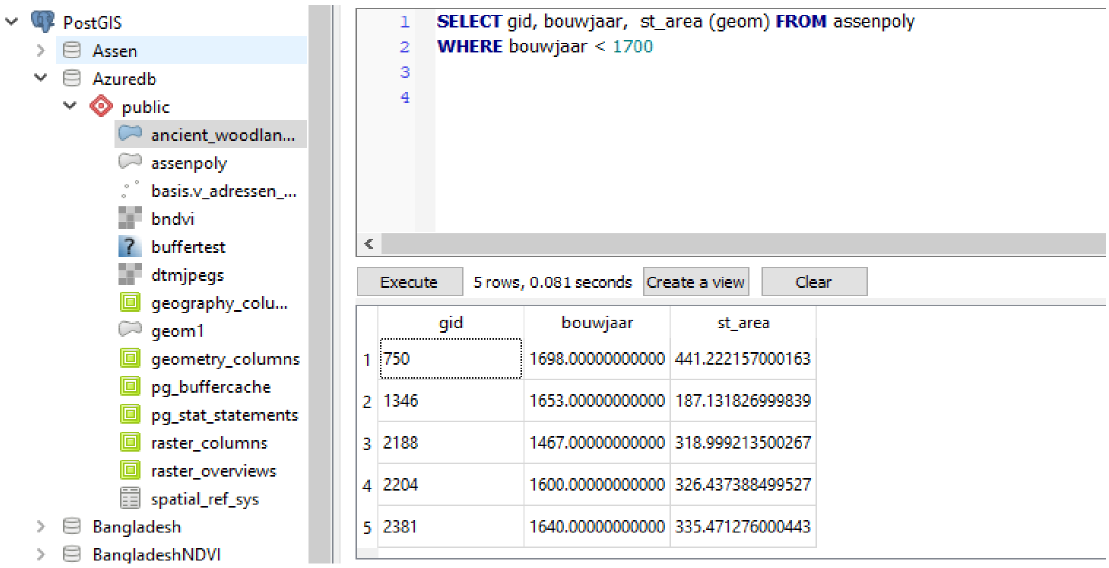


Figure 8.4 Example of query on the Assen Polygons carried out using QGIS

Visualising Queries

The rendering time was also noted on relevant (non-descriptive) queries this was tested using QGIS (PostGIS) and MapBuilder (Oracle).

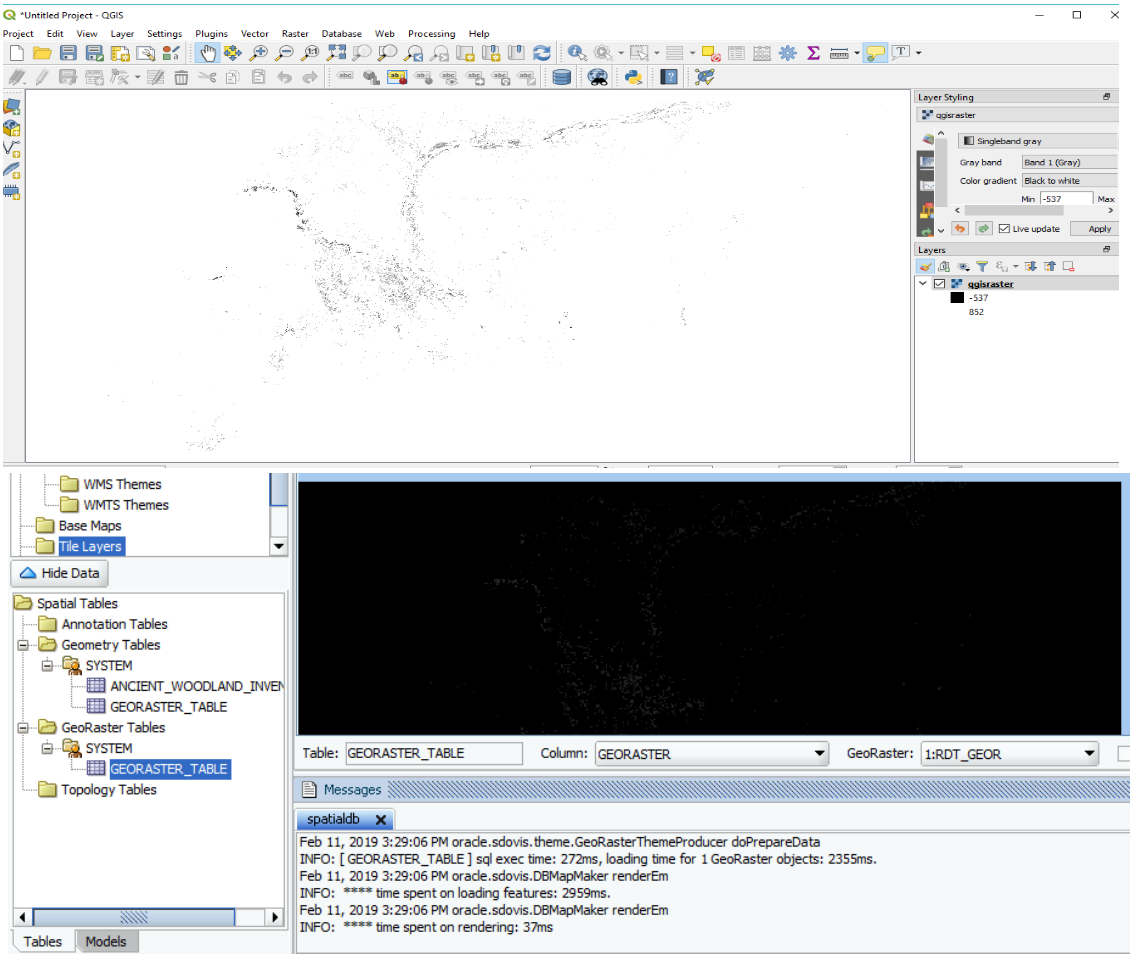


Figure 8.5 An individual timestamp query of the BangladeshNDVI visualised on QGIS above and Mapbuilder (below)

Multiple Queries

Queries 1 to 5 were run simultaneously on two clients and the response time was recorded and averaged. This was done to more accurately estimate IaaS performance.

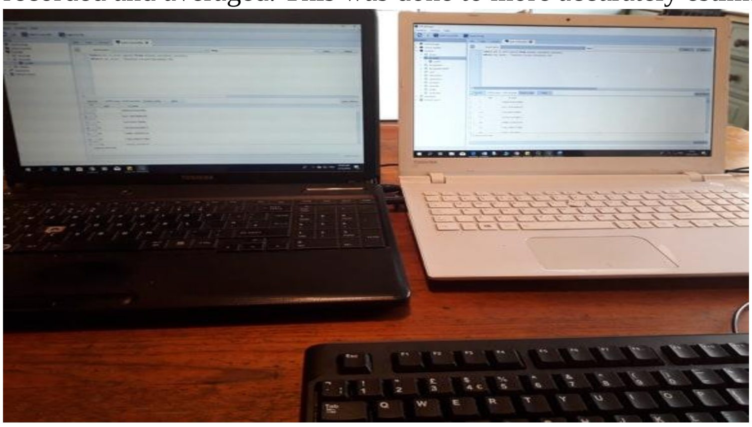


Figure 8.6 Running the queries simultaneously on two clients.

Appendix H: Feedback Form

1. **Apdex**

   This research used an Apdex method to rate cloud satisfaction between 0-1. How would you rate this element of the approach?

   1 2 3 4 5

Useless Very Useful

Further Comment:

2. **Attribute Importance Ratings**
   The cloud evaluation approach adopted by this research used attribute importance ratings to weigh the importance of different cloud attributes. How would you rate this element of the approach?

   1 2 3 4 5

Useless Very Useful

Would you have liked other attributes to have been considered in this model?

Further Comment:

3. **Report**
   A report was provided following the completion of this research. How useful was it to you?
   1 2 3 4 5

Useless Very Useful

Further Comment:

4. **Future Use**
   How likely are you to use the results of the research to guide future cloud projects?
   1 2 3 4 5

Unlikely Very Likely

Further Comment

5. **Future Use**
   How likely are you to use the results of the research to guide future cloud projects?

   1 2 3 4 5

6. Do you have any further comments in general about the cloud evaluation approach?

Appendix I: Cloud Briefing Document

INTRODUCTION TO CLOUD COMPUTING

Cloud Briefing Document for GI SMEs migrating the Cloud Services

Eoin Scollard

MSc Researcher in Geographical Information Management and Applications

Introduction

1.1 What is “the Cloud”?

In the past, digital content was confined to personal devices such as desktop computers, laptops and flash drives. However, in the mid-noughties, it became apparent that data processing and management could be done more efficiently, remotely, from large data farms. The outsourcing of data processing and management tasks became known as cloud computing.

Cloud computing was made possible by advances in internet connectivity as reliable, high bandwidth internet became widely available. The advantages of Cloud computing became apparent as users could have “on the fly” access to content, without having to locally maintain hardware or software. Data can also be processed in a more sophisticated and less labour-intensive manner, remotely.

The cloud is not only attractive to large enterprises but also to small to medium enterprises (SMEs) and to governmental and non-profit organisations. The cloud gives users an opportunity to essentially “rent” computing power, digital storage space and IT tools from a cloud provider, via an internet connection (Kumar & Mishra, 2012).

Sun Micro-Systems (2009) takes an inclusive view of the cloud, suggesting that the cloud broadly describes the many different ways in which data functionality can be provided over the internet. Cloud computing, in contrast, describes the process involved in establishing these cloud functionalities.

Today, major IT companies such as Google, Amazon (AWS), IBM, Microsoft (Azure) and Oracle have become cloud vendors and manage data remotely. However, little research has been carried out to systematically review the appropriateness of cloud migration for different organisations. Moreover, there is an absence of literature specifically focusing cloud platforms which predominately handle spatial data – or ‘geoclouds’.

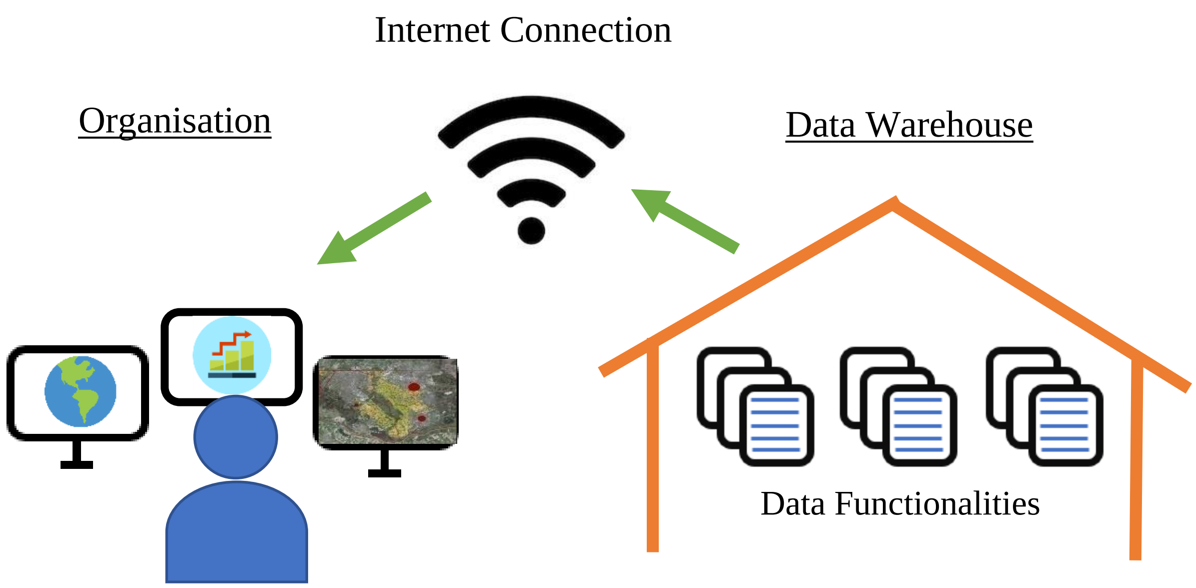


Figure 1.1 A conceptual model of the cloud.

1.3 Cloud Services

What does the cloud do? From an IT perspective, at present there are several prominent cloud delivery models including; Infrastructure-as-a-Service (IaaS), Software-as- a-Service (SaaS), Data-as-a-Service

(DaaS), Platform-as-a-Service (PaaS), Remote Desktop-as-a-Service (RDaaS) and Cloud-as-a-Service (CaaS) (see figure 1.2 for more details). IaaS, SaaS and PaaS (and their hybrids) are by far the most established cloud services and these three delivery models be considered in detail in this research.

Infrastructure-as-a-Service (IaaS): An IaaS system involves the virtual provision of computing power and/or memory by means of the (automated) management of hardware (servers) and software related to remote data storage, monitoring and retrieval (Mereno, 2013). Examples of IaaS include; Amazon Web Services (AWS) and Cisco.

Software-as-a-Service (Saas): Software as a Service is the provision of remote access to software as a web-based service. SaaS users gain online access to existing software applications, that can be used directly by a lay-person (Apostu et al., 2013). Examples of SaaS include online writing software like Google Docs and Grammarly, customer relations software like Bitrix24 and Asana and analytical software like Qualtrics.

Data-as-a-Service (DaaS): DaaS is the most recent member of the "as-a-service" family of cloud functionalities. DaaS is the provision of data and software related to data manipulation. DaaS has grown in popularity with increases in data harvesting and the development of technologies such as the "Internet of Things" (IoT), in recent years (Rayesh and Reddy, 2012).

Platform-as-a-Service (PaaS): Platform as a Service is the provision of an online environment for application development or content customisation. Several programming languages can be used including python, CSS, SQL and HTML (Devi and Janesen, 2012). The most prominent example of a PaaS is Google App Engine, however other PaaS systems exist such as Heroku, Amazon EC2 and Microsoft Azure.

Remote Desktop-as-a-Service (RDaaS): Remote Desktop as a Service is the provision of remote access to desktop interfaces from which greater computer capacities or software can be utilized RDaaS is utilised in particular by Microsoft Azure who have developed a 'Remote Desktop Protocol' (Azure, 2016).

Hybridised Cloud Functionalities; While IaaS, SaaS and PaaS are best described as separate entities from a theoretical perspective, hybridised versions of these services are often implemented in practice. Cloud providers such as AWS, Azure and Oracle offer integrated IaaS and SaaS services for example. A simple illustration of an integrated IaaS and SaaS is Google Drive, which stores data remotely but also provides an easy to use interface for data retrieval, formatting and sharing.

Cloud-as-a-Service (CaaS): Cloud-as-a-Service describes the collection of services (e.g. IaaS, SaaS, DaaS etc.), which can be offered by an individual cloud vendor. These services may be integrated or standalone services (Duan et al., 2016).

Figure 1.2 Prominent Cloud Service Models

1.3 Key Cloud Concepts and Terminologies

Cloud computing introduces new concepts and terminologies to the field of IT. Some of the most important concepts and terms have been described below in figure 1.3. These concepts have been grouped into five areas of interest: **1)** Cloud Management, **2)** Hardware Management, **3)** Cloud Configuration, **4)** Cloud Organisation, and **5)** Cloud Connectivity. All of the concepts listed below (figure 1.3) will apply to all larger cloud vendors (e.g. AWS, Azure and Oracle) and in various degrees to smaller cloud vendors (e.g. Geocloud, MyGeodata Cloud and OmniSci).

Cloud Management

Console or Portal: The cloud management interface which you will have for your cloud services (AWS, 2018; Azure, 2018; Oracle 2018).

Migration Hub: Software used by AWS, Azure and Oracle to help move offline 'legacy' data or applications to the cloud (AWS, 2018).

Command Shells: Command line management applications used for the completion of certain task by Amazon, Azure and Oracle Clouds (Azure, 2018).

Hardware Management

Data Regions: Data regions in cloud computing relates to the geographic location in which the data or services are *physically* located. Different cloud vendors will have different data regions (e.g. *Europe the Middle East and Africa (EMEA)*) (AWS, 2018b; Azure, 2018b; Oracle, 2018)

Data Zones: Data regions in larger cloud vendors will also be broken down into different zones (e.g. Central Europe, Eastern U.S.). Data regulation and tax are dependent on the legal jurisdiction where the data is located (AWS, 2018b)

In some case certain cloud services are only available in certain zones or data regions (Oracle, 2018). In other cases, the same services can be rolled out to multiple data regions to improve efficiency and different "read" and "write" functionalities can be assigned to different regions (Azure, 2018b).

Service Level Agreements (SLA) Legal agreement as to the quality, reliability of responsibilities of the cloud providers (AWS, 2018).

Cloud Configuration

Virtual Machine (VM) or Amazon Machine Image (AMI): A VM or AMI is a template for the configuration of instances on a virtual machine which defines the operating system, middleware and system settings (e.g. "Oracle Windows Datacentre 2016") (AWS, 2018c; Oracle, 2018).

Instances: Instances are virtual servers which are uniquely configured by the user in order to host data, applications or services and to allow other user to access and interact with the online product or application (Oracle, 2018).

Shape or Scalability or Capacity: Shape, Scalability or Size are terms used by could vendor to describe the user's ability to alter the capacity of their cloud services. These terms refer to the allotted Central Processing Units (CPUs) (Oracle, 2018; Azure; 2018b; AWS, 2018b).

Cloud Organisation

Volume: A fixed amount of storage in a given instance (Oracle, 2018; Azure; 2018; AWS, 2018).

Bucket: A container for the storing digital objects which be retrieved by authorized users via a public or private IP Address (AWS, 2018; Oracle, 2018).

Cluster or Resource Group: Terminology used by cloud vendors to describe the grouping of cloud services (AWS, 2018b; Azure, 2018).

Root: A root or root network describes the parent container in a cluster or resource group (Oracle, 2018; Azure, 2018)

Cloud Connectivity

IP Address: A numeric code (e.g. 54.4.5.1) which can be accessed by users on devices which are connected to the internet and have the appropriate credentials. IP addresses can be public or private (AWS, 2018; Azure; 2018; Oracle, 2018).

Domain Name: The user-friendly URL name which can be attached to an IP address (e.g. www.researchingcloud.aws.com) (AWS, 2018; Azure; 2018; Oracle, 2018).

SSH: Secure Shell Protocol (SHH) is an authentication method for access to an IP address over an unsecure internet connection.

Key Pairs: Two randomly generated public and private codes which are used to access an IP address with an SSH (AWS, 2018; Oracle, 2018).

Remote Desktop Protocol (RDP): An RDP is a cloud access method used by Microsoft Azure involving access to a VM with login credentials (Azure, 2018).

Figure 1.3 A list of key cloud concepts and terminologies.

The above list is by no means an exhaustive list of cloud terminologies. Please see the following pages for more comprehensive glossaries:

AWS click here

Azure click here

Oracle click here.

Figure 1.3.1 (next page) displays how key cloud concepts are typically utilized to establish a cloud service in large cloud vendors.

1.4 Who Uses the Cloud?

Cloud infrastructures are being made a reality in many industries today including; gaming, commerce, academia and retail. The cloud is experiencing exponential growth with some users interacting with the cloud explicitly, and more and more users are becoming implicit cloud users (Marinescu, 2012). Ried and Kisker (2012) estimated that the global cloud market will be worth $241 billion by 2020. Garrison et al. (2015) further estimate that data-using organisations will rely on cloud services for more than half of their IT operations by 2020.

1.3.1 Key Concepts: Building a Cloud Service

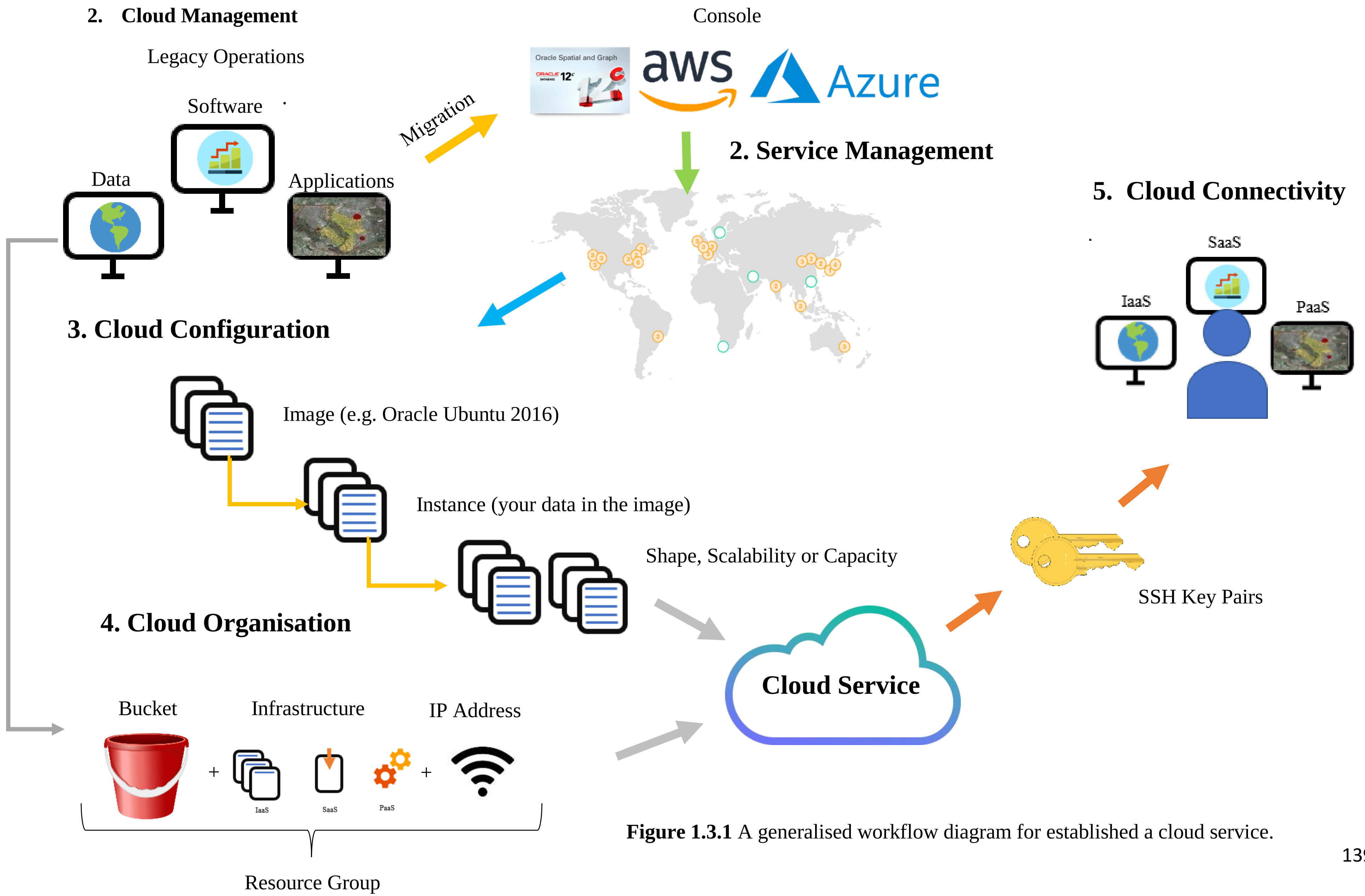


Figure 1.3.1 A generalised workflow diagram for established a cloud service.

Cloud Anatomy

This chapter discusses the physical infrastructures behind the provision of cloud services. This will involve outline traditional installation and 'client-server' processes by comparison to newer cloud infrastructures.

2.1Traditional Vs Cloud Architectures

2.1 Traditional Architectures

- **Local Installation**

In recent years there have been significant developments in high-performance personal computers and network connectivity. With the rise of local computational power, large mainframe computers are often now being downsized or replaced entirely by personal computers with, the same, or greater computational capacities (Chandra Yadav & Kumar Singh, 2009). The increased computational power of personal computers has allowed for sophisticated applications such as ESRI's ArcMap, to be installed and run on a local hard-drive. Local installation will provide offline access to an IT resource, on a hard-drive in a given location (see below).

s

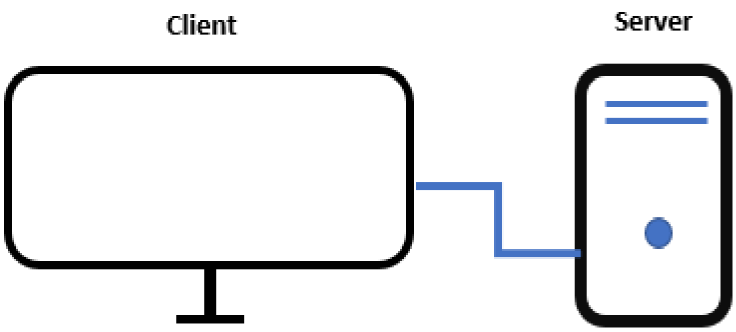


Figure 2.1.1: A model for local installation

- **The Client-Server Model**

Two core concepts within digital data management are clients and servers. Clients are requesters of information, for example web-browsers or offline applications such as ArcMap. Servers, on the other hand, are infrastructures which provide the relevant content such as local hard-drives or remote computers (Shakirat Oluwatosin, 2014). Typically, a client-server architecture is facilitated by the internet and/or physical access hardware and software or an in-house data centre. The client-server model has existed since the 1980s with the interaction of personal computers with networks. This model describes the retrieval of digital content from a centralised in-house network (Yadav and Kumar Singh, 2009).

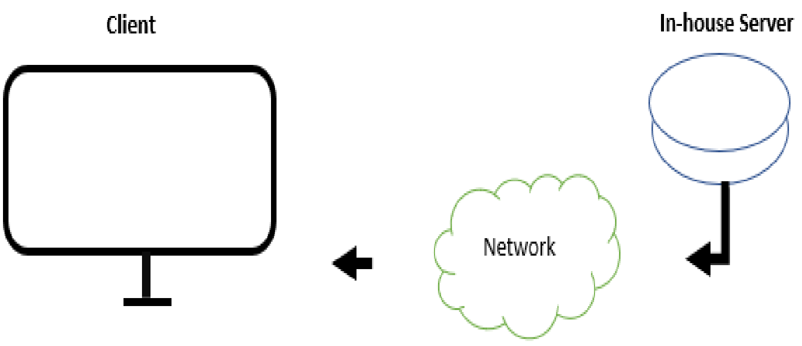


Figure 2.1.2: The 'client-server' model

➢ Peer-to-Peer (P2P) Model

Peer to Peer (P2P) is an alternative architecture for data management in which each relevant device, serves as a client with some level of server functionality. Each device ("or peer") acts as a client and server at the same time both initiating and responding to requests from other peers (see below). An example of a P2P architecture would be BitTorrent, where downloaded content on devices is also "seeded" or re-uploaded onto the server. In traditional client-server architectures, performance will typically deteriorate as the number of clients requesting services increases. In contrast, because server functionalities are decentralised in P2P architectures, performance will increase as the number of peers in the network increases. Additionally, P2P architecture is also advantageous because when one device is down, it can be compensated for by another peer, increasing the reliability of this architecture (Government of Hong Kong, 2008).

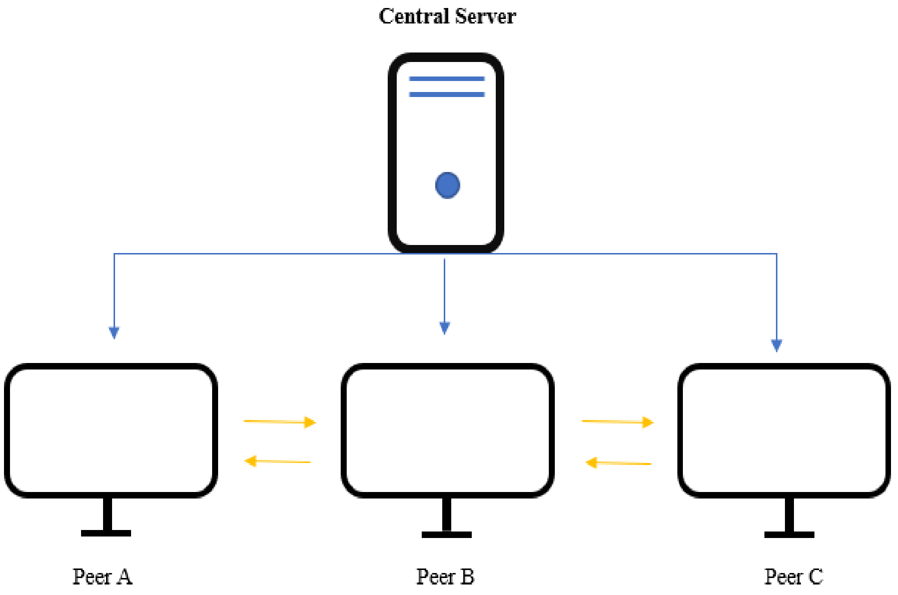


Figure 2.1.3 Peer-to-Peer Architecture

2.2 Cloud Architectures

➢ Cloud Architectural Models

Cloud services are often provided by means of elaborate client server architectures. However, in contrast to traditional client server models, cloud servers are located remotely and not locally. In the cloud content can be requested from the different data centres in which it is stored (see below). Different architectural features, however, may be involved in providing different cloud services. SaaS and IaaS involve remote access to software and storage space, whereas PaaS involves interaction between the cloud and user and, as a result, may have more complex architectures (Moreno et al., 2013).

- **Cloud Architectural Models**

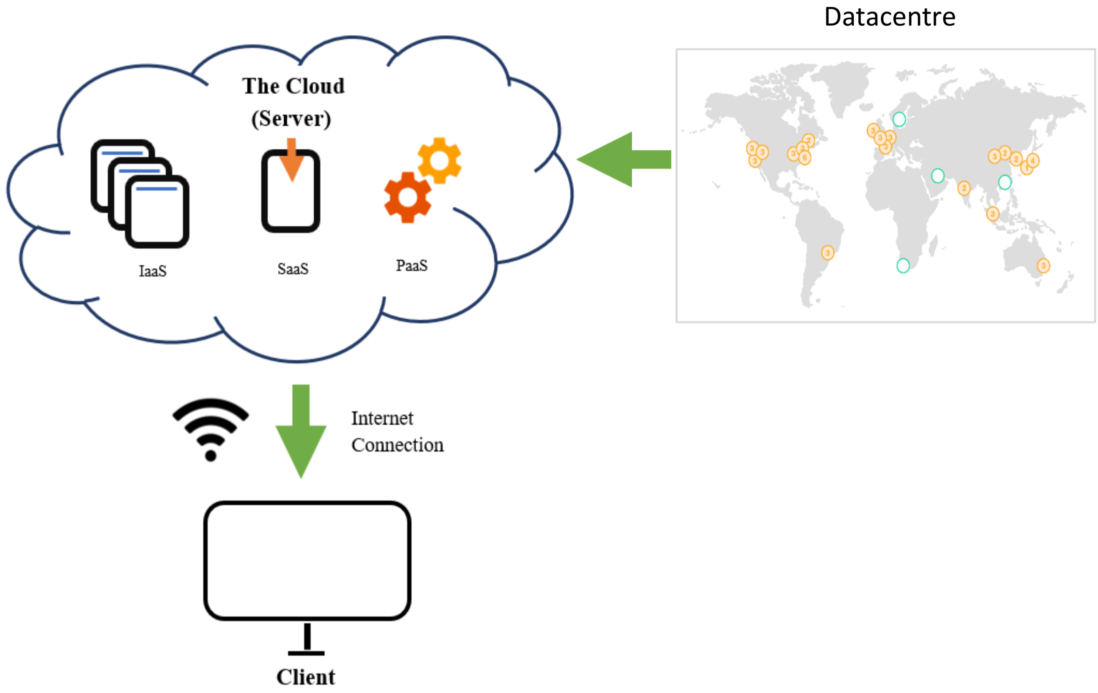


Figure 2.2.1 Generalized Cloud Architecture

2.3 Cloud Architectures

Traditional data flow architectures provide both advantages and disadvantages. It is evident that local installation, ensures greater security of data as it is geographically constrained to individual devices. In contrast and onsite client server architecture can provide access via a localised server to a group of people or a workplace adding to efficiency to increasing cost and security risk. Employing a P2P architecture, for data management, increases risk for content provision increases risk by also can greatly improve the reliability and speed of the data management flow.

In contrast to these architectures, a cloud data management architecture involved the subscription to a cloud provider and remote access to data services. Utilizing a cloud architecture has several advantages including a reduced cost and access to more sophisticated data management tools. However, the outsourcing of IT architectures can also be disadvantages due to “the loss of data control” and increased security risks.

Cloud Deployment Models

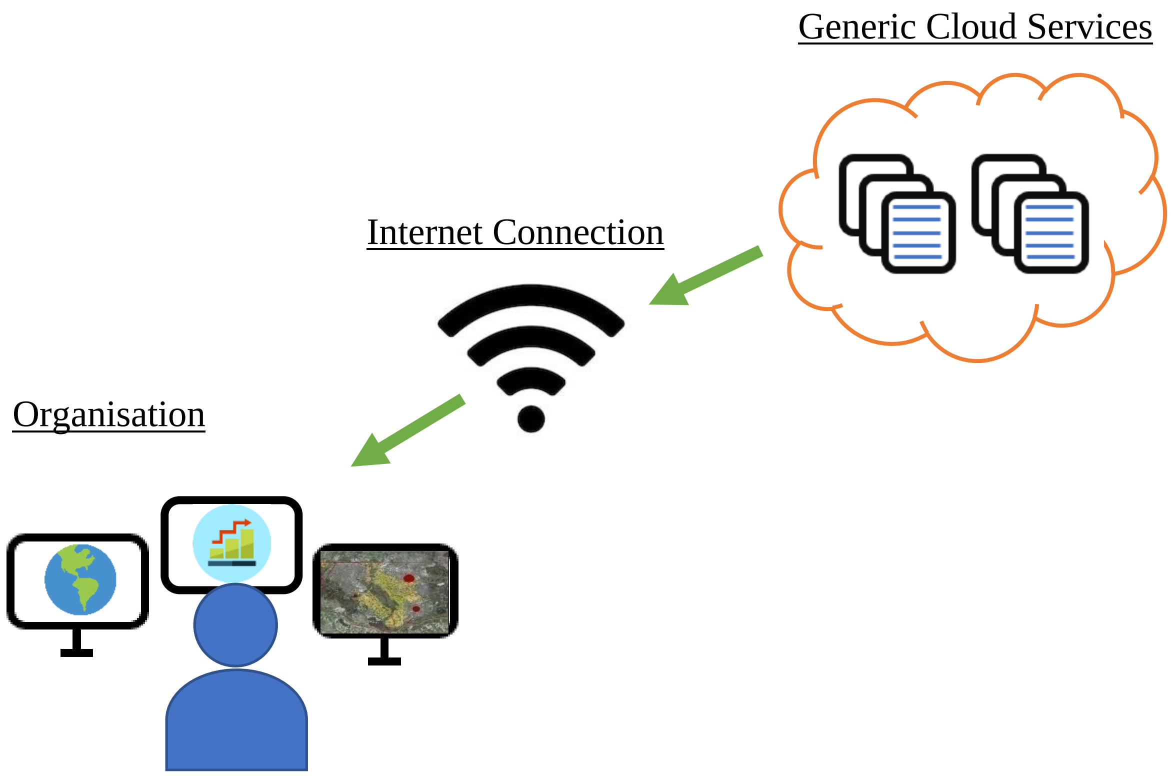
Cloud services can be employed with in different ways. Public, Private, Hybrid and Community model of cloud deployment are all being utilised in different circumstances by different organisation. Here, the different cloud deployment models will be described and discussed.

Public Cloud

A public cloud is the provision of content and data services over a non-specific (public) internet connection. Most cloud vendors provide services (IaaS, SaaS, PaaS) by means of a public cloud. Public cloud deployment model are most often utilised in cases of;

- Low data management budget
- Low security data
- Low data sensitive
- High-Level data process is need
- Limited on-site expertise/physical space

Utilizing this deployment model, the cloud provider will manage data hardware, security and back-up. This approach is more easily scaled than private cloud models, provides easy accessibility and likely enables access to more sophisticated data services. The disadvantages of deploying a public cloud include; the loss of data control particularly for sensitive or high value data operations, the risk of complications with the cloud vendor and the risk of vendor lock in. To minimise risk, public cloud services should be utilized when data value and sensitivity is low (DynaSis, 2018; Goyal 2014).



Private Cloud.

Private cloud are cloud infrastructures, which have been constructed exclusively for one organisation's data management. There are two types of private cloud;

1) **Internal Cloud**

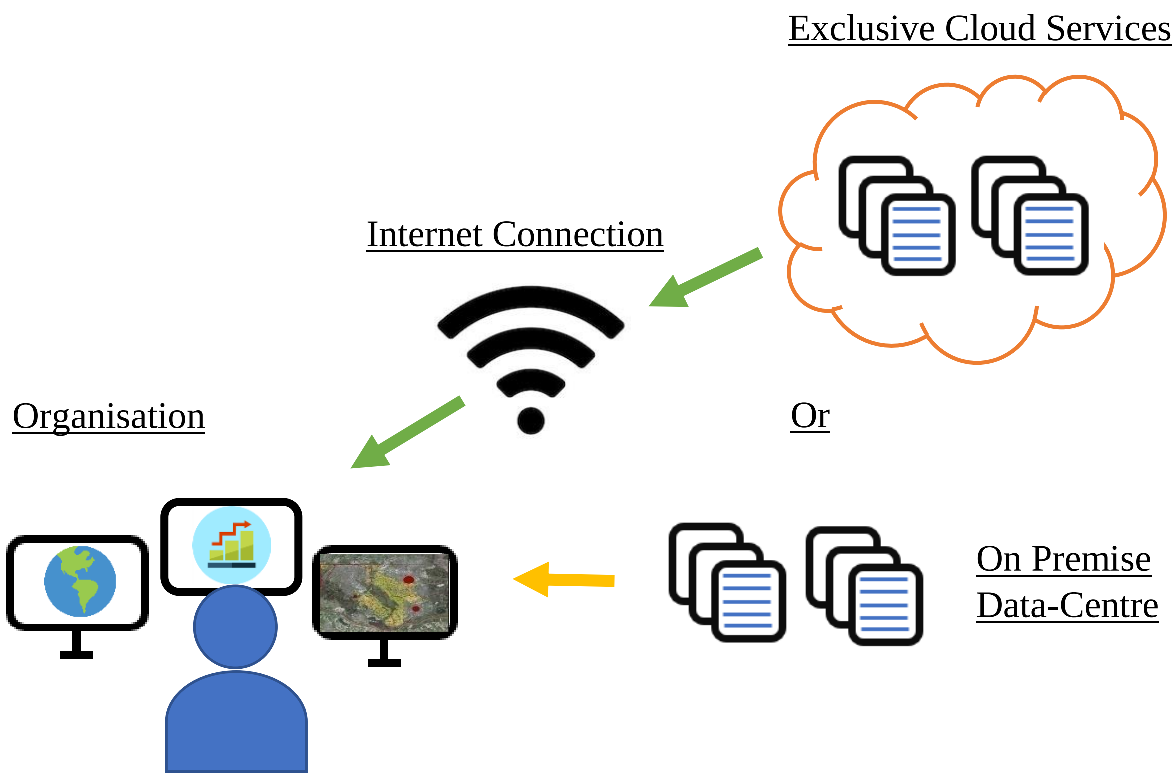
An internal or on-site cloud deployment model is one which is construction using a datacentre which is on the premises of the organisation. An internal cloud provides access to content or data services by means of a local network connect or intranet. The deployment model will be firewall protected. An internal cloud is particularly useful in the cases of:

- Internal Archives
- High Data Sensitivity
- High Value Data
- Storing Accounts

The benefits of deploying an internal private cloud include; increased security and control surrounding data management. The disadvantages of deploying this type of cloud is that it is likely to increase the cost of cloud provision and the responsibility of maintaining and updating the in house data centre, will fall on the organisation itself (DynaSiS, 2018)

2) **Off Premises Private Cloud**

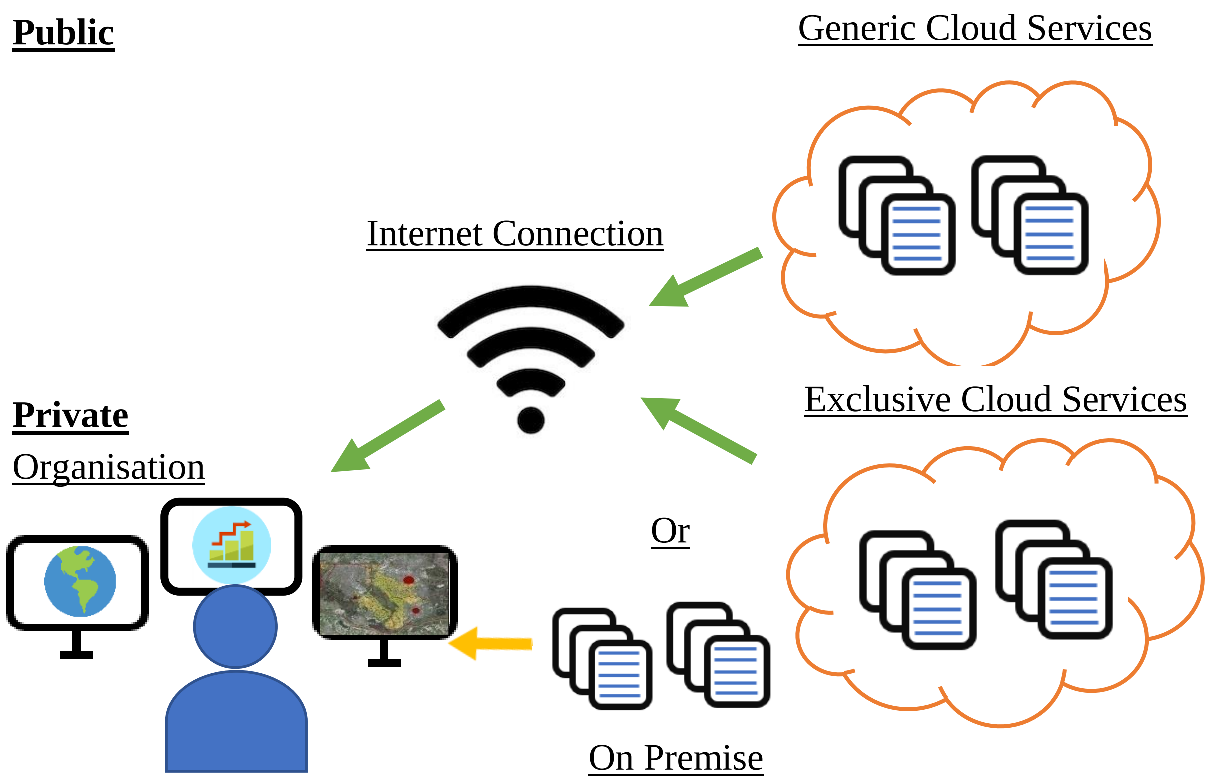
The second type of private cloud which can be employed by an organisation is an off-premises private cloud. An off-premises private cloud is utilized in instances similar to internal cloud models. Contrastingly, to an internal cloud, an off premises deployment model, outsources data management to a third-party cloud provider. Within such a model the organisation has exclusive rights to their IT services (hardware, IaaS, SaaS, PaaS), however these services are maintained by the cloud provider.



An off-premise model of cloud provision provides organisations with the advantage of outsourcing the construction and maintenance of a datacentre to a third-party service provider. The disadvantage of this deployment model is that it increases the cost of establishing a cloud (DynaSiS, 2018)

Hybrid Cloud Models

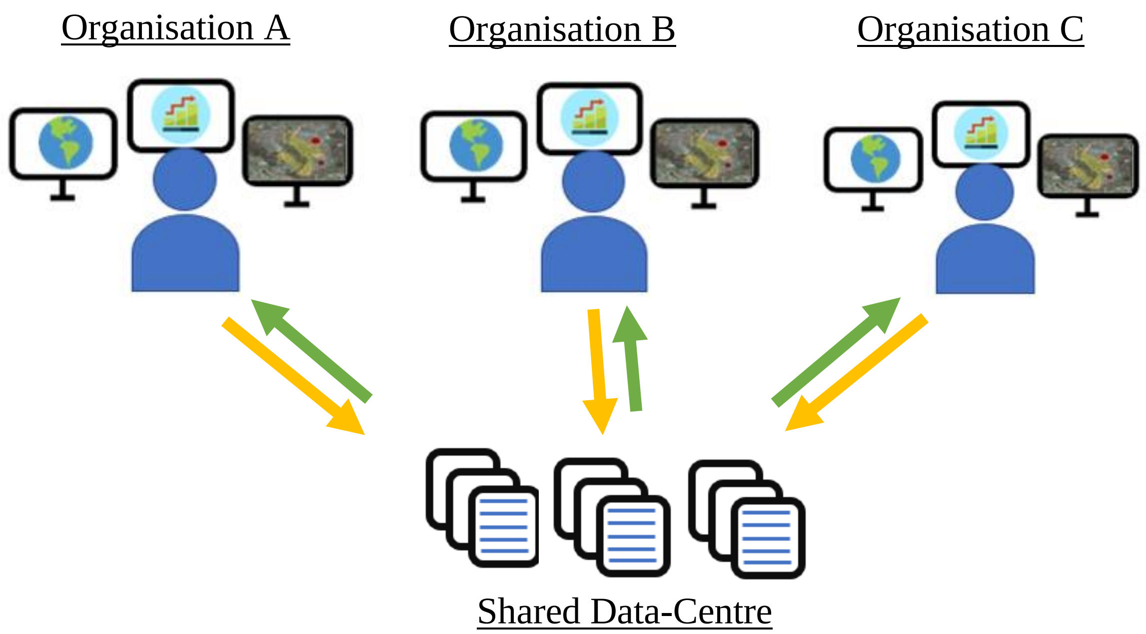
Hybrid cloud models combine elements of both private and public cloud deployment. Hybrid cloud are often used where high value or sensitive data and low value data is processed within the same organisation.



An example of a hybrid cloud would be if a retailer wanted to run data analytics on the amount of money spent in their stores (public cloud), whilst storing the identity of their customers in a private cloud. The disadvantages of hybrid models include; increased cost as internal or off premises model as well as public models must be established, and a higher level of technical expertise necessary to implement hybrid cloud types (Goyal 2014)

Community Cloud Models

Community cloud models describe a semi-private cloud deployment model whereby cloud services are shared among organisations with similar IT requirements. The cost of building an exclusive private cloud system, is as such, mitigated. The community cloud aspires to combine distributed resource provision from grid computing, distributed control from digital ecosystems and sustainability from green computing however, the community cloud is still in it’s infancy.



The advantages of a community cloud include; pool financial and personnel resources between organisations and reduced cloud cost. This model however, is more expensive than the public cloud and relies on the connectivity bandwidth of the participating organisations (Goyal, 2014).

<u>Public</u> - Access to generic cloud services from a vendor **Features** - Low Cost - Easy Accessibility - Sophisticated Services - Reduced Control/ Security	**<u>Private</u>** - Established exclusively (internally or off premise) for a single organisation. **Features** - Increased Security and Control - Increased Cost
<u>Hybrid</u> - Both Public and Private Cloud Models are utilized **Features** - Data is managed both publicly and privately increasing security where necessary while also utilizing powerful public cloud tools - Increased cost and expertise needed.	**<u>Community</u>** - A semi-private deployment model between a cohort of organisation with similar IT needs. **Features** - Reduced cost compared to private models and increased cost compared to public models - Relies on participant internet power for distributed resource provision.

Figure 3.1 A summary of cloud deployment models

What Deployment Model Should an Organisation Use?

It is clear from the current review that the appropriateness of a cloud deployment model is dependent on objectives, resources and risks attached to an organisation's data management. Public cloud models are attractive, in terms of providing easy, low cost access to powerful data services. However, public models may compromise both data security and data control. The public cloud, as such, is best utilised for software application and development (SaaS and PaaS).

Private clouds involve the exclusive establishment of services for an organisation by a cloud vendor or the construction of an in-house data centre, improves both data security and control. Private clouds however, come at a higher cost and have reduced scalability. The private cloud may be best utilized for data storage services or IaaS.

Hybrid clouds are combined cloud architectures which utilise both private and public deployment model depending on the organisation's needs. Public cloud can be used with low risk data in tandem with a private cloud for high-risk data. This hybrid approach gives organisation the comfort of higher security but also the computing power of the public cloud, where possible. Both SaaS and PaaS services (public cloud) and IaaS (private cloud), may be incorporated into a hybrid deployment model.

Community or co-operative clouds involved the establishment of a data-centre between two or more organisations, with similar IT needs. This provides the participating organisation with a semi-private architecture with less cost due to distributed resourcing. IaaS, SaaS and PaaS can all potentially be developed collaboratively in this environment, however the community cloud is more typically used for SaaS and PaaS purposes, due semi private nature of this deployment model.

Again, the optimum cloud deployment model will vary depending on the need of individual organisation. In this review it was seen that public cloud model are most appropriate for the provision of SaaS or PaaS and less suitability for IaaS. Security and control concerns regarding IaaS can be reduced by means of Private or Hybrid deployment models. Community models can also reduce cost and pool resources for the provision of semi-private IaaS, SaaS and PaaS services.

Migrating to the Cloud

The Advantages and Disadvantages of the Cloud

This section will answer the question "why are so many organisations migrating to the cloud?" and "what are the disadvantages of cloud services?". The advantages of the cloud can broadly be grouped into three categories 1) Increased Efficiency 2) Reduced Cost and 3) Improved Data Services. The most cited cloud benefits are described below (in green). Conversely, the risks and threats attached to each of these three cloud elements have also been outlined (in red).

The overall merit of the cloud adoption has been weighed up in section 4.

1. Increased Efficiency

Migration to the cloud gives organisations convenient access to their content or services via an internet connection. Furthermore, the cloud adaption can facilitate the fast deployment of SaaS or PaaS services which may be of importance in some contexts.

- **Ease of Access and Interaction**

One of the key advantages of managing data in a cloud environment is ease of access. Cloud vendors typically provide on-demand access to data services (SaaS, PaaS and IaaS), anywhere that there is an internet connection. The allows for the convenient retrieval and manipulation of data on multiple devices such as laptops, smartphones and tablets. This enables registered cloud users or clients to have on the fly access to their content and to be more effective with their time. Developed IaaS, SaaS and PaaS infrastructures also encourage the automatization of workflows which can reduce the manual labour necessary to process data (Marinescu, 2012; Obrutsky, 2016).

- **Fast Deployment**

In the cloud, the deployment of new content or applications happens almost instantly in the case of IaaS and SaaS services. For example, new sales figures can quickly be uploaded into, and saved, within a company's financial cloud system. Similarly, once purchased cloud software such as Britrix24 can be employed after a matter of minutes. PaaS need to be developed and as a result are slower to initiate. Nonetheless, applications built using a cloud PaaS, are usually quicker to deploy than those built offline (Apostu et al., 2013).

- **Simple Backup and Recovery**

Most cloud vendors have integrated back-up and recovery infrastructures into their services. Storing and retrieving content from a cloud, is generally, more reliable and simpler than doing so locally from a hard drive (Thomas, 2012). However, other research has also highlighted that higher storage needs and costs are also attached to cloud back-up and recovery features (Badhel and Chole, 2013).

Risks and Threats

- **Cloud Vulnerability**

The primary challenge posed to data management in the cloud is content security. Due to the ease of access to content over the internet, concerns have been raised due to data vulnerability. In a review of cloud security issues, funded by IBM, 382 organisations disclosed cloud security issues in 2016 across 16 different industries (Prasead Mozumber et al., 2017). The security issues faced by cloud environments include; the mis-use of cloud content, malicious hacking, failure of vendor security and shared technology vulnerabilities (Kuhmar and Mishra, 2012). While improve cloud security is an area currently undergoing considerable research (e.g. Bindra, 2012, Schwarzkopf, 2012), Subramanian and Jeyarai (2018) observe that the security of cloud content is vulnerable on several levels. On a "communications level" risk arises from the sharing of sensitive information (e.g. access passwords). On a "security level" the cloud is vulnerable to password cracking, cookie poisoning and CAPTCHA breaking among other threats. Moreover, cloud content is subject to Service Level Agreements (SLAs) such as legal or confidentiality requirements which may compromise data security. Due to the multi-tiered vulnerability of cloud architecture, current innovations aiming to improve cloud security are unlikely to remove all levels of threat.

➤ **Technical Issues**

Although CC offers improved efficiency by means of "on demand" content access, the cloud can also be prone to technical malfunctions such as outages. Even the most established cloud vendors do encounter unexpected technical problems despite generally having high standards of maintenance (Apostu et al. 2013). Aggregating statistics from press reports, Gagnaire et al. (2012) estimate that cloud services are unavailable for 7.5 hours per year (99.9% reliability). While, at a glance, this figure may seem impressive, it does not reach the expected reliability quotient of 99.999% for sensitive data management.

2. Reduced Cost

One of the key advantages of the cloud is it's potential to reduce data management cost for organisations. Adopting a cloud infrastructure can reduce investment costs, data costs and minimise the financial risks of new projects.

➤ **Reduced Investment Costs**

Cloud IaaS and PaaS systems can negate the need for an organisation to invest in, and maintain on-site servers. This may be particularly beneficial for smaller organisations with less capital to spend and limited office space (Marinescu, 2012).

➤ **Reduced Running Cost**

Adding up the licence fees of several users, traditional desktop software is generally more expensive than online access to a cloud SaaS. This is due to the economy of scale, as large cloud vendors can offer the same data service online cheaper than can be offered for physical access to the software. Many cloud providers also operate on a "pay as you go" basis in which organisations only pay in accordance with their service usage. This avoids overpaying for data services and generally reduces cost (Obrustsky 2016; AWS, 2018).

➤ **Elastic Scalability**

An additional advantage of outsourcing data management to the cloud, is that the scale of the necessary services (e.g. the number of servers) can be easily scaled up or down avoiding unnecessary cost. Successful projects can be easily scaled up in the cloud whereas underperforming projects can be easily downscaled. The flexibility of the scale of cloud information management is known as "elastic scalability". Elastic scalability can allow organisations to reduce and maximise profit (Al-Duraibi et al., 2018).

Risks and Threats

- **Cost Creep**

At first glance migrating to a "pay-as-you-go" pricing model as employed by many cloud providers may seem financially attractive. However, it has been well documented that organisations that migrate to a cloud environment are often charged with additional hidden usage charges. Additional usage charge can accumulate to be a deterrent to cloud adoption, particularly for smaller enterprises (Al-Duraibi, 2018; Apostu et al. 2013).

- **Financial Risk in Disaster Scenarios**

Cloud users can incur significant costs in cases of cloud outage, security breach or vendor lock-in (see below). According to the Penomen Institute, for example, in 2016, the average distributed cost incurred by a data centre outage was almost $750, 000 (Penomen, 2016). In the same year data breaches, depending on their nature, are estimated to have cost between around $130 and $170 to resolve per record (see Prasead Mozumber et al. 2017). The cost in these scenarios may fall on either the cloud utiliser or the cloud vendor, depending on the pre-defined contract between the two parties.

3. Improved Data Services

Cloud migration is not only attractive to organisations because of improved efficiency but also because the cloud provides access to the "latest and greatest" of data management services. Specialised and new IT services are typically offered by cloud providers, which are likely to be unrealistic to build for smaller organisations or enterprises. However, organisations can rent these tools within their cloud package. Together with practically "unlimited" storage, cloud environments give organisations with attractive opportunities to grow their operations.

- **Access to Specialised IT Services**

Using a cloud environment can provide benefits in terms of giving an organisation additional access to automated data processing or analytical tools (AWS, 2018). For example, Qualtrics provides power analytical tools to organisations at a fraction of the cost of building these tools from scratch.

- **Access to New IT Services**

Cloud users may also gain access to new and emerging technologies, provided by their cloud vendor, this can further help to give organisations "the edge" in terms of providing quality services for their clients (Apostu, 2013).

- **"Unlimited" Storage Potential**

Using a major cloud vendor gives most organisations a practically "unlimited" storage potential, help their operations to grow unhindered by the constraints of physical space requirements (Apostu, 2013).

Risks and Threats

- **Vendor Lock-In**

"Vendor Lock-In" describes a situation in which an organisation cannot easily transition their content or service offline or to another cloud provider after establishing them with one cloud vendor. Cloud providers design their services in a unique way (e.g. in particular data formats). This makes it difficult for cloud users to discontinue cloud use or transition to another cloud provider (Opara-Martins et al. 2014).

4. *The Cloud: State of Play*

The above synthesis provides organisations with an overview of the benefits and risks of using cloud environments for data management. The overall advantages, risks and threats of cloud migration is summarized in table 4.1.

The attractiveness of the cloud is evident from the current review. Cloud environments can improve workflow efficiency while reducing cost. Moreover, cloud vendors give smaller enterprises, in particular, the opportunity to “rent” powerful data tools, storage space and computing power via an internet connection. Given the clear advantages of the cloud adoption, it is unsurprising that many enterprises from large companies to start-up initiatives are migrating to the cloud.

However, negative complications are also attached to the cloud. The primary concern for high-value or sensitive data operations is cloud vulnerability. Subramanian and Jeyarai (2018) emphasise that there is a much higher risk of data breach or misuse in cloud environments. Moreover, cloud architectures still encounter technical issues such as outages and lags.

The pay-as-you-go payment structure and “elastic scalability” of many cloud packages also appeals to many organisations wishing to reduce cost and mitigate financial risk. However, cloud adopters may nonetheless be faced with cost creep and other hidden charges. Moreover, in the event of data breaches, cloud outages or vendor lock-in, data owners may be faced with larger financial losses.

Vendor Lock-In may deter organisations from migrating to the cloud as many vendors design their services to be as proprietary as possible (Opara Martins et al., 2014). Future decisions to pull data offline, or to another cloud provider, may be hindered by this cloud feature. Marinescu (2012) further posits that vendor lock-in and proprietary cloud computing environments are likely to have an increasingly negative impact on the field of CC in the future.

Apostu et al. (2013) further emphasise that cloud migration is likely to be beneficial to all organisations. However, the advantages and disadvantages of cloud migration need to be studied in detail, and cloud implementation needs to be adapted accordingly.

Moreover, CC is still a field is still in its infancy and in the absence of cloud standardisation and legislation, potential users need to be prudent when migrating to a cloud environment.

Increased Efficiency	**Cost[ł]**	**Improved Data Services***
	Advantages	
- Ease of Access and Interaction* - Fast Deployment - Simple Backup and Recovery	- Reduced Investment Cost - Reduced Running Cost - Elastic Scalability	- Access to specialised data services - Access to new services - Unlimited Data Storage
	Risks or Threats	
- Cloud Vulnerability[ł] - Technical Issues[ł]	- Cost Creep - Significant Financial Loss	- Vendor Lock-In[ł]

Table 4.1. A summary of cloud advantages, risks and threats.

[ł] ***Cloud features may also incur additional cost.***

**** Improved data services and ease of access and interaction may be one in the same.***

Choosing a Cloud Vendor

Many major IT companies, such as Google, Amazon, IBM, Apple, Microsoft and Oracle, now also provide cloud services. As data services are increasingly being outsourced to the cloud, choosing an appropriate cloud vendor is seen as crucial to data management success. However, different cloud vendors offer different services under different conditions and pricing, often making it difficult for potential cloud users to choose the most appropriate cloud services.

Very little scientific research has been carried out to comparatively assess the capabilities of the different cloud vendors. The Cloud Industry Forum (2018) describe eight considerations which ought to be taken into account by organisations before committing to a cloud vendor.

1) Certification and Standards
2) Technologies
3) Data Security, Governance and Policy
4) Service Dependencies and Partnerships
5) Contracts, Commercials and SLAs
6) Reliability and Performance
7) Migration Support and Exit Planning
8) Business health and Company profile

A number of methods have been developed for choosing an appropriate cloud provider. Most methods described thus far depend on the judgement of Decision Makers (DM) relative to cloud considerations such has been described above (e.g. Mishra et al. 2011, Teutenberg, 2012). An analytical hierarchy process (AHP), which weighs DM judgements is typically utilized. The AHP method helps to organise the merit of arguments in complex decision making by creating a weighted matrix. Due to the likely inconsistency and ambiguity in qualitative judgement. “fuzzy” considerations, such as statistical variance, are often also incorporated into decision making models for assessing cloud services (e.g. Kahraman 2015; Teutenberg, 2012).

The models discussed above, however, are best applied to quantifiable cloud features such as cost or security ratings. Liu et al. (2016) further emphasise the importance of subjective cloud considerations such as technology, organisation and environment. The authors propose a “Multi-Attribute Group Decision Making” (MAGDM) approach for choosing an appropriate cloud vendor. The MAGDM approach involves the weighting of grouped (objective and subjective) considerations and the ranking of the appropriateness of potential cloud vendors.

Recently, Abdel Basset et al. (2018) also presented a “ Neutrosophic Multi-Criteria Decision Analysis” (NMCDA) to help decision makers to choose a cloud provider. Neutrosophy involves comparing, two or more considerations together (e.g.” cloud security is better with vendor A than with vendor B, but worse than with vendor C”). This method allows for a more statistically robust measure of cloud performance.

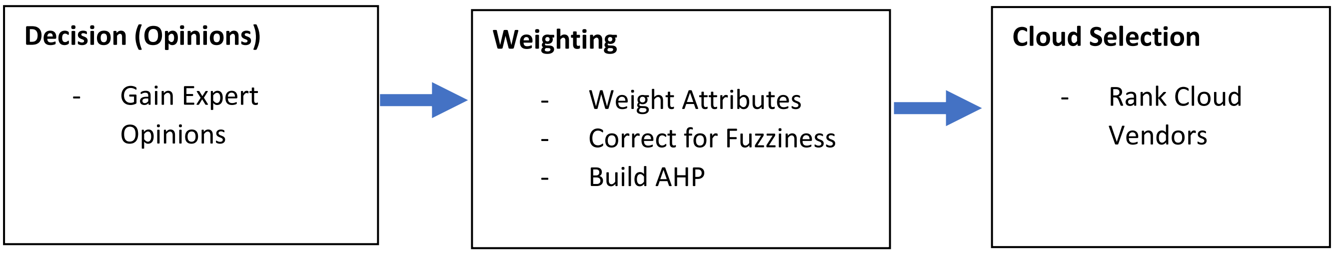


Figure 4.2 Generic Workflow of Cloud Services Decision Models

A major shortcoming of the approaches currently described in the literature is that they rely on decision makers already having extensive knowledge of cloud vendor performance. Multi-attribute decision analyses also depend on having a high-level statistical proficiency.

These limitations make the multi-attribute decision analyses for cloud vendors, unrealistic for many organisations, particularly SMEs.

This thesis will present a simplified multi-attribute decision analysis based both on the subjective cloud preferences of decision makers and on the objective testing of (geo) cloud vendor performance.

The Geo Cloud

Despite the recent growth of cloud technologies, very little academic research has investigated the role of spatial data in cloud technologies. While the cloud is likely to further empower the potency and dissemination of geodata, some issues, uniquely related to spatial data "in the cloud" have been identified. These issues are discussed below in relation to the three cloud delivery models.

IaaS: Issues of storing geodata in traditional databases will also be encountered in a cloud IaaS. Because x, y, z co-ordinates need to be taken into account with spatial data storage, cloud databases will often poorly equipped for this purpose.

SaaS: Unlike many forms of non-spatial data, spatial data needs to be visualised relative to a co-ordinate system in to be understood. Visualising spatial data (e.g. producing a map) is more challenging in an online environment, likely to be HTML.

PaaS: The "geo" aspect of spatial data presents a challenge to the process of developing spatial applications on the cloud. Geo cloud applications must take into account; spatial co-ordinates, projection methods and means of visualisation. This means that, customized, rather than generic programming methods will need to be employed.

Migrating to a Geo Cloud

Very little research has also been carried out focussing on migrating to a spatial data cloud. In 2013, the Indian Government did publish a "Roadmap" for the migration of their National spatial data to the cloud. This initiative was a self-built project, whereby a cloud infrastructure was put in place which gathered geodata from many public bodies (DEIT, 2013).

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