A Factor Framework for Experimental Design for Performance Evaluation of Commercial Cloud Services

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Abstract—Given the diversity of commercial Cloud services, performance evaluations of candidate services would be crucial and beneficial for both service customers (e.g. cost-benefit analysis) and providers (e.g. direction of service improvement). Before an evaluation implementation, the selection of suitable factors (also called parameters or variables) plays a prerequisite role in designing evaluation experiments. However, there seems a lack of systematic approaches to factor selection for Cloud services performance evaluation. In other words, evaluators randomly and intuitively concerned experimental factors in most of the existing evaluation studies. Based on our previous taxonomy and modeling work, this paper proposes a factor framework for experimental design for performance evaluation of commercial Cloud services. This framework capsules the state-of-the-practice of performance evaluation factors that people currently take into account in the Cloud Computing domain, and in turn can help facilitate designing new experiments for evaluating Cloud

Index Terms—Cloud Computing; commercial Cloud services; performance evaluation; experimental design; factor framework

I. INTRODUCTION

Along with the boom in Cloud Computing, an increasing number of commercial providers have started to offer public Cloud services [24], [30]. Since different commercial Cloud services may be supplied with different terminologies, definitions, and goals [30], performance evaluation of those services would be crucial and beneficial for both service customers (e.g. cost-benefit analysis) and providers (e.g. direction of improvement) [24]. Before implementing performance evaluation, a proper set of experiments must be designed, while the relevant factors that may influence performance play a prerequisite role in designing evaluation experiments [18]. In general, one experiment should take into account more than one factor related to both the service to be evaluated and the workload.

After exploring the existing studies of Cloud services performance evaluation, however, we found that there was a lack of systematic approaches to factor selection for experimental design. In most cases, evaluators identified factors either randomly or intuitively, and thus prepared evaluation experiments through an ad hoc way. For example, when it comes to

the performance evaluation of Amazon EC2, different studies casually considered different EC2 instance factors in different experiments, such as VM type [32], number [32], geographical location [16], operation system (OS) brand [24], and even CPU architecture [16] and brand [27], etc. In fact, to the best of our knowledge, none of the current Cloud performance evaluation studies has used "experimental factors" deliberately to design evaluation experiments and analyze the experimental results.

Therefore, we decided to establish a framework of suitable experimental factors to facilitate applying experimental design techniques to the Cloud services evaluation work. Unfortunately, it is difficult to directly point out a full scope of experimental factors for evaluating performance of Cloud services, because the Cloud nowadays is still chaotic compared with traditional computing systems [33]. Consequently, we used a regression manner to construct this factor framework. In other words, we tried to isolate the de facto experimental factors from the state-of-the-practice of Cloud services performance evaluation. In fact, the establishment of this factor framework is a continuation of our previous work [21], [22], [23] that collected, clarified and rationalized the key concepts and their relationships in the existing Cloud performance evaluation studies. Benefitting from such a de facto factor framework, new evaluators can explore and refer to the existing evaluation concerns for designing their own experiments for performance evaluation of commercial Cloud services.

Note that, as a continuation of our previous work, this study conventionally employed four constrains, as listed below.

- We focused on the evaluation of only commercial Cloud services, rather than that of private or academic Cloud services, to make our effort closer to industry's needs.
- We only investigated Performance evaluation of commercial Cloud services. The main reason is that not enough data of evaluating the other service features could be found to support the generalization work. For example, there are little empirical studies in Security evaluation of commercial Cloud services due to the lack of quantitative metrics [22].
- We considered Infrastructure as a Service (IaaS) and Plat-

form as a Service (PaaS) without considering Software as a Service (SaaS). Since SaaS with special functionalities is not used to further build individual business applications [4], the evaluation of various SaaS instances could comprise an infinite and exclusive set of factors that would be out of the scope of this investigation.

We only explored empirical evaluation practices in academic publications. There is no doubt that informal descriptions of Cloud services evaluation in blogs and technical websites can also provide highly relevant information. However, on the one hand, it is impossible to explore and collect useful data from different study sources all at once. On the other hand, the published evaluation reports can be viewed as typical and peer-reviewed representatives of the existing ad hoc evaluation practices.

The remainder of this paper is organized as follows. Section II briefly introduces the four-step methodology that we have used to establish this factor framework. Section III specifies the tree-structured factor framework branch by branch. An application case is employed in Section IV to demonstrate how the proposed factor framework can help facilitate experimental design for Cloud services performance evaluation. Conclusions and some future work are discussed in Section V.

II. METHODOLOGY OF ESTABLISHING THE FRAMEWORK

As previously mentioned, this factor framework is established based on our previous work, which is mainly composed of four steps, as listed below and respectively specified in the following subsections:

- Conduct a systematic literature review (SLR).
- Construct a taxonomy based on the SLR.
- Build a conceptual model based on the taxonomy.
- · Establish an experimental factor framework at last.

A. Conduct Systematic Literature Review

The foundation for establishing this factor framework is a systematic literature review (SLR) on evaluating commercial Cloud services. As the main methodology applied for Evidence-Based Software Engineering (EBSE) [8], SLR has been widely accepted as a standard and systematic approach to investigation of specific research questions by identifying, assessing, and analyzing published primary studies. Following a rigorous selection process in this SLR, as illustrated in Figure 1, we have identified 46 Cloud services evaluation studies covering six commercial Cloud providers, such as Amazon, GoGrid, Google, IBM, Microsoft, and Rackspace, from a set of popular digital publication databases (all the identified evaluation studies have been listed online for reference: http: //www.mendeley.com/groups/1104801/slr4cloud/papers/). The evaluation experiments in those identified 46 studies were thoroughly analyzed. In particular, the atomic experimental components, such as evaluation requirements, Cloud service

 $^1 The\ complete\ SLR\ report\ can\ be\ found\ online: https://docs.google.com/open?id=0B9KzcoAAmi43LV9IaEgtNnVUenVXSy1FWTJKSzRsdw$

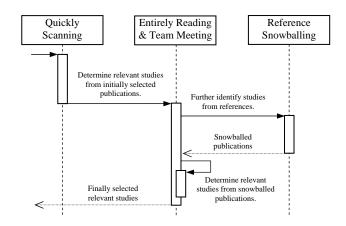


Fig. 1. The study selection sequence in the SLR on evaluating commercial Cloud services.

features, metrics, benchmarks, experimental resources, and experimental operations, were respectively extracted and arranged.

B. Construct Taxonomy

During the analysis of these identified evaluation studies, we found that there were frequent reporting issues ranging from non-standardized specifications to misleading explanations [21]. Considering that those issues would inevitably obstruct comprehending and spoil drawing lessons from the existing evaluation work, we created a novel taxonomy to clarify and arrange the key concepts and terminology for Cloud services performance evaluation. The taxonomy is constructed along two dimensions: Performance Feature and Experiment. Moreover, the Performance Feature dimension is further split into *Physical Property* and *Capacity* parts, while the Experiment dimension is split into *Environmental Scene* and *Operational Scene* parts, as shown in Figure 2. The details of this taxonomy has been elaborated in [21].

C. Build Conceptual Model

Since a model is an abstract summary of some concrete object or activity in reality [26], the identification of real and concrete objects/activities plays a fundamental role in the corresponding modeling work. Given that the taxonomy had capsuled relevant key concepts and terminology, we further built a conceptual model of performance evaluation of commercial Cloud services to rationalize different abstractlevel classifiers and their relationships [23]. In detail, we used a three-layer structure to host different abstract elements for the performance evaluation conceptual model. To save space, here we only portray the most generalized part hosted in the top classifier layer, as shown in Figure 3, which reflects the most generic reality of performance evaluation of a computing paradigm: essentially, performance evaluation can be considered as exploring the capacity of particular computing resources with particular workloads driven by a set of operations.

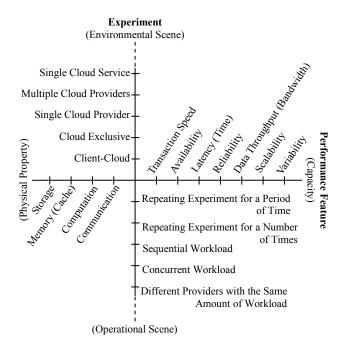


Fig. 2. Two-dimensional taxonomy of performance evaluation of commercial Cloud services.

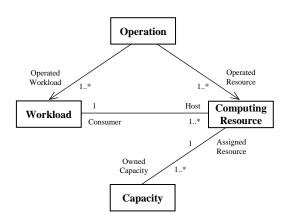


Fig. 3. Conceptual model of Cloud services performance evaluation in the top classifier layer.

D. Establish Factor Framework

In fact, the specific classifiers in the abovementioned conceptual model [23] has implied the state-of-the-practice of performance evaluation factors that people currently took into account in the Cloud Computing domain. According to different positions in the process of an evaluation experiment [1], the specific classifiers of Workload and Computing Resource indicate input process factors; the specific classifiers of Capacity suggest output process factors; while the Operation classifiers are used to adjust values of input process factors. The detailed experimental factors for Cloud services performance evaluation are elaborated in the next section.

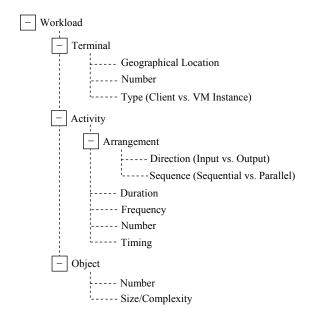


Fig. 4. The workload factors for experimental design.

III. THE TREE-STRUCTURED FACTOR FRAMEWORK

As mentioned previously, the experimental factors for performance evaluation of commercial Cloud services can be categorized into two input process groups (Workload and Computing Resource) and one output process group (Capacity). Thus, we naturally portrayed the factor framework as a tree with three branches. Each of the following subsections describes one branch of the factor tree.

A. Workload Factors

Based on our previous work [21], [23], we found that a piece of workload used in performance evaluation could be described through one of three different concerns or a combination of them, namely Terminal, Activity, and Object. As such, we can adjust the workload by varying any of the concerns through different experimental operations. The individual workload factors are listed in Figure 4.

- 1) Terminal: In contrast with services to be evaluated in the Cloud, clients and particular Cloud resource (usually VM instances) issuing workload activities can be viewed as terminals. Correspondingly, the geographical location or number of both clients [11] and VM instances [14] have been used to depict the relevant workload. Meanwhile, the terminal type can also be used as a workload factor. For example, the authors evaluated Cloud network latency by using client and EC2 instance respectively to issue pings [2]. In this case, the terminal type has the equal essence to the factor communication scope (cf. Subsection III-B1).
- 2) Activity: The concept "activity" here describes an inherent property of workload, which is different from, but adjustable by, experimental operations. For example, disk I/O request as a type of activity can be adjusted by operations like the number or time of the requests. In fact, the number- and time-related variables, such as activity duration [11], frequency

- [5], number [5], and timing [10], have been widely considered as workload factors in practice. Furthermore, by taking a particular Cloud resource being evaluated as a reference, the factor activity direction can be depicted as input or output [2]. As for the activity sequence in a workload, the arrangement generates either sequential [2] or parallel [14] activity flows.
- 3) Object: In a workload for Cloud services performance evaluation, objects refer to the targets of the abovementioned activities. The concrete objects can be individual messages [13], data files [14], and transactional jobs/tasks [6] in fine grain, while they can also be coarse-grained workflows or problems [6]. Therefore, the object number and object size/complexity are two typical workload factors in the existing evaluation studies. Note that we do not consider object location as a workload factor, because the locations of objects are usually hosted and determined by computing resources (cf. Subsection III-B). In particular, a workload may have multiple object size/complexity-related factors in one experiment. For example, a set of parameters of HPL benchmark, such as the block size and process grid size, should be tuned simultaneously when evaluating Amazon EC2 [3].

B. Computing Resource Factors

According to the physical properties in the performance feature of commercial Cloud services [21], the Cloud Computing resource can be consumed by one or more of four basic styles: Communication, Computation, Memory (Cache), and Storage. In particular, the VM Instance resource is an integration of all the four basic types of computing resources. Overall, the computing resource factors can be organized as Figure 5 shows.

- 1) Communication: As explained in [21], Communication becomes a special Cloud Computing resource because commercial Cloud services are employed inevitably through Internet/Ethernet. As such, the Ethernet I/O Index is usually pre-supplied as a service-level agreement (SLA) by service providers. In practice, the scope and level of communication have been frequently emphasized in the performance evaluation studies. Therefore, we can summarize two practical factors: The factor Communication Scope considers intra-Cloud and wide-area data transferring respectively [24], while the Communication Level distinguishes between IP-level and MPI-message-level networking [12].
- 2) Computation: When evaluating PaaS, the Computation resource is usually regarded as a black box [16]. Whereas, for IaaS, the practices of Computation evaluation of Cloud services have taken into account Core Number [3], Elastic Compute Unit (ECU) Number, Thread Number [2], and a set of CPU characteristics. Note that, compared to physical CPU core and thread, ECU is a logical concept introduced by Amazon, which is defined as the CPU power of a 1.0-1.2 GHz 2007 Opteron or Xeon processor [28]. When it comes to CPU characteristics, the Architecture (e.g. 32 bit vs. 64 bit [16]) and Brand (e.g. AMD Opteron vs. Intel Xeon [27]) have been respectively considered in evaluation experiments. Processors with the same brand can be further distinguished

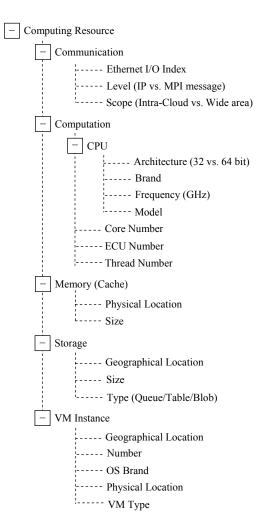


Fig. 5. The computing resource factors for experimental design.

between different *CPU Models* (e.g. Intel Xeon E5430 vs. Intel Xeon X5550 [3]). In particular, *CPU Frequency* appears also as an SLA of Cloud computation resources.

- 3) Memory (Cache): Since Memory/Cache could closely work with the Computation and Storage resources in computing jobs, it is hard to exactly distinguish the affect to performance brought by Memory/Cache. Therefore, not many dedicated Cloud memory/cache evaluation studies can be found from the literature. In addition to the SLA Memory Size, interestingly, Physical Location and Size of cache (e.g. L1=64KB vs. L2=1MB in Amazon m1.* instances [28]) have attracted attentions when analyzing the memory hierarchy. However, in [28], different values of these factors were actually revealed by performance evaluation rather than used for experimental design.
- 4) Storage: As mentioned in [21], Storage can be either the only functionality or a component functionality of a Cloud service, for example Amazon S3 vs. EC2. Therefore, it can be often seen that disk-related storage evaluation also adopted experimental factors of evaluating other relevant resources like VM instances (cf. Subsection III-B5). Similarly, the predefined

Storage Size acts as an SLA, while a dedicated factor of evaluating Storage is the Geographical Location. Different geographical locations of Storage resources can result either from different service data centers (e.g. S3 vs. S3-Europe [29]) or from different storing mechanisms (e.g. local disk vs. remote NFS drive [31]). In addition, although not all of the public Cloud providers specified the definitions, the Storage resource has been distinguished among three types of offers: Blob, Table and Queue [24]. Note that different Storage Types correspond to different sets of data-access activities, as described in [22].

5) VM Instance: VM Instance is one of the most popular computing resource styles in the commercial Cloud service market. The widely considered factors in current VM Instance evaluation experiments are Geographical Location, Instance Number, and VM Type [3], [13], [14], [16], [24], [28], [32]. The VM Type of a particular instance naturally reflects its corresponding provider, as demonstrated in [24]. Moreover, although not common, the OS Brand (e.g. Linux vs. Windows [24]) and *Physical Location* [7] also emerged as experimental factors in some evaluation studies. Note that the physical location of a VM instance indicates the instance's un-virtualized environment, which is not controllable by evaluators in evaluation experiments [7]. In particular, recall that a VM Instance integrates above four basic types of computing resources. We can therefore find that some factors of evaluating previous resources were also used in the evaluation of VM Instances, for example the CPU Architecture and Core Number [3], [28].

C. Capacity Factors

As discussed about the generic reality of performance evaluation in Subsection II-C, it is clear that the capacities of a Cloud computing resource are intangible until they are measured. Meanwhile, the measurement has to be realized by using measurable and quantitative metrics [20]. Therefore, we can treat the values of relevant metrics as tangible representations of the evaluated capacities. Moreover, a particular capacity of a commercial Cloud service may be reflected by a set of relevant metrics, and each metric provides a different lens into the capacity as a whole [9]. For example, Benchmark Transactional Job Delay [25] and Benchmark Delay [19] are both Latency metrics: the former is from the individual perspective, while the latter from the global perspective. As such, we further regard relevant metrics as possible output process factors [1] when measuring a particular Cloud service capacity, and every single output process factor can be used as a candidate response [1] in the experimental design. Since we have clarified seven different Cloud service capacities [21], i.e. Data Throughput, Latency, Transaction Speed, Availability, Reliability, Scalability, and Variability, the possible capacity factors (metrics) can be correspondingly categorized as Figure 6 shows. Due to the limit of space, it is impossible and unnecessary to exhaustively list all the metrics in this paper. In fact, the de facto metrics for performance evaluation of commercial Cloud services have been collected and summarized in our previous work [22].

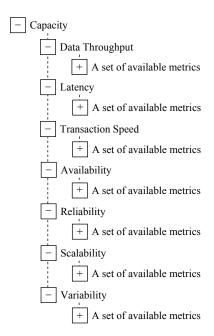


Fig. 6. The capacity factors for experimental design.

IV. APPLICATION OF THE FACTOR FRAMEWORK

Since the factor framework is inherited from the aforementioned taxonomy and modeling work, it can also be used for, and in turn be validated by, analyzing the existing studies of Cloud services performance evaluation, as described in [21], [23]. To avoid duplication, we do not elaborate the analysis application scenario, and the corresponding validation, of the factor framework in this paper. Instead, we particularly highlight and demonstrate how this factor framework can help facilitate designing experiments for evaluating performance of commercial Cloud services.

Suppose there is a requirement of evaluating Amazon EC2 with respect to its disk I/O. Recall that relevant factors play a prerequisite role in designing evaluation experiments. Given the factor framework proposed in this paper, we can quickly and conveniently lookup and choose experimental factors according to the evaluation requirement. To simplify the demonstration, here we constrain the terminal to be clients, while only consider the direction of disk I/O and data size to be read/write in workload factors, and only consider the EC2 VM type in computing resource factors. As for the capacity factors, we can employ multiple suitable metrics in this evaluation, for example disk I/O latency and data throughput. However, since only one metric should be determined as the response in an experimental design [1], we choose the disk data throughput in this case. Thus, we have circled active direction, object size, and VM type as factors, while data throughput as response in the framework for designing experiments. In particular, we use two-level settings for the three factors: the value of active direction can be Write or Read; object size can be Char or Block; and VM type only covers M1.small and M1.large. In addition, we use "MB/s" as the unit of data throughput.

Since only a small amount of factors are concerned, we

can simply adopt the most straightforward design technique, namely Full-factorial Design [1], for this demonstration. This design technique adjusts one factor at a time, which results in an experimental matrix comprising eight trials, as shown in Matrix (1). For conciseness, we further assign aliases to those experimental factors, as listed below. Note that the sequence of the experimental trials has been randomized to reduce possible noises or biases [1] during the designing process.

- A: Activity Direction (Write vs. Read).
- B: Object Size (Char vs. Block).
- C: VM Type (M1.small vs. M1.large).
- Response: Data Throughput (MB/s).

trial	A	B	C	Response	
1	Write	Block	M1.small	?	
2	Read	Char	M1.large	?	
3	Write	Char	M1.small	?	
4	Read	Char	M1.small	?	(1)
5	Read	Block	M1.large	?	
6	Read	Block	M1.small	?	
7	Write	Char	M1.large	?	
8	Write	Block	M1.large	?	
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Following the experimental matrix, we can implement evaluation experiments trial by trial, and fill the Response column with experimental results. For our convenience, here we directly employ the evaluation results reported in [15], as listed in Matrix (2).

$$\begin{bmatrix} trial & A & B & C & Response \\ 1 & Write & Block & M1.small & 73.5 & MB/s \\ 2 & Read & Char & M1.large & 50.9 & MB/s \\ 3 & Write & Char & M1.small & 25.9 & MB/s \\ 4 & Read & Char & M1.small & 22.3 & MB/s \\ 5 & Read & Block & M1.large & 64.3 & MB/s \\ 6 & Read & Block & M1.small & 60.2 & MB/s \\ 7 & Write & Char & M1.large & 35.9 & MB/s \\ 8 & Write & Block & M1.large & 63.2 & MB/s \\ \end{bmatrix}$$

Finally, different analytical techniques can be employed to reveal more comprehensive meanings of experimental results [1] for commercial Cloud services. For example, in this case, we can further investigate the significances of these factors to analyze their different influences on the disk I/O performance. In detail, by setting the significance level α as 0.05 [17], we draw a Pareto plot to detect the factor and interaction effects that are important to the process of reading/writing data from/to EC2 disks, as shown in Figure 7.

Given a particular significance level, Pareto plot displays a red reference line besides the effect values. Any effect that extends past the reference line is potentially important [1]. In Figure 7, none of the factor or interaction effects is beyond the reference line, which implies that none of the factors or interactions significantly influences the EC2 disk I/O performance. Therefore, we can claim that EC2 disk I/O is statistically stable with respect to those three factors. However, Factor B (Data Size to be read/written) has relatively significant influence on the performance of EC2 disk I/O. Since the throughput of small-size data (Char) is much lower than that of large-size

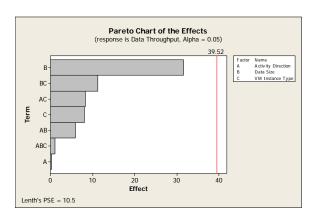


Fig. 7. The Pareto plot of factor effects.

data (Block), we can conclude that there is a bottleneck of transaction overhead when reading/writing small size of data. On the contrary, there is little I/O performance effect when switching activity directions, which means the disk I/O of EC2 is particularly stable no matter reading or writing the same size of data.

Overall, through the demonstration, we can find that this factor framework offers a concrete and rational foundation for implementing performance evaluation of commercial Cloud services. When evaluating Cloud services, there is no doubt that the techniques of experimental design and analysis can still be applied by using intuitively selected factors. Nevertheless, by referring to the existing evaluation experiences, evaluators can conveniently identify suitable experimental factors while excluding the others, which essentially suggests a systematic rather than ad hoc decision making process.

V. CONCLUSIONS AND FUTURE WORK

Cloud Computing has attracted tremendous amount of attention from both customers and providers in the current computing industry, which leads to a competitive market of commercial Cloud services. As a result, different Cloud infrastructures and services may be offered with different terminology, definitions, and goals [30]. On one hand, different Cloud providers have their own idiosyncratic characteristics when developing services [24]. On the other hand, even the same provider can supply different Cloud services with comparable functionalities for different purposes. For example, Amazon has provided several options of storage service, such as EC2, EBS, and S3 [5]. Consequently, performance evaluation of candidate services would be crucial and beneficial for many purposes ranging from cost-benefit analysis to service improvement [24].

When it comes to performance evaluation of a computing system, proper experiments should be designed with respect to a set of factors that may influence the system's performance [18]. In the Cloud Computing domain, however, we could not find any performance evaluation study intentionally concerning "factors" for experimental design and analysis. On the contrary, most of the evaluators intuitively employed experimental factors and prepared ad hoc experiments for evaluating

performance of commercial Cloud services. Considering factor identification plays a prerequisite role in experimental design, it is worthwhile and necessary to investigate the territory of experimental factors to facilitate evaluating Cloud services more systematically. Therefore, based on our previous work, we collected experimental factors that people currently took into account in Cloud services performance evaluation, and arrange them into a tree-structured framework.

The most significant contribution of this work is that the framework supplies a dictionary-like approach to selecting experimental factors for Cloud services performance evaluation. Benefitting from the framework, evaluators can identify necessary factors in a concrete space instead of on the fly. In detail, as demonstrated in the EC2 disk I/O evaluation case in Section IV, given a particular evaluation requirement, we can quickly and conveniently lookup and circle relevant factors in the proposed framework to design evaluation experiments, and further analyze the effects of the factors and their interactions to reveal more of the essential nature of the evaluated service. Note that this factor framework is supposed to supplement, but not replace, the expert judgement for experimental factor identification, which would be particularly helpful for Cloud services evaluation when there is a lack of a bunch of experts.

The future work of this research will be unfolded along two directions. First, we will gradually collect feedback from external experts to supplement this factor framework. As explained previously, Cloud Computing is still maturing and relatively chaotic [33], it is therefore impossible to exhaustively identify the relevant experimental factors all at once. Through smooth expansion, we can make this factor framework increasingly suit the more general area of evaluation of Cloud Computing. Second, given the currently available factors, we plan to formally introduce and adapt suitable techniques of experimental design and analysis to evaluating commercial Cloud services. With experimental design and analysis techniques, this factor framework essentially acts as a solid base to support systematic implementations of Cloud services evaluation.

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