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Enterprise adoption of cloud computing with application portfolio profiling and application portfolio assessment

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Abstract

With the continued appeal and adoption of cloud computing, an assessment of cloud run costs and migration affordability prior to adoption would assist enterprises that have several legacy applications targeted for cloud migration. However, as cloud migrations have become more prevalent, many have been characterised by unsuccessful migration or application modernisation attempts. The primary reason behind the failed attempts is insufficient planning upfront, to identify which legacy applications are suitable to realise the benefits of public or private cloud, leading to time and cost overruns. There is a need for strategic decision making for application portfolios to mitigate the risks of cost overruns and migration delays. Thus, a Rough Order of Magnitude (ROM) of cloud run costs for an application portfolio is required in the planning phase as an input into IT governance. To obtain the ROM cloud run costs, it is necessary to baseline application data, preferably through automated discovery, and perform quantitative analysis of the applications. Therefore, we propose an approach to (a) baseline application data using *Application Portfolio Profiling* (APP), and (b) perform quantitative analysis of applications using an *Application Portfolio Assessment* (APA), to inform the legacy application migration decision. APP and APA are proposed as part of a Cloud Computing Considerations for Companies (CCCC) framework that enables an enterprise to make an informed decision regarding which legacy applications are to be migrated as part of enterprise Cloud Computing adoption. This decision is important because of the change in operating model, infrastructure requirements, hidden costs and commercial models inherent with cloud computing adoption. We validate the proposed framework through applying it to a real-world use case scenario that provides the necessary coverage to test the proposed framework.

Keywords: Enterprise cloud computing adoption, Application portfolio profile, Application portfolio assessment, Cloud migration, Affordability

Introduction

Problem statement

There is a global trend emerging whereby government agencies from the United States, Europe and Australia are encouraging the industry adoption of cloud computing services in order to boost productivity, innovation and business agility across the digital economy [1–5]. Market research indicates that the uptake of cloud computing is on the rise; according to Flexera [6], 20% of global enterprises invested more than $20 M on public cloud usage in 2019 while 78% have a hybrid cloud pattern of at least one public and one private cloud. With this level of cloud computing adoption and investment, an assessment of an application portfolio's suitability and affordability by determining a Rough Order of Magnitude (ROM) [7] of cloud run and migration costs prior to adoption, would assist those enterprises with several legacy applications to be migrated.

The primary reason for cost and time overruns is insufficient planning or governance, and therefore a lack

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of mitigation plans for cloud risks, or alignment to business strategy. Creating a business case for cloud computing is a complex task due to the number of stakeholders that enterprises typically need to engage with, hence most enterprises do not create a business case at all before they start using cloud services [8, 9]. Traditionally, a business case process has been triggered by the need to justify large capital investments, however with one of the cloud commercial models allowing users to quickly obtain the desired capabilities, enterprises wrongly assume that they will not require additional capital investments. However, as cloud adoption ramps up, most enterprises understand that the new operating model does impose capital investment beyond the migration itself but lack an approach to obtain a ROM of the investment required prior to adoption.

Some organisations have successfully adopted cloud computing without a documented business case; however, later adopters are favouring a more cautious approach to align their cloud strategy with business strategy in the context of enterprise strategy and IT governance. Knowing what business benefits are sought and doing a cost analysis in advance can prevent encountering one of the common pitfalls in the adoption of cloud computing, which is unexpected costs or delays in legacy application migration. A rushed or unplanned migration without a clear understanding of the applications and their dependencies can cost an enterprise more than existing costs, as not all legacy applications are suitable for public cloud and a PAYG consumption commercial model. Developing an understanding of the ROM of projected cloud run costs and identifying the capital investment required for application migration prior to cloud computing adoption can prevent enterprises from being surprised, unprepared or unwilling to undertake the necessary investments. The ROM estimation is a first rough estimate and can cover any or all service models, according to the enterprise's cloud migration plan as part of broader IT governance [10].

While IT or business Subject Matter Experts (SMEs) can make tactical cloud migration decisions one application at a time, this does not guarantee an optimal cloud migration decision for an enterprise's application portfolio as ongoing and migration costs are not always considered [11]. Thus, a methodical approach and cloud framework is required. The survey presented in [12] evaluated forty-three Cloud Adoption and Migration framework studies and found that cloud migration processes and cost models are currently dispersed and fragmented. Essentially, economies of scale can only be realised by taking an enterprise approach to legacy application migration using an application portfolio assessment as input to assessing an application's cloud readiness [11]. Ideally, when considering Cloud Computing adoption, an enterprise will want to assess prioritised groups of applications with business and IT strategy alignment, starting with applications with similar roles (such as web servers) while leaving the most complex ones until last. Considering one application at a time does not take into account interdependencies between applications, hence an enterprise approach is recommended to ensure alignment with the enterprises business strategy [10, 13] to mitigate against re-work. Moreover, the business case for adoption of Cloud Computing at enterprise scale is more compelling when it incorporates the benefits that stem from transforming and removing complexity, and therefore cost, from the current IT infrastructure.

Beginning the assessment of Cloud Computing adoption with a holistic methodology to generate a ROM for cloud run costs will help mitigate the risk of cost and time overruns. Balancing the term with a commercial outcome of any 3- or 5-year forecast model of cloud platform run costs needs to be beyond Reserved Instances in an IaaS model for public cloud and include projected PaaS, SaaS and private cloud costs. While there have been several approaches at migration frameworks [9, 14–17] and TCO calculators for public cloud [15, 16], our approach provides a holistic methodology that enables an assessment of affordability through analysis of the application portfolio and estimation at a ROM confidence level to provide guidance on the affordability of Cloud Computing adoption of suitable legacy applications. Moreover, our approach has been to generalise the cloud service providers' calculators and cater for the hidden costs of cloud adoption, the evolution of commercial models or for new entrants to the cloud service provider market. Most importantly, the generated ROM costs enable an assessment of hybrid cloud computing affordability, while also determining the capital investment required for timely and cost-effective legacy application migration.

Cloud computing considerations for companies framework motivation

To address the challenges outlined above, we propose the Cloud Computing Considerations for Companies (CCCC) framework, which provides a holistic methodology to determine the affordability of enterprise Cloud Computing adoption. This approach balances the time required to perform the assessment, with the degree of detailed and timely information required to provide a confidence level in a ROM estimate of cloud costs. It extends our previously developed Cloud Decision Framework (CDF) [18–20], which provides decision support for single application placement onto a public or private cloud platform, to support enterprises in making their decision to adopt Cloud Computing for an application portfolio. The CDF supports the assessment of one application independently, whereas the CCCC framework supports the assessment of a suite or portfolio of applications in the context of application dependencies.

There is a need for strategic decision making for application portfolios to mitigate the risk of cost overruns or delays, thus a ROM of cloud run costs for an application portfolio is required upfront as an input into IT governance. To do this, it is necessary to baseline application data, preferably through automated discovery and perform quantitative analysis of the applications. Therefore, the proposed approach is to baseline application data using Application Portfolio Profiling (APP) and perform quantitative analysis of applications using an Application Portfolio Assessment (APA) to inform the legacy application migration decision.

Enterprise Cloud Computing adoption can be considered a strategic decision where numerous stakeholders require consultation and agreement as opposed to a tactical cloud platform decision for a single application [14]. Enterprises across every industry want to remain competitive, and there is a sense of urgency to adapt quickly to new business models or become irrelevant. The pressing need is to secure the right amount of infrastructure flexibility, performance and elasticity to manage unpredictable usage volume and geographic dispersion while taking care of the predictable monolithic workloads. Many enterprises are already trialling Cloud Computing with varying degrees of success [17, 21, 22]. The CCCC framework provides a holistic methodology to assess the application portfolio for suitability to hybrid cloud platforms and alignment to the business strategy to then assess the affordability, via the Financial Viability Assessment (FVA), that provides a view of the cloud run costs.

The complexity of cloud computing adoption for legacy applications is that it requires a different operating model, therefore assessing affordability and suitability to public or private cloud from the outset is critical. Identifying and accounting for the hidden costs of cloud is critical for an enterprise when they consider or plan to migrate their legacy applications to Cloud Computing [23] as these costs can be high enough to render the actual cloud run costs as unaffordable. For example, considering the risk appetite for the dual run of the legacy platforms and new cloud platforms at the time of production cutover. For significant mission critical applications and business services, these costs can be significant. Therefore, a cloud strategy needs a systematic framework that aligns to business strategy in the context of an application portfolio. That, in turn, contributes to define the cloud target state to achieve a hybrid cloud outcome. This is vital from a business and IT governance perspective, as the projected cloud run costs can be compared with as-is costs to determine any cost savings in the first instance followed by obtaining migration costs to understand the necessary capital investment required.

Paper organisation

The rest of the paper is organised as follows. Section 2 presents related work on the implications of cloud migration for an application portfolio ranging from varying commercial models, private and public cloud calculators and the inherent complexity when adopting Hybrid Cloud. Section 3 presents an overview of the CCCC framework with a specific focus on Application Portfolio Profiling and Application Portfolio Assessment as an input into the broader IT governance for Cloud Computing adoption. Section 4 validates the framework's suitability using a real-world use-case scenario. The scenario underpins the motivation and need for enterprise decision support and associated FVA during planning for cloud migration by aggregating the cloud run costs for each application in the portfolio and comparing them against the as-is run costs. Section 5 provides a discussion of the strengths and limitations of the framework while Section 6 concludes the paper by providing a summary of the completed work and identifying areas of future work.

Related work

This section covers related work with consideration to cloud adoption frameworks, enterprise strategy, cloud migration, cloud economics, cloud standards, cloud SLAs and cloud metrics.

Cloud adoption frameworks comparison

A review of enterprise Cloud Computing adoption frameworks within recent literature and industry reports [8, 9, 12, 14, 17, 24], shows that there have been several attempts at decision support models for cloud adoption. Moreover, a recently published literature study [12] that evaluated 43 Cloud Adoption and Migration Framework studies, found that cloud migration frameworks, processes and cost models are currently dispersed and fragmented with a need for further enhancement of the cloud migration research using more methodological approaches. The new CCCC framework methodology proposed in this paper, provides a Cloud Computing adoption methodology from a technical and financial perspective that provides an assessment of an application portfolio's suitability and affordability. Although trivial migration projects of single applications may be manageable from a cost and schedule perspective, a methodological approach becomes increasingly important when there is a plan to move large-scale and complex legacy applications that support core business processes of an organisation. As shown in Table 1, the CCCC framework compares favourably against the key assessment criteria of the evaluation framework in [12].

The cloud framework evaluation criteria [12] have been used to contextualise the most comparative approaches with the CCCC framework, in terms of tasks

Table 1 Cloud Evaluation Framework Criteria Coverage

Cloud Framework Evaluation Criteria/Frameworks	**CCCC Cloud Adoption Framework**	**ARTIST Methodology and Framework [9]**	**Migration to PaaS clouds - Migration process and architectural concerns [17]**	**Cloud Calculator: A cloud assessment tool for the public administration [24]**	**A knowledge management-based cloud computing adoption decision making framework [14]**
Analysing Context – identify business value and relevant stakeholders to quantify if there is business value in moving the application to cloud	Fully Supported	Fully Supported	Fully Supported	Not Supported	Fully Supported
Understanding Legacy Applications – capture an abstract of the as-is application	Fully Supported	Fully Supported	Fully Supported	Fully Supported	Partially Supported
Analysing Migration Requirements – Determine if a prototype is required to manage technical risks	Fully Supported	Fully Supported	Partially Supported	Partially Supported	Partially Supported
Planning Migration – Develop a migration plan for the legacy application	Fully Supported	Partially Supported	Partially Supported	Partially Supported	Partially Supported
Cloud Service Platform Selection – Identify the cloud platform features required by the application	Fully Supported	Partially Supported	Fully Supported	Partially Supported	Fully Supported
Migration Type – Determine migration approach from the least intrusive: 'lift and shirt' to the most intrusive: cloud native transformation	Fully Supported	Partially Supported	Partially Supported	Not Supported	Not Supported
Unit of Migration – Identify any components that are subject to regulations or compliance that are not suitable for cloud	Fully Supported	Not Supported	Not Supported	Not Supported	Not Supported
Training – understanding new documentation, Application Programming Interfaces, tools and data movement charges	Partially Supported	Not Supported	Partially Supported	Not Supported	Partially Supported
Re-architecting Legacy Applications – Specify the Target architecture model that addresses transformation requirements	Fully Supported	Partially Supported	Partially Supported	Partially Supported	Not Supported
Testing and Continuous Integration – test adaptions from a functional and non-functional perspective as they are made	Not Supported	Not Supported	Not Supported	Not Supported	Not Supported

that might be performed in an application portfolio assessment for the purposes of assessing legacy application migration to cloud. Note, environment configuration and continuous monitoring criteria were not used in the assessment as these qualities of service are being examined in future work for the CCCC framework and didn't have coverage in the frameworks being compared against. The CCCC framework provides a higher degree of coverage across the evaluation criteria compared with four other popular frameworks that provide the necessary diversity for comparison:

The ARTIST Methodology and Framework [9] covers the technical and economic feasibility as a prerequisite to the migration of a legacy application. However, it does not provide coverage for the hidden costs of cloud computing in the calculation of projected cloud run costs, nor does it provide decision support for determining private or public cloud suitability for the placement of an application. It has a limitation of considering applications independently, and therefore can overlook application dependencies, which in turn may cause delay and cost overruns. The implication of this is an application's performance and stability may suffer due to integration taking longer between the cloud platform and legacy applications yet to be migrated. Alternatively, [17] identifies a best-practice approach in mapping software from on-premise to cloud platforms to take advantage of cloud benefits such as elasticity and performance. The shortcomings of the approach are that the framework assumes all applications are suitable for public cloud and therefore does not provide decision support for the public versus private cloud application placement decision. Moreover, the application utilisation projections for using the PaaS tier functions are not assessed for affordability, nor is the degree of vendor lock-in to a PaaS cloud provider. From a quality of service perspective, the equivalent SLAs of the legacy applications' components are not compared and assessed for suitability.

The cloud computing adoption framework proposed in [14] focuses on macro criteria such as organisational readiness, skills availability, security readiness and telecommunications infrastructure being available. Alternatively, the framework in [24] hones-in upon the technical criteria for cloud migration of an application in a government context. It includes a 'Cloud Calculator' that totals a score based on the weight of each criterion to assist in determining if public cloud is suitable. The CCCC framework differs from both of these frameworks in that it caters for an application portfolio with each application requirement's driving cloud platform selection and FVA of cloud run and migration costs to provide a holistic methodology that contributes to the cloud adoption affordability decision as part of IT governance processes.

Conversely, to demonstrate the fragmentation that exists in current research, there have been cloud adoption frameworks focused narrowly on application requirements or criteria, exclusively to assess the suitability of legacy application migration to public cloud [25, 26] while others have focused on public cloud run cost estimation [15, 16]. Another alternative approach proposes non-functional requirements only for assessing legacy applications for cloud migration [27].

In summary, existing frameworks are either too high level to assess cloud platform suitability and affordability; fragmented in their approach; incomplete without coverage for private cloud; constrained to existing commercial models; or not extensible or generalised to accommodate comparison of public cloud service models. These limitations reduce their usefulness in providing decision support for legacy application migration as input to IT governance. The CCCC framework provides a more comprehensive and holistic methodology with a focus upon decision support for public or private cloud with forecast cloud costs and the capital investment required for cloud migration in the context of business plans for the application portfolio to enable assessment of affordability.

Enterprise strategy, cloud migration and cloud economics

Alignment between business and IT strategy is of critical importance for effective cloud migration projects [13, 28]. The CCCC framework extends upon the alignment principle to provide a technique to capture and quantify the business plans for each application in a portfolio that directly influences the enterprises migration plans. For those legacy applications targeted for Cloud Computing, their suitability is determined for public or private cloud followed by a ROM estimate for their cloud run and migration costs. If the approach is deemed unaffordable, a lower number of legacy applications for Cloud Computing adoption can be identified to re-assess the affordability of legacy application migration.

The CCCC framework plays a role in governing cloud migration [10] to provide decision support for the selection of legacy applications and their suitable cloud platform. The resultant ROM estimate of cloud run and migration costs provides the ability for decision makers to then choose and prioritise their IT investments [29] as part of IT governance. Moreover, the generalised FVA provides a means to select a commercial model that is fit for purpose, on an application by application basis (IaaS Reserved Instance's or Pay as You Go, PaaS, SaaS or combination) to perform comparison and incorporate enterprise discounts where applicable. In terms of application migration itself, each application is assessed for the degree of transformation required as part of the migration, if any.

More narrow cloud migration approaches tend to focus upon guidance for application suitability to public cloud [30–32], provide high level macro criteria to determine an enterprise's infrastructure readiness for cloud adoption [24, 33] or specify technical criteria to address an application migration approach [14, 25]. From an economic perspective, if a calculator is provided to assess cloud run costs it tends to use service provider calculators such as Amazon Web Services [15] and Microsoft Azure [16], data centre [47] or private cloud service providers [28, 34] that are platform focused and do not capture the hidden costs of cloud computing adoption. As cloud solutions or business services continue to fragment, with compute, storage, network and other services running in Hybrid Cloud from various providers with different pricing structures, building a ROM for an application portfolio becomes a non-trivial task [13, 35, 36], something that is addressed by the holistic and flexible CCCC framework and methodology.

A recent literature study [37] analysed fifty three cloud economics articles and identified that there is a clear research gap regarding cloud computing costs as well as no consistent body of research for cloud economics. Similarly, Gartner's [8] findings were that a new cloud operating model imposes new requirements, which incur additional costs that must be accounted for and are currently overlooked when building a business case for cloud migration [8]. To address this gap an appropriate cloud migration governance process and methodology is needed to (a) understand the application architecture and characteristics that determine the selection between public or on-premise private clouds, and (b) capture the platform associated hidden costs and model cloud pricing schemes [37], in the planning phase [23, 38]. Having a ROM of cloud run and migration costs in the planning phase as input into IT governance will reduce the risk of cost overruns and increase the probability of a sustainable cloud migration so any capital investment can be quantified.

In terms of industry frameworks to address the enterprise adoption of Cloud Computing, Gartner's approach [8] has several limitations in terms of providing a more methodical and holistic methodology. For instance, it does not provide decision support for an assessment of applications suitability for public or private clouds, instead it is left to the user to discern this and then select the service models applicable to the legacy application in public cloud without providing any coverage for private cloud. To estimate cloud costs, the preferred service provider calculator is recommended, hence the risk of cost overruns arises due to the hidden costs including the cloud costs of quality [39] not being assessed that directly impact the cloud adopter.

Using cloud standards to avoid lock-in

Hybrid Cloud consists of multiple cloud platforms and services from cloud service providers each offering different commercial models and SLAs [13, 40] that requires careful consideration and traceability to legacy application requirements. As enterprises consider adopting Cloud Computing, multiple technical, non-functional and commercial considerations arise. In [40], the authors recommend avoiding vendor lock-in when choosing a public cloud provider, hence, a focus on application portability [33] is encouraged during the transformation of the application as part of migration and application transformation. Cloud standards play an important role in migrating applications from one environment to another (private-public, public-private, hybrid, multi-cloud, federated) and in developing the right cloud strategy for a business environment to avoid lock-in. A Federated Cloud Manager and Federation Carrier as defined in the National Institute of Standards and Technology (NIST) for Cloud Computing [41], plays a key role in enabling migration of virtual machines, containers, or disk images from one cloud service provider to another using telecommunications networks between cloud service providers and consumers. The intent of the federated cloud standards is to enable interoperability of applications and data between clouds except for the PaaS tier that is likely to require manual intervention to support a hybrid cloud outcome. In the context of the CCCC framework, if Cloud Computing adoption is affordable, then the NIST Federation standards are an input into the definition of a Standard Operating Environment (SOE) for each of the Hybrid Cloud Platforms to enable interoperability. Thus, cloud standards are considered in the next phase of the migration project after the FVA.

Cloud SLAs and SLA metrics

Cloud SLAs in a hybrid, federated and multi-cloud environment consist of complexity and ambiguity, which leads to hidden cost and service level risks. Hybrid Cloud has a combination of public and private cloud platforms that have business services delivered via two or more dependant applications deployed to multiple platforms. The resultant SLAs in a Hybrid Cloud pattern, with public and private cloud service offerings having different SLAs present a service level risk to users in an enterprise. The business service they support may not have equivalent or higher service levels for those components deployed to public and private cloud [40], thus a conscious architectural decision regarding each applications placement and redundancy requirements is necessary to manage the service level risk.

With Hybrid Cloud platforms delivering business services, legacy application migration complexity increases due to differences in clouds' offerings for networking, compute, storage options, service levels, redundancy, Recovery Time Objective (RTO) and Recovery Point Objective (RPO). As correctly identified in [12, 42], cloud migration is not simply a matter of replicating functionality in the cloud or porting an application to the cloud – it is also about ensuring that the associated non-functional requirements will be matched or exceeded. Hybrid cloud infrastructure service level requirements such as reliability, resilience, availability and recoverability require more than auto-scaling in cloud services to be met. It begins by selecting the fit for purpose cloud platform, service models and offerings for a business service, then adopting the architecture, redundancy, tools and techniques to measure and achieve them.

In the context of the CCCC framework, it provides decision support for application placement to public or private cloud based on application requirements and grouping of applications with technical and business dependencies to ensure these constraints are factored into the migration plans for the enterprise. When compared with other cloud migration frameworks [9, 14, 17, 24], little attention is paid to public versus private cloud decision support for legacy applications, nor the associated private cloud FVA to calculate a ROM for the projected cloud run costs, or include and capture redundancy costs where needed to meet highly available and redundant infrastructure requirements. The risk of the alternative approaches is without consideration of private cloud as a platform, public cloud may not be fit for purpose, nor financially viable, hence subjecting the enterprise adoption of cloud for legacy applications to service level risks, cost overruns, delays to cloud adoption and business disruption through the inability to meet the necessary SLA metrics.

CCCC framework

In this section, we present our CCCC framework. It extends our previously developed Cloud Decision Framework (CDF) [18–20], which provides decision support for single application placement onto a public or private cloud platform, to support enterprises in making their decision to adopt Cloud Computing for an application portfolio. The CDF supports the assessment of one application independently, whereas the CCCC framework supports the assessment of a suite or portfolio of applications in the context of application dependencies.

Cloud decision framework

The CDF uses Rule-based Reasoning (RBR) and Case-based Reasoning (CBR) to provide a cloud platform recommendation for a given application during the planning phase of cloud migration (see Fig. 1). Under normal

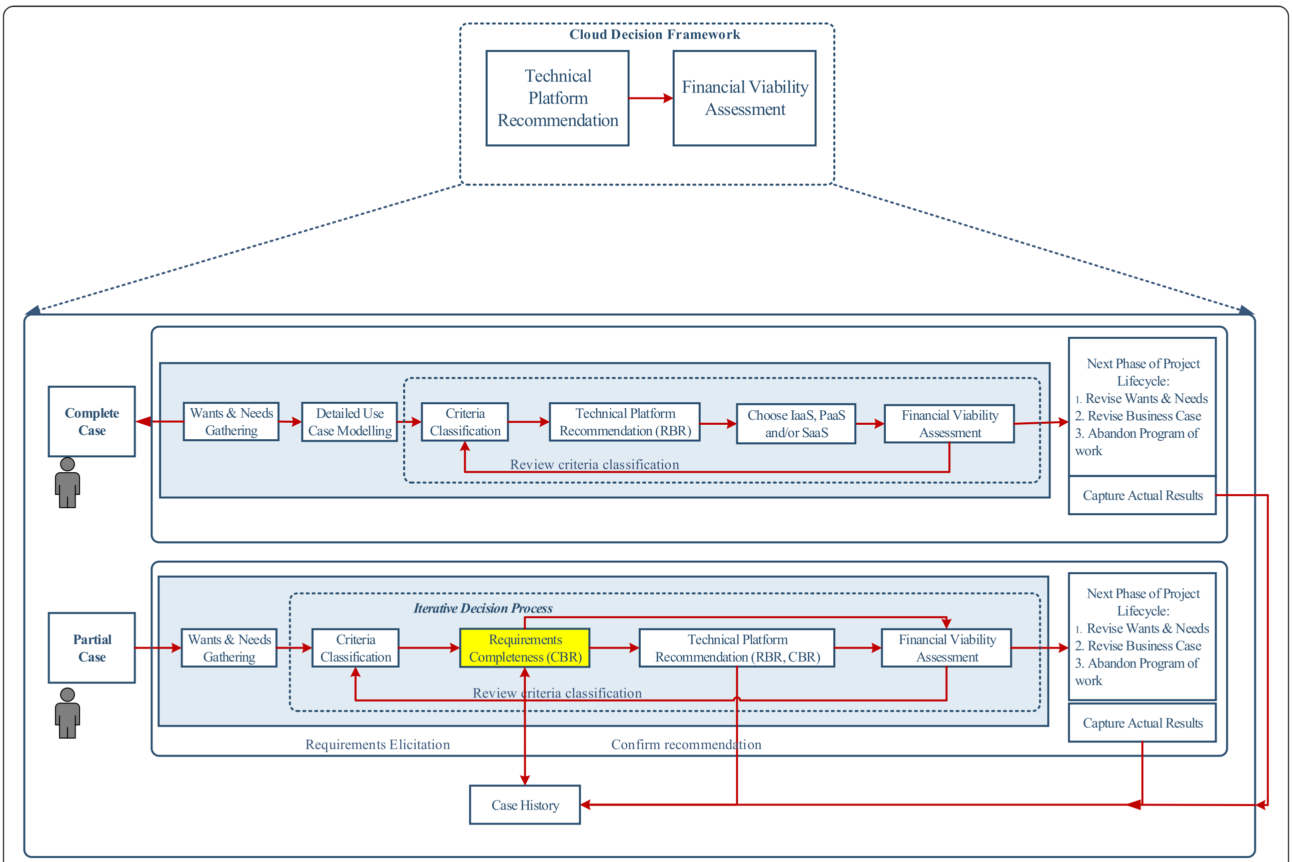

Fig. 1 Cloud Decision Framework using RBR and CBR

circumstances, the RBR-based decision framework requires a business sponsor to identify a comprehensive criterion set with classifications to have a TPR provided. However, with the cloud platform decision moving towards business sponsors, it is unlikely that all the criteria in the framework will be known by the business SME for applicability or values because requirements gathering will not have been completed. When the cloud adopter is unsure of requirements or does not have access to complete information, our approach of combining RBR with CBR supports the cloud adopter in the elicitation of business requirements and cloud platform recommendation. The CBR technique uses the subset of known criteria to search the case history for similar cases and recommends the closest match to the user for adoption which includes the technical platform associated with the application requirements. As shown in Fig. 1, the decision-making process begins with the business SME developing a business case for cloud migration and requiring making a choice between multiple alternatives – traditional IT, private cloud, public cloud or combinations of them for their initiative. The decision-making process is an iterative one comprising the following three steps: *Criteria Classification* (CC) – a criteria can have the classification of 'Required' or 'Optional' from a cloud adopter or business SME perspective, *Technical Platform Recommendation* (TPR) – the resultant recommendation of public or private cloud based on the CC entries using Rules Based Reasoning (RBR), and *Financial Viability Assessment* (FVA) – generalised cloud run costs calculator that incorporates all the entries and formulas from service providers including the hidden costs of cloud computing.

Cloud computing considerations for companies (CCCC) framework overview

The CDF as shown in Fig. 1 provides the tactical decision support necessary to decide between public and private cloud IaaS to ensure the Cloud Computing platform is fit for purpose and financially viable. However, it is inappropriate when assessing an application portfolio, since application dependencies need to be checked across the portfolio after the IaaS decision to validate that application placement will not inadvertently impact application performance or increase costs. A 'Data Placement' architectural decision requires a broader range of information across the application portfolio that allow application dependencies to be understood. Often poor data placement decisions lead to higher than anticipated data costs due to egress charges or underperforming applications. Regardless of where data is placed for hybrid cloud applications, it is likely to cross private and public cloud boundaries, which can trigger cloud and network charges. Data movement between the cloud platform and the data center may be priced by data volume and can add thousands of dollars per month to a Cloud Computing bill [43].

The advantage of taking an application portfolio approach during the planning phase of enterprise Cloud Computing adoption is that it often uncovers the following issues:

- Application silos per business unit with a nest of interconnections are discovered that require consideration to identify the dependencies and therefore allocate applications into migration waves to ensure end users are not impacted during the migration. Waves are essentially 'sub-projects' or self-contained work tasks with virtual or physical server to application grouping [44].
- Fragile and brittle coupling between applications such as point to point integration that have hard coded configurations that must be updated during the migration process.

Therefore, in this paper, we extend the previous CDF, which we now refer to as the CCCC framework as depicted in Fig. 2. The CCCC framework provides support for:

- *Strategic decision making for application portfolios* – by incorporation of two new processes of APP and APA to support Cloud Computing adoption across application portfolios to enable the identification of legacy applications suitable for cloud computing from a technical and economic perspective while understanding and allowing for their dependencies in forecasting migration and cloud run costs using:
- *Application Portfolio Profiling* – this phase involves interviews with application stakeholders to obtain business plans for each application such as 'retire soon' or identify the application as strategic, followed by detailed data gathering to establish baseline information from which an APA is based to obtain TPR and FVA for each application
- *Application Portfolio Assessment* – this phase involves identification of each application's dependencies, application role, application affinity, cost saving opportunities such as duplicate licensing and consolidating managed services or service desks

- *Enterprise Cloud Computing Adoption Recommendation* - expansion of the tactical streamlined decision-making to support enterprise Cloud Computing adoption:
- Assess cloud adoption affordability, incorporating the hidden costs of cloud computing, using the output of the CCCC framework that enables

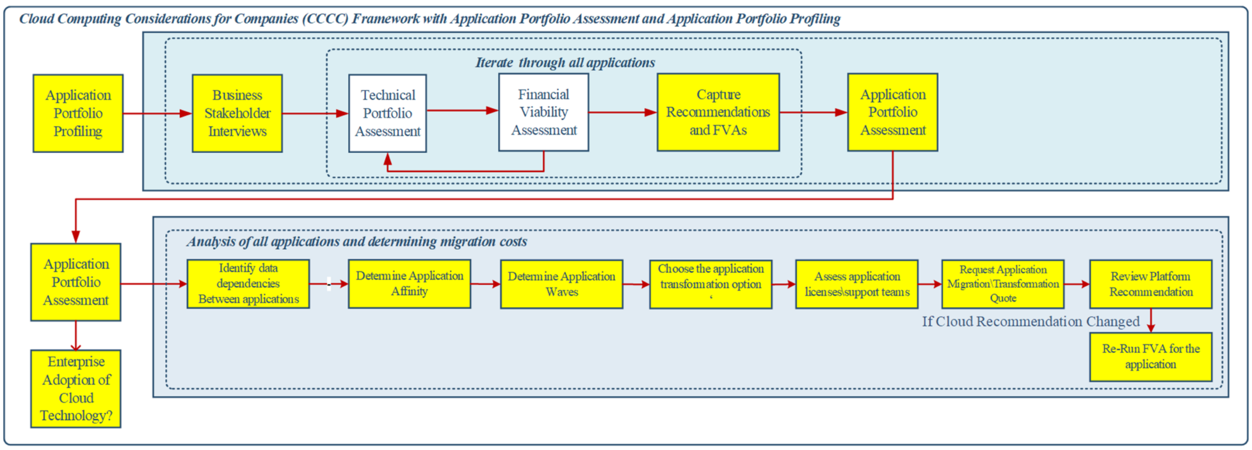

Fig. 2 Cloud Computing Considerations for Companies (CCCC) Framework

comparison between public and private cloud costs for each application to provide stakeholders the information they may need for due diligence purposes
- Assess if the savings are enough to pay for the migration and transformation of applications to Hybrid Cloud
- The business case formula to determine if the planned savings cover the investment required to migrate and/or transform the applications to Hybrid Cloud is: As-Is Compute/Network/Storage costs compared with the projected public and private cloud IaaS costs for Year 1, Year 2, Year 3, Year 4 and Year 5. If the savings from the move to Cloud Computing in Year 1, Year 2 and Year 3 cover all or most of the Application Transformation and transition costs, then Enterprise Cloud Computing adoption is considered feasible and recommended.

Application portfolio profiling

As shown in Fig. 2, the CCCC framework begins with the APP, which comprises the following steps:

Interviewing business stakeholders

In this step, key stakeholders are interviewed to obtain business plans for an application, and key success factors such as compliance with performance and availability Service Level Agreement's (SLA) for applications once migrated.

Data collection

In this step, the business application inventory is collected, including name, footprint and frequency of use. Preferably an automated data collection mechanism is implemented using Commercial-off-the-shelf (COTS) tools such as BMC Helix Discovery[1] and IBM Tivoli Application Discovery and Dependency Management.[2]

Application filtering

Applications that are no longer strategic and targeted for retirement are identified. For example,

- Software licensing agreements and operating system choice are reviewed for each application, and those applications that may not be fit for purpose or redundant in a cloud computing model are excluded from the assessment
- For those applications that are targeted for retirement or that are no longer strategic, they are not included in the assessment

For those applications nominated as strategic, key stakeholder interviews are conducted to identify the migration method for the application and the degree of application transformation required, if any. Having completed the discovery of application data and profiling the applications, the focus can be given to confirmation of the discovered data and the application migration method: as-is or require transformation as part of the process taking into account business plans.

Capturing TPRs and FVAs

For each application included in the assessment, the TPR and FVA is tallied by the cloud adopter or business SME for their hybrid Cloud Computing platforms.

[1]https://www.bmc.com/it-solutions/bmc-helix-discovery.html
[2]https://www.ibm.com/support/knowledgecenter/en/SSPLFC_7.3.0/com.ibm.taddm.doc_7.3/AdminGuide/c_cmdb_overview.html

Application portfolio assessment

Next, in the APA step, the following tasks are performed:

Identification of data dependencies between applications This step involves identifying data dependencies that influence data management requirements in the target cloud platforms, such as: data migration, master data management and reference data management are identified using automated data collection tools mentioned previously.

Identification of application affinity This step involves identifying logical groups of applications that should be migrated together. The steps required to identify Application Affinity include:

- Validation of the current physical and virtual server environment
- Sizing of target environment
- Identification and establishment of application linkage/communications from an 'as-is' environment and 'to-be' environment
- Building an application migration wave plan based on Application Affinity and defining target architecture configurations with the aim of minimizing migration risk. This involves mapping applications to a functional map to identify any duplication in functionality in the portfolio and allocating applications to an application grouping and therefore a migration wave group.

Selection of application transformation option This step involves determining the transformation work required to migrate to the recommended cloud platform. Example tasks include:

- Identifying key opportunities for transformation to exploit the Cloud Computing platform
- Implementing a security design, such as, encryption, zoning map, professional services partner access to the environment, procedures and processes

Assessment of software license/support teams In this step, software licences and/or the application support group are assessed to identify the ones that can be retired, are surplus to requirements or can be consolidated.

Request for application migration/transformation quote Quotes are requested for the migration and transformation for the applications identified as suitable for Cloud Computing.

Platform recommendation review For each application, the TPR is reviewed based on their allocation to application waves. Where the TPR is changed, the FVA should be re-run and the amalgamated costs updated with the alternative platform costs.

Framework illustration

To validate the proposed CCCC framework incorporating APP and APA, we present a real-world use case scenario involving an (anonymised) medium sized banking company that provides the necessary coverage to test the proposed enhancements. The scenario involves a medium-sized (anonymised) banking company that is considering the enterprise adoption of Cloud Computing to lower its hosting costs. It is facing capacity constraints in the primary data centre both in terms of floor space and electrical power. The enterprise has a portfolio of approximately 350 high priority applications (Additional file 1) and wants to determine which ones could be migrated to the (public or private) cloud in order to reduce data centre capacity for priority applications and to lower hosting costs. The decision-makers have the following key questions regarding Cloud Computing adoption that need to be answered to help them make a strategic decision on Cloud Computing adoption:

- **Q1:** Which applications in the portfolio are suitable for Cloud Computing?
- **Q2:** What is the migration impact in terms of cost and duration?
- **Q3:** What are the cost savings of moving suitable applications to the Cloud Computing?
- **Q4:** What is the split of applications being deployed between public and private cloud?

Our CCCC framework can be used to answer Q1, Q3 and Q4 and contributes to a large degree in answering Q2. However, the estimation of the migration work and duration of the migration work needs to be estimated by the bank's application team and is out of the scope of the CCCC framework.

Data collection

As part of APP, the first step is to perform automated data discovery in the current environment – in this instance using the IBM Tivoli Application Discovery and Dependency Mapping - to gather baseline application information and dependencies, validate the information, and understand the business plans for the applications with a business SME. The data collection includes virtual server counts and configurations, identification of standard COTS applications (SAP in this case), and application dependencies where integration exists such as Active Directory. Sample output of the SAP Enterprise Resource

Table 2 Example Output from Automated Application Discovery

Application	Role	Environment	Operating System	vCPU	RAM	Quantity
SAP	ERP	Test	Windows	4	14	1
SAP	ERP	Development	Windows	4	14	1
SAP	E0RP	Production	Windows	16	56	1
S4/Hana	Business Suite	Development	SuSE Linux	4	14	1
S4/Hana	Business Suite	Test	SuSE Linux	16	128	1
S4/Hana	Business Suite	Production	SuSE Linux	32	256	1
SAP	Business Connector	Development	Windows	2	7	1
SAP	Business Connector	Production	Windows	2	7	1
SAP	Print Server	Production	Windows	2	7	1
Shared	Active Directory	Production	Windows	2	7	1
Shared	Active Directory	Disaster Recovery	Windows	2	7	1

Planning (ERP) and S4/Hana application footprint and dependent applications is shown in Table 2 Example Output from Automated Application Discovery. This process of data discovery is repeated for all 350 applications.

The key data to be identified for SAP in the application portfolio is:

- Upstream/Downstream dependencies of the applications – Active Directory
- Complexity (Simple/Medium/Complex) & Criticality – Complex and Critical (based on interview with application owner)
- Review of Application sunset schedule – SAP is strategic (based on interview with application owner)
- Business *Impact* i.e. *SLA, DR/BC* – High

Following a successful discovery of data over four to 6 weeks, the output is used in the interviews with application stakeholders to validate accuracy. Any data that looks exceptional should be validated with application stakeholders. The lessons learnt in the automated application discovery are:

- For accurate utilisation data, the application discovery is scheduled over a four to six-week period as it apparent when the peak periods of utilisation are. If discovery was not performed twice daily, then peak periods are at risk of being missed.
- The application data is collected both during business hours and out of business hours to ensure coverage of utilisation data. If discovery is performed only during one period of the day, the peak utilisation periods could be missed.
- The findings are validated with the stakeholders to determine if any of them were unexpected as discovered data may be exception for the time of year it is taken.

Technical platform recommendation

Once the baseline application data has been collected and validated with the key stakeholders, the next step is to obtain the TPR. The cloud adopter assesses each application in the portfolio against the Cloud Decision Criteria (CDC) and classifies the criteria as being 'Required' or 'Optional'. Table 3 shows the example criteria classification for the SAP application. Following the criteria classification, Rules Based Reasoning (RBR) is used to

Table 3 Example Criteria Classification (For SAP)

Scenario	*SAP*	
Cloud Decision Criteria	*Criteria*	*Criteria Classification*
	Availability	Required
	Business Service Availability	Required
	Long running business process	Required
	Application Usage	Required
	Regulatory requirements	Required
	Operating Costs	Required
	Performance	Required
	Application architecture	Required
	Application constraints	Required
	Security	Required
	Data Security Classification	Required
	Network Global Load Balancing	Optional
	Connectivity to private MPLS network or internet VPN	Required
	Hypervisor	Required
	Enterprise Control	Required
	Data Classification	Required
	Technology Standardisation	Required

obtain a platform recommendation in the TPR step. The recommended platform for the application under consideration is either public cloud or private cloud. This process is repeated for all 350 applications in the portfolio.

Once the applications that are suited for migration have been identified, different COTS tools can be used for the automated migration of the application to the cloud. There are different types of migration scenarios including physical machine to virtual machine migration (P2V), virtual machine to virtual machine migration (V2V) and data migration. Example tools that can be used include PlateSpin[3] for P2V migration, VMWare vMotion[4] for V2V migration and NetApp tools[5] for data migration.

In our scenario, of the 350 applications assessed, 204 applications are assessed as suitable for migration to the private cloud and 93 applications for the public cloud as shown in Table 4. The remaining 53 applications are assessed as being unsuited for cloud migration.

Table 4 Application Portfolio Technical Platform Recommendation

	Private Cloud	Public Cloud	No Change
Applications	204	93	53

Financial viability assessment

With the destination Cloud Computing platform being recommended, the cloud adopter must identify the current platform sizing or footprint in terms of virtual or physical machines as those quantities are used to populate the FVA calculator. In building our FVA calculator, we looked at leading public and private cloud providers that make their calculators publicly available. We used a bottom-up approach to build the generalised FVA calculator, i.e., we use the cost criteria and formulas from publicly available calculators for both public and private cloud providers (such as Amazon Web Services, Microsoft Azure, DELL VCE and Equinix) as a starting point and then add additional cost items that may be relevant to the cloud adopter's scenario. Table 5 contains the Cloud Cost Items that are common to both cloud platform calculators.

Table 6 lists the additional cost items that do not have coverage in the cloud calculators but should be considered to gain a complete view of the one off and on-going costs. These additional items come from Rational Unified Process, Best Practices for Software Development Teams [45, 46]. The implication of not including them is to have an incomplete view of costs that will impact the business initiative and hence likely result in the project being over budget.

Tables 4 and 5 are used as the basis to capture the quantities for each of the cost attributes based on the application sizing, duration of the project, monitoring and management, network connectivity considerations and any custom cost attributes considered important in the comparison. Following this, the FVA can be carried out for the application. The calculator can be extended to cater for applications that require bare metal or custom features particular to public cloud provider above the IaaS offering.

Using our framework, each application's forecast run cost is determined using our FVA calculator based on the TPR of public or private cloud (Table 7). This is repeated for each application in the portfolio in each calculator: public and private cloud. Once the forecast run costs have been calculated for each application, they are consolidated. The consolidated managed private cloud FVA is captured in Table 8 (the requirements for SAP are included with the other applications recommended for private cloud) that underpins the monthly fee. The monthly price of Managed Private Cloud derived using the FVA calculator is: $908,757 per month with 60 servers and 510 TB of data in a Managed Private Cloud replicated in two Data Centers. Similarly, the total public cloud costs for all the applications recommended for public cloud are: $215,422 per month using the FVA calculator.

The costs per month using our FVA with a combination of *Amazon Web Services* and *DELL's VBlock private cloud* as pricing sources are calculated. This is compared with the run and support cost of the applications recommended for Cloud Computing on their existing platforms is: $1,475,000 per month (provided by the company the use case scenario applies to).

It should be noted that typically the savings obtained in the migration are required to be less than the forecast

Table 5 Public and Private Cloud Cost Items in Provider Calculators

Public Cloud Cost Items		
Virtual Compute	Storage	Ingress
Egress	Backup	Audit
DNS Services	Elasticity	Custom Items
Private Cloud Cost Items		
Compute	Storage	Data Centre Space
Air Conditioning	Audit	Power
Backup	Installation	Software licensing
Frame	Custom Items	

[3]https://www.microfocus.com/en-us/products/platespin-migrate/
[4]https://www.vmware.com/au/products/vsphere/vmotion.html
[5]https://www.netapp.com/us/index.aspx

Table 6 Additional Cost Items Not Included in Provider Calculators

Cost Item	Public Cloud	Private Cloud	Relevance
Architecture & Project Management			
Solution Architecture	√	√	The work required to ensure the application, infrastructure, data and service management solution are cohesive.
Project Management	√	√	Project Managers are charged with planning, budgeting and resourcing.
Network Connectivity, Security			
Security Services	√	√	Provides consideration for new firewall, anti-virus or Denial of Service
DNS Services	√	√	A scalable and highly available domain name that is part of a public or private cloud platform service
Database as a Service	√	√	An example of a custom entry in the cost model
Connectivity to a private network	X	√	Local access from a data centre to the client's private network
Monitoring & Management			
Lifecycle Management	√	X	It is an IT Asset lifecycle is a sequence of events to determine if the asset requires refresh or replacement
Automation Components	√	√	Components used to automate a manual process or part thereof.
Governance of resources	√	√	A method of providing role-based access for rights for the provisioning of cloud resources.
Commercial Considerations			
PAYG Commercial Model	√	X	A flexible payment arrangement that provides consumption on a granular basis
Reserved Instances Commercial Model	√	X	A dedicated resource is a reservation of resources and capacity typically over a multi-year commitment in public cloud.
Managed Private Cloud providing a 30% resource overhead to the baseline requirement	X	√	We have used a heuristic of 30% that balances elasticity, peak loads, professional services cost and overhead in the private cloud to account
Elasticity of Public Cloud	√	X	Enable periodic or seasonal requirements for elasticity in public cloud to be captured to balance this against the resource overhead in Managed Private Cloud
High Availability	√	√	Public Cloud and Managed Cloud providers will have dependencies upon components to meet high availability requirements.
Custom Items	√	√	Any items considered important by the Cloud Adopter to be included that are above the IaaS layer and specific to a public or private cloud.

migration, transformation and transition project costs for the Cloud Computing business case to be feasible. If the savings from the move to Cloud Computing in Year 1, Year 2 and Year 3 cover all or most of the Application Transformation and transition costs, then Enterprise Cloud Computing adoption is considered feasible and recommended. The savings from subsequent years could then be invested into new business opportunities, training of staff or governance and automation tools for Cloud Computing adoption. It is worth noting that, based on our criteria, moving all applications to the public cloud would not be the most suitable approach. Our CCCC framework does not attempt to capture the migration costs; hence a request of the bank's application transformation and migration team is required to provide this. It is an essential step in the overall enterprise decision to adopt Cloud Computing because it informs the business case of the transformation and migration costs.

Application portfolio assessment

Once the FVA has been completed for all applications that have been selected for cloud migration, each application is reviewed and allocated one of the following categories – Migrate As-Is, Transform/Re-Platform, Re-installs and Review TPR. Some examples are given below:

- SAP – The TPR is Private Cloud and is assessed as suitable. As the SAP version is current and deployed to VMWare, the decision is to Migrate As-Is to Private Cloud.
- Contact Centre – The TPR is Private Cloud and is assessed as suitable. The version of the software is 2 versions behind the current version; hence the decision is to transform the software through a two-stage upgrade process.
- Microsoft Outlook – The TPR is Public Cloud and is assessed as suitable.

Table 7 Consolidated Managed Private Cloud Financial Feasibility Assessment

	Up-front	Monthly	End of contract	Qty	Year 0	1	3	4	5	6
					Up-front	Accumulative	Accumulative	Accumulative	Accumulative	Accumulative
Architecture & PM										
Solution Architecture	$ –	$ –	$ –	0	$ –	$ –	$ –	$ –	$ –	**$**
Project Management	$ –	$ –	$ –	0	$ –	$ –	$ –	$ –	$ –	**$**
Connectivity	$ –	$ –	$ –	0	$ –	$ –	$ –	$ –	$ –	**$**
Design & Implement (PROD)	$ 1,295,000.00	$ –	$ –	2	$ 2,590,000.00	$ 2,590,000.00	$ 2,590,000.00	$ 2,590,000.00	$ 2,590,000.00	**$ 2,590,000.00**
Design & Implement (DR)	$ –	$ –	$ –	0	$ –	$ –	$ –	$ –	$ –	**$**
Compute & Storage (PROD)										
Vblock 350 Frame	$ –	$ 29,450.00	$ –	2	$ –	$ 706,800.00	$ 1,413,600.00	$ 2,120,400.00	$ 2,827,200.00	**$ 3,534,000.00**
Virtual Blades	$ –	$ 2450.00	$ –	60	$ –	$ 1,764,000.00	$ 3,528,000.00	$ 5,292,000.00	$ 7,056,000.00	**$ 8,820,000.00**
Physical Blades	$ –	$ 1150.00	$ –	0	$ –	$ –	$ –	$ –	$ –	**$**
Storage	$ –	$ 7450.00	$ –	1	$ –	$ 89,400.00	$ 178,800.00	$ 268,200.00	$ 357,600.00	**$ 447,000.00**
Compute & Storage (DR)										
Vblock 350 Frame	$ –	$ 29,450.00	$ –	2	$ –	$ 706,800.00	$ 1,413,600.00	$ 2,120,400.00	$ 2,827,200.00	**$ 3,534,000.00**
Virtual Blades	$ –	$ 2450.00	$ –	60	$ –	$ 1,764,000.00	$ 3,528,000.00	$ 5,292,000.00	$ 7,056,000.00	**$ 8,820,000.00**
Physical Blades	$ –	$ 1150.00	$ –	0	$ –	$ –	$ –	$ –	$ –	**$**
Storage	$ –	$ 7450.00	$ –	1	$ –	$ 89,400.00	$ 178,800.00	$ 268,200.00	$ 357,600.00	**$ 447,000.00**
Ingress & Egress Fees	$ –	$ –	$ –	$	– $	– $	– $	– $	– **$**	
Monitoring & Management	$ –	$ 25,000.00	$ –	19	$ –	$ 5,700,000.00	$ 11,400,000.00	$ 17,100,000.00	$ 22,800,000.00	**$ 28,500,000.00**
Data centre										
Power	$ –	$ –	$ –	0	$ –	$ –	$ –	$ –	$ –	**$**
Cooling	$ –	$ –	$ –	0	$ –	$ –	$ –	$ –	$ –	**$**
Floor space	$ –	$ –	$ –	0	$ –	$ –	$ –	$ –	$ –	**$**
Lifecycle Management										
Platform engineering	$ 1200.00	$ –	0.5 $	–	$ 7200.00	$ 14,400.00	$ 21,600.00	$ 28,800.00	**$ 36,000.00**	
Incident management & remediation	$ –	$ –	$ –	0	$ –	$ –	$ –	$ –	$ –	**$**
Platform migration	$ 1200.00	$ –	$ 1200.00 20	$	24,000.00 $	24,000.00 $	24,000.00 $	24,000.00 $	24,000.00 **$**	**24,000.00**
Predeployment validation lab	$ –	$ –	1 $	–	$ –	$ –	$ –	$ –	**$**	
Backup	$ –	$ 128.57	$ –	44	$ –	$ 67,885.71	$ 135,771.43	$ 203,657.14	$ 271,542.86	**$ 339,428.57**
Contract Administration	$ –	$ 500.00	$ –	1	$ –	$ 6000.00	$ 12,000.00	$ 18,000.00	$ 24,000.00	**$ 30,000.00**
Audit	$ –	$ 300.00	$ –	1	$ –	$ 3600.00	$ 7200.00	$ 10,800.00	$ 14,400.00	**$ 18,000.00**
					$ 2,614,000.00	$ 13,519,085.71	$ 24,424,171.43	$ 35,329,257.14	$ 46,234,342.86	**$ 57,139,428.57**

Table 8 Application Portfolio Technical Platform Recommendation

Applications	Private Cloud	Public Cloud	No Change
Migrate as-is	97	49	
Transform or Re-platform	71	17	
Re-install	36	27	
	204	93	53

- ESRI – The TPR is Private Cloud and is assessed as suitable. The software will be re-installed in private cloud with cost effective run time costs due to the static nature of the application
- Inventory - The TPR is Public Cloud and is assessed as required to be in Private Cloud due to data dependencies and integration with SAP. The target platform recommendation is changed to Private Cloud and the FVA re-run.

Table 7 below provides a summary of the transformation options for the 297 applications recommended for cloud migration.

The four migration waves are driven by the degree of transformation or the complexity of application transformation (lowest to highest) starting with the low complexity waves that don't require a detailed assessment and obtain buy-in and agreement of implementation schedules. The subsequent migration waves are determined by the degree of application: re-install, automated migration or application transformation. The next step is to examine the data tier of the applications and review the application waves and group those applications that have data dependencies through integration in the same wave:

- Wave 1: In the first wave, 151 applications comprising Web Servers and applications running on VMWare are selected for migration with the duration estimated to be 1.5 months.
- Wave 2: In the second wave, 67 independent applications that require transformations are selected. The application transformation is estimated to take 3 months and the application migration is estimated to take 2 months.
- Wave 3: 54 applications with dependencies are grouped together for migration in Wave 3 with a subset requiring transformation. The application transformation is expected to take 2 months and the application migration is estimated to take 3.5 months.
- Wave 4: 25 applications with dependencies are grouped together for migration in Wave 4 with a subset requiring the most complex transformation. Application transformation is expected to take 4 months while migration is estimated to take 4–5 months.

Recommendation

The overall recommendation from our CCCC framework is to adopt Cloud Computing technology pending validation that the migration, transformation and transition project costs are met by the savings gained from the run costs and reduction in support team. This would enable the banking enterprise's desire to meet, for example, agility and elasticity for its internet facing applications, to reduce its data centre footprint and ability to meet future business plans.

In summary, the use case scenario illustrates the CCCC framework beginning with discovering baseline application and utilisation information, determining the TPR and calculating the FVA to minimise the risk of budget overruns due to working off inaccurate information and therefore not sizing the target Cloud Computing platform correctly. Each application's TPR is assessed for its suitability, and if changed, the FVA rerun and collated to enable an enterprise architectural decision to adopt Cloud Computing. The answers to questions 1, 3 and 4 are:

- Q1: Which applications are suitable for Cloud Computing?
- 297 out of 350 applications in the portfolio are suitable for Cloud Computing
- Q2: What are the cost savings of moving those applications to the Cloud?
- The cost savings of moving those applications to Cloud Computing is $350,821/month. Additional savings of a reduction in two people in the platform support team due to a smaller footprint in the bank's data centre has resulted in a saving of $350,000/month or $29,166/month.
- Q3: What is the split of applications being deployed between public and private cloud?
- 93 applications are targeted for public cloud (31%) while 204 applications are targeted for the private cloud. 53 applications are left as-is.

Using the APA approach means applications can be migrated in logical groups appreciating complexity, business priority, data placement, performance, availability and dependencies to start realising savings.

Discussion

This section provides a discussion of the strengths and limitations of the CCCC framework for enterprise cloud adoption and migration of legacy applications as input into IS investment measures in IT governance.

The CCCC framework provides a holistic methodology for cloud migration decision making thereby addressing a key research gap in existing work. The CCCC framework provides a methodology and decision support for legacy application assessment for cloud migration and a ROM of cloud run and migration costs to determine affordability. Common measures to evaluate IS investments are: Return on Investment (ROI) [37], Net Present Value (NPV) [34], Internal Rate of Return (IRR) [34]. The key difference in our proposed approach as compared with the common measures to evaluate IS investments is that the CCCC framework supports an initial assessment of affordability using a methodical approach with associated techniques to discover the existing environment, decide suitability of cloud platforms for the application portfolio, capture the business strategy alignment and determine a ROM for cloud run and migration cost to achieve this outcome. The output of the exercise can be used as input to the formal IS methods of evaluating and prioritising investments [29] or be input into a broader IT governance process.

The strength of the CCCC framework is that it provides decision support from a technical and economic perspective. It can then be utilised as input into traditional IS measures of investment. Alternative approaches typically provide more narrow guidance from either a technical or economic perspective. Most importantly, the CCCC framework provides coverage of private cloud in the platform decision support and financial viability that informs the cloud adopter of a recommended platform that assists in mitigating the risk of incorrect platform choice. This is imperative when several stakeholders are required to be convinced that there is enough consideration of public and private cloud options from a technical and economic perspective in the planning phase to ultimately obtain their support.

Alignment between business strategy and IT strategy as part of a blueprint is important to be captured and assessed in IT governance [10, 13]. The CCCC framework enables the alignment of a cloud strategy and business strategy for an application portfolio to be captured for each application using a combination of information captured via automated discovery and interviews with business stakeholders. This enables selection of legacy applications to be migrated based upon business plans for the enterprise.

The FVA component of the CCCC framework extends upon prior research to provide coverage for private cloud ROM estimation combined with incorporating the hidden costs according to the migration plans of the enterprise. The hidden costs provide coverage for open source or ISV software license models in cloud, quantification of vendor lock-in through forecasting data transfer and PaaS costs, identification of the duration of the dual run of the legacy platforms and new cloud platforms to manage the risk of the migration being unsuccessful, placeholders for PaaS and SaaS service model forecast of consumption and generalisation of the FVA to be applied across service providers from a public or private cloud perspective catering for commercial model choice to be aligned with business plans and application usage. Accounting for the hidden costs as part of a ROM is a key consideration when input into an enterprise's IT governance and the decision to adopt cloud computing as those costs when added to those derived from a service provider calculator can push the forecast cloud run cost to be beyond a range the cloud adopter, enterprise or business stakeholders are willing to accept or support.

Limitations of the CCCC framework relate to the hidden costs associated with hybrid cloud adoption specifically in the scenario where a business service is delivered by applications deployed to both public and private cloud. The CCCC framework hidden costs can be extended to include the build and run costs for a component such as an SLA Manager to monitor a business service, and ensure that costs are captured to implement the standards required for consistency across platforms and management tools to minimise the risk of inconsistencies as they can increase complexity and cost.

To the best of our knowledge, our approach in this paper is the first to provide a holistic framework and methodology to enable enterprises in making and prioritising the strategic decision of enterprise cloud computing adoption in terms of affordability as input into IT governance.

Conclusion

Migration to cloud computing offers a way to shorten development cycles, scale at demand, and reduce operational and infrastructure expenses. As cloud adoption and therefore cloud migration of legacy applications become more prevalent, a holistic methodology for enterprise cloud computing adoption is required that can provide input into IT governance decision making. However, our literature review identified a gap in research for cloud adoption and legacy application migration with many existing approaches being fragmented with coverage from either a technical or economic perspective. Therefore, in this paper, we proposed an approach to (a) baseline application data using APP, and (b) perform quantitative analysis of applications using an APA, in order to obtain a ROM of cloud run and migration costs for an application portfolio in the planning phase of cloud migration. We extended our previously developed cloud decision framework to incorporate both APP and APA. The resulting CCCC framework provides a holistic methodology with coverage from both technical and economic perspectives in the one framework and helps an enterprise to make an informed decision regarding which legacy applications are to be migrated as part of enterprise cloud computing adoption. We validated the CCCC framework by applying it to a real-world use case scenario that provided the necessary coverage to test the framework.

The next focus of our work will be to enhance the CCCC framework to (a) assess and include the build and run costs for a SLA Manager to monitor business services where federated or hybrid cloud is used, (b) assess and define the standards required for consistency across environments and management tools to minimise the risk of an increase in complexity of managing federated or hybrid cloud, and (c) further validate the CCCC framework using additional case studies from various industries. We will also extend the CCCC framework to consider additional factors including organisational culture, skills or experience of people that influences training requirements and assess the implications for onshore/off-shore teams.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13677-020-00210-w.

Additional file 1: Appendix A. Application Portfolio. **Table 9** Application Portfolio Migration Outcome

Abbreviations

APA: Application Portfolio Assessment; APP: Application Portfolio Profile; CBR: Case Based Reasoning; CCCC: Cloud Computing Considerations for Companies; CDC: Cloud Decision Criteria; COTS: Commercial-Off-The-Shelf; FVA: Financial Viability Assessment; IaaS: Infrastructure as a Service; IRR: Internal Rate of ReturnNISTNational Institute of Standards and Technology; NPV: Net Present Value; PaaS: Platform as a Service; RBR: Rules Based Reasoning; SaaS: Software as a Service; SLA: Service Level Agreement; SME: Subject Matter Expert; TPR: Technical Platform Recommendation

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Authors' contributions

Kent R. Ramchand developed the framework, then captured, analysed and performed the calculations for the case study. Mohan Baruwal Chhetri and Ryszard Kowalczyk contributed to the final version of the manuscript. Mohan Baruwal Chhetri and Ryszard Kowalczyk supervised the project. The authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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