CCalc: Cloud Calculator for the Public Administration

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Abstract

As cloud adoption becomes increasingly popular as a way to host services and improve businesses, its adoption and migration still remain to be a clearly defined process. Specifically, when the adoption is to be made within the public administration, where additional constraints apply when compared to the private sector. Legislation needs to be created, standards need to be developed, and public organizations need to be in sync with their cloud goals and approaches. This work aims to create a simple to use tool that allows determining the viability of cloud migration or adoption of a system. To do this, a set of criteria based on a previously conducted literature review is created, aiming to represent the spectrum of technological aspects to take into consideration in a cloud feasibility analysis of a given system. From this set of criteria, a questionnaire is also created to ease the understanding of each criterion, to make the tool accessible to decision makers who do not possess an expert level of cloud-related knowledge. This work is then married with a multi-criteria decision-making algorithm to produce a recommendation score for the evaluated system, where this translates to if the system should or should not go to a cloud environment. The tool is then tested against a real-life scenario of cloud feasibility analysis to evaluate its usability and applicability.

Keywords: Cloud adoption, Migration tool, Feasibility assessment, Multi-criteria decision-making

1. Introduction

1.1. Motivation

Despite all the advances made in the latest years, cloud migration remains a process with many uncertainties, specifically when it comes to governmental organizations since these are often subject to additional constraints when tackling the adoption of cloud computing. This is mostly due to the lack of legislation and definition of standards on how to approach a sizable transformation as the adoption of cloud. Even when looking at the development of cloud frameworks, it can be observed that to this day there is not a unified approach to take when facing the possibility of cloud adoption [9, 21, 19, 7, 18].

In essence, there is a lack of tools and mechanisms that enable an efficient and yet simplified cloud feasibility analysis while trying to converge on a standardized approach. An approach that takes the full spectrum of technological aspects of the evaluated system into account and combines them with a decision-making support system, while simultaneously simplifying the process. This makes it easier to use for decision makers who do not possess as high level of knowledge about the cloud environment as an expert of the field. Convergence on a standardized approach would not only be beneficial for cloud adoption or migration in general, but it would have considerably more impact from a public administration point of view.

1.2. Context and Problem Overview

However, cloud adoption does not come without its challenges, one of the biggest being security since it brings new possible vulnerabilities and threats along with all of the benefits it brings [10]. Another challenge involves the architecture of the software product, where a loosely coupled architecture is required, which is something that generally does not exist in legacy applications, these being the subjects to cloud migration frequently [9].

Despite all the advances made in the latest years, cloud migration remains a process with many uncertainties, specifically when it comes to governmental organizations since these are often subject to additional constraints when tackling the adoption of cloud computing. This is mostly due to the lack of legislation and definition of standards on how to approach a sizable transformation as the adoption of cloud. Even when looking at the development of cloud frameworks, it can be observed that to this day there is not a unified approach to take when facing the possibility of cloud adoption [9, 21, 19, 7, 18].

There have been efforts to produce tools to aid in the process of decision making for cloud computing adoption, but usually, these are built with fixed criteria in mind and lack when it comes to customization [18, 11, 5, 20]. It is also worth mentioning that none of these tools allow for the measurement of cloud readiness of a given system, which is something that can be useful, particularly when the subject of evaluation is a legacy system where different aspects need to be assessed and evaluated to conclude if the required changes to adapt the system to the cloud environment are proven to be worth doing as to benefit from the best that the cloud has to offer.

In essence, there is a lack of tools and mechanisms that enable an efficient and yet simplified cloud feasibility analysis while trying to converge on a standardized approach. An approach that takes the full spectrum of technological aspects of the evaluated system into account and combines them with a decision-making support system, while simultaneously simplifying the process. This makes it easier to use for decision makers who do not possess as high level of knowledge about the cloud environment as an expert of the field. Convergence on a standardized approach would not only be beneficial for cloud adoption or migration in general, but it would have considerably more impact from a public administration point of view.

The importance of creating standards and procedures to follow across departments and institutions can be considered greater when comparing to the private sector, creating demand for tools and consolidation of knowledge to be used and standardized across all governmental entities and institutions that may require the adoption of cloud services. With this work we intend to develop a tool that addresses the issues stated and contributes to the overall process of cloud adoption within the public administration, by making it a usable yet effective instrument to aid in the decision-making process of cloud adoption and migration.

1.3. Objectives

The objective of this thesis consists in the development of a tool to aid the public administration institutions in the decision-making process of cloud adoption for a given system. By taking advantage of multi-criteria decision-making algorithms as well as a system that allows the simplification of score attribution, we intend to offer a simpler process to assess the cloud feasibility of a system for decision makers that do not possess an expert level of knowledge when it comes to cloud. Not only this, but the tool is also to be developed with flexibility and future changes in mind, allowing for customization for almost everything it contains.

By taking advantage of previously developed work, where we were able to gather enough information, we created a set of criteria to use for the general case of cloud migration. With this new information, we now use it as a basis for the development of the tool and expand upon it as to create a simpler process.

With this work we intend to bring the following contributions:

- Consolidation of knowledge and criteria required for the technological assessment of cloud feasibility analysis
- Study and application of multi-criteria decision-making algorithms that use the previously mentioned criteria set to produce a tool to aid decision-makers
- A tool built with simplification and ease of use in mind, making it accessible to decision-makers who do not possess an expert level of knowledge while still requiring some baseline knowledge about the cloud environment

2. Background

2.1. Cloud migration challenges

Despite all the benefits that come with migrating to the cloud, they can only be achieved if the applications that are migrated are designed and developed with the cloud mindset and architecture in consideration [14].

This makes cloud transitioning challenging for a lot of companies who have a lot of legacy applications that are based on different principles from the ones used in the cloud. To make legacy applications better candidates to move into the cloud, most of the times it requires a rebuild of the underlying structure of the applications [9]. Since cloud computing requires a loosely coupled architecture, it is ideal for stateless services and applications since they do not have infrastructure dependencies. Most of legacy applications rely on stateful services, and the cost of making a transition into stateless can make the transition to cloud unfeasible.

One of the major concerns and challenges presented by the cloud is security [10]. But this can be minimized and even prove to be a better security solution if the application is designed from the ground up with the cloud security architecture in mind.

Another challenge is the impact made in the organization when transitioning to cloud. Managing change and the people that work inside the company is difficult and poses as a risk, although this can be mitigated by starting with smaller and lower-risk initiatives as early candidates for cloud computing projects. This allows a paced adaptation process to the new business process, by giving time to new cloud specialized workers to teach and support the ones that are making the transition to the cloud model.

2.2. Current state of cloud in the Portuguese public administration

The purpose of cloud adoption in the Portuguese public administration is to improve the quality of public services provided while achieving reduced costs for both citizens and companies and reducing public expenditure, particularly in Information and Communication Technologies (ICT) [17].

The Portuguese government identified two strategic sectors that focus precisely on cost reductions and in the implementation of common IT solutions across the public administration. An initiative was launched to rationalize the already existing data centers with the intent to fulfill the following objectives:

- Increase the profitability of the investments made in public infrastructure and data centers, resorting to the private cloud whenever it proves to be a more competitive solution
- Unification of existing data centers
- Provide guidance to promote the adoption of cloud computing in the public administration
- Assure the adoption of more agile and transparent solutions, as well as its management, with improved security, lower costs, and efficient use of resources

The results of the initiative showed the fragmentation of acquisition and management of infrastructure, with a lot of redundant and replicated systems. It was also noted that the use of open-source software and norms was lacking, and cloud adoption benefits were identified.

2.3. Multi-criteria decision-making

Multi-criteria decision-making consists of finding the best solution from a pool of possible candidates according to selected criteria, by basing the decision on mathematical and programming tools [1]. The process of applying MCDM techniques is made of several phases such as establishing the criteria to use in the evaluation, the number of alternative solutions one wants to decide upon, applying weights to the previously defined criteria, and then apply the MCD method itself. This whole process is more comprehensible in figure 1 [4].

There are two types of MCDM approaches that can be used: there is Multi-Attribute Utility Theory (MAUT) and outranking approaches [1]. MAUT consists in obtaining a function that represents the utility of an alternative, where the alternative then attributes a marginal utility, with a number representing the preferability of the alternative. The total utility score results from the sum of all marginal utilities.

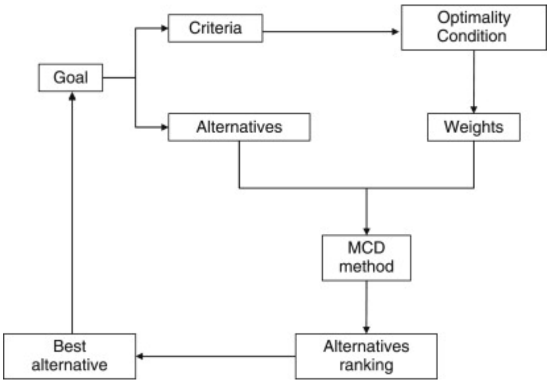


Figure 1: General structure of an MCDM process

On the other hand, outranking approaches are based on pairwise comparisons between the aspects of the considered solutions to establish which solution is better than the other.

Within these two approaches, there are commonly used techniques such as AHP, ELECTRE, PROMETHEE, TOPSIS, and VIKOR.

AHP is a technique that takes into account the mutual relationship between criteria, since it is not always possible to keep them all independent from each other in real-world problems [23]. It is based on pairwise comparisons of the criteria, where these are organized in a hierarchical relationship.

ELECTRE is a technique that falls in the class of outranking methods, which consists of performing pairwise comparisons between alternatives and creates an outranking relationship among them [23]. The created relationship is then used to identify and exclude the alternatives that are dominated by other alternatives, reducing the total number of possible alternatives.

PROMETHEE stands for preference ranking organization method of enrichment evaluation and is an outranking method just like ELECTRE, but unlike it, it stands as an improved technique over ELECTRE. The difference between the two lies in the pairwise comparison stage [23]. Instead of only verifying if an alternative is better than another, it also checks the degree to which an alternative is better or worse than the other.

TOPSIS tries to select an alternative with the following two conditions: it needs to be the closest to the ideal solution while simultaneously being the farthest from the anti-ideal solution [23].

VIKOR focuses on the ranking and selection from a set of alternatives in the existence of conflicting criteria [16]. It is similar to the TOPSIS method, the difference being that VIKOR looks to find the alternative that is closest to the ideal solution.

2.4. Criteria used in cloud adoption evaluation

To establish the criteria for assessing cloud adoption feasibility within public administration institutions, a systematic literature review of existing cloud migration frameworks and their respective utilized criteria was conducted to analyze what solutions and parameters are the most popular and comprehensive.

The articles used in the literature review are present in journals and conferences obtained using search engines of publishers such as Springer, IEEE, ResearchGate, and Elsevier. Others were obtained using the Google Scholar search engine. It is also worth noting that only articles published starting in the year 2015 were considered, to constrain the number of results further as well as having the most recent research material on cloud computing adoption. The keywords used to conduct the search for relevant articles were a mix of the following: Cloud, Adoption, Migration, Framework, Criteria, Assessment, Tool, Feasibility.

After collecting around 30 possibly relevant articles using the method described above, a manual review was conducted to filter them further. Importance was given to those who presented literature reviews about cloud adoption criteria and frameworks as well as those that propose their own frameworks and decision support tools to be used or that extend already existing tools and frameworks. This resulted in a total of 13 relevant articles to be studied.

The analysis of the 13 articles that either specifically mention criteria used in the phases of cloud feasibility analysis/assessment or mention cloud migration goals that can be translated into criteria, was followed by the consolidation of the criteria and respective definitions. This was achieved by merging similar characteristics with similar definitions present in several articles. Some less popular criteria were also included due to their considered relevance to the work to be developed.

The first iteration of knowledge consolidation related to the criteria resulted in the following criteria set and definitions:

The **complexity** of current systems was first derived from analyzing [21] (also appearing in [9, 18]), where this aspect allows to assess the degree of technical complexity of the current system (in the case of legacy migration) or of the new system that is to be implemented directly in the cloud. In the case of legacy migration, this can be related to the concept of interoperability present in [9, 7, 3, 22, 13] referring to the level of application integration across multiple platforms, contributing to the level of complexity present/required in the application.

Compatibility with current systems according to [21] is the level of modularity present in the current system and the ability to seamlessly interface with other applications that may not be in the cloud and that are already in use. This concept is also mentioned in [9, 3, 6, 12, 15, 22, 13] even though in most of them it is not as clearly defined.

Availability and accessibility as mentioned in [2, 3] refer to their respective levels of requirement by the system and the existence of redundancy measures within it, as well as the extent up to which the cloud providers can support these requirements. It also refers to the ease of access to the system from different devices [6]. These two aspects are sometimes combined and used as one [21, 7]. Both characteristics are related to what the cloud providers present as service level agreements (SLAs), since the requirements of availability of service and accessibility are some of the aspects covered in these agreements to give reassurance to cloud service providers' (CSP) clients while giving them a realistic view of what level of service quality to expect.

Security as defined in [21] represents the security measures that are necessary in the system: if they need to be location-based, if the cloud provider is able to replicate the same measures such as protecting organization data and maintaining the same level of privacy and confidentiality of the data [3, 15]. Not only this but it is also important to assess the existing level of expertise in dealing with security threats whether it is from the current IT staff or expertise given by the cloud provider. This represents the major risk in cloud adoption [13], having only two articles that do not mention it directly. The article [2] also underlines the importance of having control mechanisms able to respond to security threats and incidents, including the existence of security policies as well as compliance with rules and regulations. Although the latter mentioned are not directly part of the technology that is being considered for migration, they are fundamental aspects to consider before the appliance of a system migration.

Portability as mentioned in [7] refers to the disruption level that the system will suffer when migrated to cloud, or even between cloud providers. This criterion is related to the ease of decoupling the system from the underlying infrastructure of the cloud provider, therefore avoiding vendor lock-in.

Scalability as defined in [21] is the ability to keep up with an increasing workload by incrementally increasing a proportionate amount of computational resources [6].

Trialability can be portrayed as the adequacy and availability given by the cloud providers to try out their services before the actual use [3, 15].

Testability is relevant due to the advantageous merging between agile development and cloud computing. Therefore, the level of ease or improvement in deployment speed when testing and developing a system [7] before putting it fully operational in the cloud can be considered as important factor when weighing the decision of cloud adoption/migration. Although not specifically mentioned, it can be included in the agility category mentioned in [12].

Depending on the system and organization needs, **backup and recovery** are important factors when opting for cloud migration as seen in [6, 13].

Performance as described in [7], is the throughput speed and the existing computational power, where its assessment consists in the validation according to the system requirements.

Elasticity referenced in [6] is the ability to increase and decrease computational power in a simple and instantaneous manner according to the needs of the system.

Continuous monitoring in only defined in [9] as the level of service provided when it comes to the ability to monitor the system in the cloud and cloud resources to assure SLA compliance.

2.5. Decision-making approaches to cloud adoption

One of the already existing decision-making approaches to cloud adoption uses multi-layer cognitive maps, using the FCM (fuzzy c-means) technique which combines neural networks with fuzzy logic [6]. The article in question presents a complete and tested model, having been submitted to several synthetic and real-life case scenarios to evaluate the effectiveness and usability of the model.

Another approach relies on BOCR (benefit, opportunity, cost, risk) analysis as the criteria base for the application of the AHP (analytic hierarchy process) multi-criteria decision-making algorithm [12]. The use of BOCR allows the use of a criteria set that represents the general ecosystem affected by the decision of cloud adoption, while on the other hand, it does not provide a more granular representation of the technological aspects of the system being submitted to cloud adoption decision.

Both of the approaches mentioned above consist only in model form, not providing a simple and usable tool implementation of the models.

One approach that was implemented as a tool is TradeCIS, using a trade-off based decision system [8]. This decision system utilizes the TOPSIS algorithm from a technical perspective of decision-making, and the ANP algorithm (a generalization of the analytic hierarchy process algorithm) for the business, economical, and organizational perspectives. Although the article mentions a developed and tested prototype of the tool, it does not present a general set of criteria that can be used as a basis for the cloud adoption decision process.

3. Cloud assessment tool

3.1. Solution description

To fulfill the objectives shown in subsection 1.3 and tackle the problem that is the cloud feasibility assessment of a system in a public administration environment, this work suggests the creation of a tool that simplifies the process. In doing this, it also makes the process more accessible to decision-makers that do not possess an expert level of cloud knowledge, while still requiring some basic grasp of the cloud ecosystem. This tool is comprised of two parts: a questionnaire and the calculation of the final recommendation score by resorting to an MCDM approach. It is important to note that this tool is focused on the IaaS public cloud service model, compared to a private on-site hosting approach.

The questionnaire takes as basis a refined criteria set obtained in previously developed work. Not only this allows us to display the criteria in a simpler manner, but we are also able to derive guide questions from their respective definitions, which allows us to build the questionnaire. This questionnaire in conjunction with the definition of scales to be used in its answers described in subsection 3.4, allows us to build a scoring system that is then used to obtain the values for the comparison between alternatives (on-premises or cloud hosting) for each of the criteria. A visual example of the questionnaire (in this particular case for the Trialability criterion) can be observed in figure 2.

The second part of the tool involves the use of MCDM to calculate a recommendation score for each of the alternatives (on-premises or cloud hosting). The MCDM algorithm used in this case is TOPSIS, an algorithm that was explained in subsection 2.3. This algorithm was chosen due to the way it works, in trying to find the best alternative that is both the closest to the ideal solution and the farthest from the anti-ideal solution. Not only this but it is also a relatively easy algorithm to implement, which in this case proved to be a plus. By applying the obtained information in the questionnaire in conjunction with the criteria weights required to be input, the tool is then able to feed all of this data to the MCDM algorithm, retrieving then the recommendation score for each of the specified alternatives.

The questionnaire can be submitted empty in the case of the user possessing a more detailed level of the system and the cloud environment as to feel confident enough to attribute the scores of each criterion for each of the alternatives manually. Whether the questionnaire was submitted empty or not, the user is then redirected to the calculation page. Here the interface shows the table already pre-filled (in the case of answering the questionnaire), where in the next step the user is asked to determine the importance of each criteria comparing them between one another. To aid in this weighting process, the criteria definitions are also provided to inform the user as much as possible as to obtain the most exact and valuable data possible. After the previous steps are complete, the user then submits all of the data and the tool then calculates and shows the recommendation scores for each of the alternatives.

3.2. Use cases

With this tool, we not only intend to provide a simpler process to evaluate the cloud feasibility of a system but also allow it to be customizable to the problem that the user might be trying to solve. This can be done whether by adding/deleting or editing the currently present criteria set and respective definitions, or by adding new possibly more complete or relevant questions for a criterion, or even edit the current ones or deleting ones that may not be relevant. With this level of customization, we allow the user to shape the tool around the problem to better evaluate the system at hand so that the results may be the most accurate and create the most value.

The user can also generate the numerical scores for each pair of alternatives and criteria by answering a questionnaire. This is made to facilitate the quantitative measurement of each criterion for the alternatives at hand through a qualitative process. In doing so we provide additional context and description to each criterion through questions, allowing for a clearer understanding of each criterion and what particular aspects of the system are being evaluated.

If the tool is being used by someone more knowledgeable about the cloud ecosystem, where the answering of the questionnaire may not be that relevant anymore, we allow the user to skip it entirely if needed. Whether the questionnaire is skipped or not, the user still needs to determine the weight of each criterion in the final table (by assessing which of the criteria has more or less priority in the determination of cloud feasibility).

After all the inserted data, the user can then press a button to submit the values mentioned before and obtain the calculated recommendation score for each of the alternatives that comes from the application of the MCDM algorithm.

3.3. Determination of relevant criteria set to use and respective definitions

We took advantage of the previously conducted systematic literature review, taking it a step further by refining the criteria definitions and merging some of them where it made sense to do so. The end product ended up being the following criteria:

Complexity represents the overall technical complexity of the current system (in the case of legacy migration) or of the new system that is to be implemented directly in the cloud. This complexity can include both underlying code as well as infrastructure. In the case of legacy migration, it must also be considered the level of application integration across multiple platforms, which contributes to the level of complexity present/required in the application.

Compatibility represents the level of modularity present in the system and the ability to seamlessly interface with other applications that may not be in the cloud and that are already in use.

Availability represents both the availability and accessibility requirements by the system, the existence of redundancy measures within it, as well as the extent up to which the cloud providers can support these requirements. It also refers to the ease of access to the system from different devices. Since these characteristics are usually present in the SLA (service level agreement), this is also to be included in the consideration of this criterion.

Security represents the security measures that are necessary for the system as well as the following characteristics: if the measures need to be geography-based (due to data sovereignty) if the cloud provider is able to replicate the same measures such as protecting organization data and maintaining the same level of privacy and confidentiality of the data. Not only this but it is also the existing level of expertise in dealing with security threats whether it is from the current IT staff or expertise given by the cloud provider. Another aspect to include in the consideration is the importance of having control mechanisms able to respond to security threats and incidents, including the existence of security policies as well as compliance with rules and regulations. Although the latter mentioned are not directly part of the technology that is being considered for migration, they are fundamental aspects to consider before the appliance of system migration. Another aspect to consider is backup and recovery. Continuous monitoring can also be included in security since it is an important function and a great tool to have to detect threats or unusual behavior within a system. One more aspect is the ability to monitor the system in the cloud and cloud resources to assure SLA compliance.

Portability represents the disruption level that the system will suffer when migrated to cloud, or even between cloud providers. This criterion is related to the ease of decoupling the system from the underlying infrastructure of the cloud provider, therefore avoiding vendor lock-in.

Elasticity and Scalability represents the ability to increase and decrease computational power in a simply and instantaneously according to the needs of the system. This criterion also represents the ability to keep up with an increasing workload by incrementally increasing a proportionate amount of computational resources.

Trialability represents the adequacy and availability given by the providers to try out their services before the actual use.

Testability represents how easy and quick it is to deploy a product or application when testing and developing a system before making it fully operational in the cloud.

Performance represents the throughput speed and the existing computational power, where its assessment consists in the validation according to the system requirements.

We considered best to merge the security criteria with both continuous monitoring and backup and recovery since these are parts that directly influence the security of a system, by both being able to effectively and simply monitoring all the resources and current states of the system as well as the communications with other systems. Both backup and recovery work more as measures to attenuate consequences when something goes wrong (whether its a security breach or hardware failure), but are directly connected with the ability to respond to threats if they ever emerge,

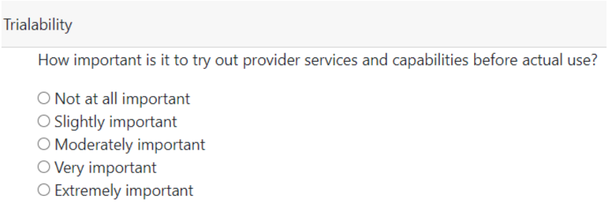
The accessibility and availability criteria were both merged to create a more solid criterion while incorporating both definitions in its definition, something similar to where the SLA component was inserted in this criteria, for it encompasses both of these aspects.

Both criteria of elasticity and scalability were merged since these two aspects always go hand in hand in a system, despite having different definitions, we thought they were better placed as part of a more general criterion, while still evaluating both the components it is made out of.

3.4. Answer scales and scoring system

To be able to translate and build a numerical score from the answers to the questionnaire, we opted for the most simple and straightforward solution. By resorting to a five-point Likert scale as well as a uniform question structure, we are able to deduce the score to add for each alternative (on-premises or cloud hosting). However, since the number of questions for each criterion can be different we end up calculating the average score for the questions for each criterion to obtain the value for the alternatives' score. In this case, we chose a maximum score for each combination of criteria and alternative of five.

For example in figure 2, assuming we are only using that question to evaluate the trialability criterion, we have five answer options. Depending on the answer given, a score is added to either the cloud adoption alternative or the hosting on-site alternative in a cumulative manner. When the answers are submitted, the tool then normalizes the trialability score by dividing the cumulative added score by the maximum score defined previously (in this case five).



Trialability

How important is it to try out provider services and capabilities before actual use?

○ Not at all important
○ Slightly important
○ Moderately important
○ Very important
○ Extremely important

Figure 2: Example of question used to assess the Trialability criterion

3.5. Solution architecture

As it was mentioned in section 3.1 the cloud assessment tool consists of two parts: a questionnaire and the multi-criteria decision-making algorithm responsible for the calculation of the cloud assessment recommendation scores for each of the alternatives (on-site hosting or public cloud). A more detailed representation of the interaction between the tool components can be observed in the application layer diagram in figure 3. The calculation of the recommendation scores takes as input the data provided by the user, this being done in two ways: the answering of the questionnaire and the attribution of the comparative weights for each of the criteria. With both inputs obtained, it is then possible to feed this data to the multi-criteria decision-making algorithm. The algorithm then produces the recommendation scores which will be displayed to the user.

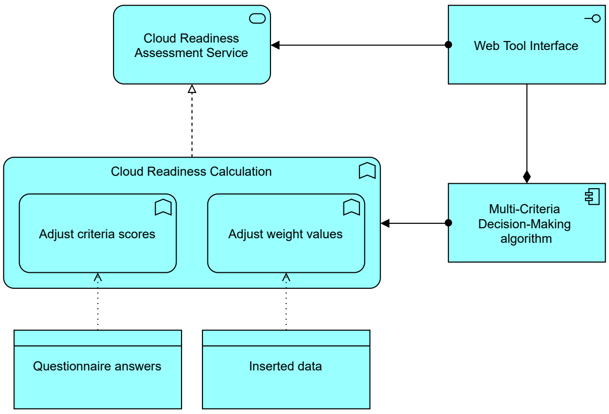


Figure 3: Application layer of the cloud assessment tool

4. Evaluation and results

4.1. Evaluation methodology

The evaluation process for this work will be primarily based on the creation of representative cases on which the tool would be used in a real-world application. These cases will describe a system with some technical aspects and also provide some context of their use and purpose. These created evaluation cases will then be distributed to a/some cloud experts who will conduct a manual cloud assessment approach (like they would normally do without resorting to the tool), and will then apply the same process but by using the tool in order to establish a base of comparison between the process that is currently used to assess the cloud feasibility of a system and our tool. After this, a survey is distributed in order to collect some feedback on the tool as well as additional information that may be useful to make the comparison.

4.2. Evaluation case

For the evaluation of our tool, we used a real cloud migration tool from AMA (the Portuguese agency for administrative modernization). This case consists of a new system, which already has the cloud paradigm in mind, with the goal of creating a unique platform to provide support to citizenship and participatory procedures within local and municipal governments. This application is based on blockchain technology as the underlying system for the attribution of votes to citizens. This project is created with the intent of having both production and pre-production environments hosted in the cloud, each with its own hardware requirements. This new system is also to be integrated with the existing governmental authentication application.

For the pre-production environment the solution is based on Apache HTTP Server, Tomcat, MariaDB, and MongoDB, which make use of Docker containers in order to allow for easier expansion to cloud-based environments. This makes it so that the application possesses both high scalability as well as a deployment with continuous delivery and development. To facilitate the administration of the MariaDB database, there are also Adminar containers. This brings it up to a total of five Docker images, which will be running on the same host. A visualization of the system setup is provided in figure 4.

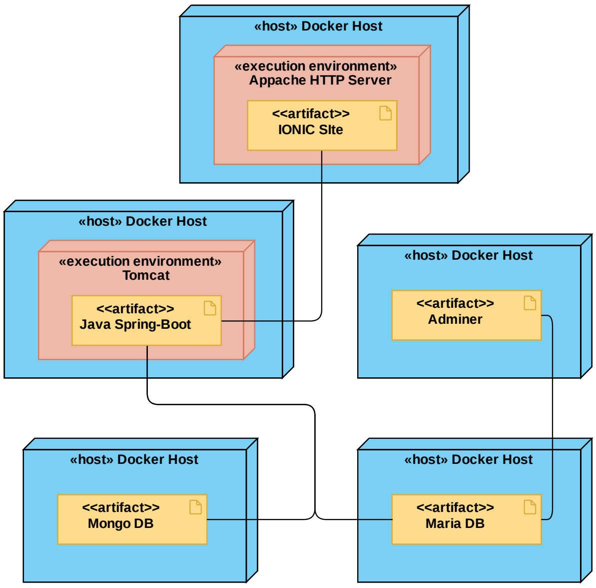


Figure 4: Pre-production deployment architecture

As for the production environment, the base of the solution is similar to the pre-production environment, by using Apache HTTP Server, Tomcat, MariaDB, and MongoDB. There is the addition of a load balancer prior to entering the application, where the amount of requests is distributed by the machines in the environment. This load balancing system is based on the Round-robin algorithm. Instead of a single host machine used in the pre-production environment, here we have a total of six host machines:

- Two Frontends
- Two Relational Database Systems
- Two Document-oriented Database Systems

These host machines will work in two sets of three (one frontend, one relational database, one document-oriented database) to attain load distribution and service availability. A visualization of the system setup is provided in figure 5.

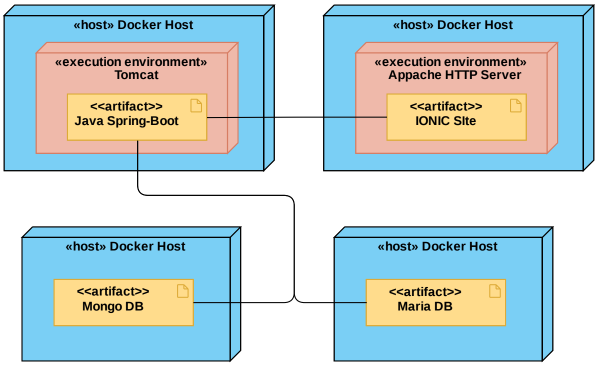


Figure 5: Production deployment architecture

4.3. Obtained results and analysis

After sending the tool to be tested to a cloud expert, the end results produced by the tool coincided with the one produced from the usual approach taken by the expert to assess the cloud feasibility of a system. In this case, the application at hand ended not being approved for cloud migration due to budgeting constraints. The tester of the tool reported that both the interface and information used was relatively easy to use and understand.

5. Conclusions

5.1. Achievements

One of the achievements reached with this work was the consolidation of knowledge that allowed us to produce a generally applicable set of criteria that can be used to assess the cloud feasibility of a system when it comes to technological factors. This criteria set allows to cover the whole spectrum of technological aspects that a system can present and require the respective evaluation.

The other achievement would be the consolidation of the criteria set with the multi-criteria decision-making approach, enabling then the creation of a tool that can be applied in the early stages of cloud adoption/migration decision. Whether it is used by cloud experts to simplify the process and confirm their own analysis or by decision-makers that do not possess such a high level of knowledge of the cloud environment but are still able to grasp key concepts so that the information contained in the tool is enough to allow them to produce an evaluation over the feasibility of cloud of a given system/application.

5.2. Limitations

Although there were some insightful achievements obtained with this work, there are also some aspects that could have gone better or could have come out improved. The fact that there was only one multi-criteria decision-making algorithm used, leaves no comprehensible basis to compare to what may have been different results produced by other algorithms. This would have enriched our work significantly. Another limitation to point out is the usability of the tool, where by being tested over a single case (albeit a real life scenario) it is still not enough to conclude the true value that the tool can bring to the cloud adoption/migration process.

5.3. Future Work

Envisioning what future directions further development of the tool, there are many possibilities to take into consideration. Starting with testing of additional multi-criteria decision-making algorithms to verify differences and maybe determine which ones are better suited for a cloud feasibility analysis or for what type of system being subjected to evaluation in said analysis. Implementation with an AI component that would not only allow for the tool to learn from previous systems that were subjected to cloud migration and cloud feasibility, but it would also allow for another factoring component to be weighed in the evaluation.

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