

# A Novel Model for Cloud Computing Analytics and Measurement

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**Abstract**—A Cloud Computing system is a complex system. The existing metric systems are inadequate for providing a high-fidelity picture of what is going on in the complex cloud and do not facilitate all the assessments needed by businesses. Therefore, we have proposed a novel model for cloud service measurement resulting in implementation of an ontology of cloud computing metrics (“web of metrics”). It provides an armada of measures, including the existing metrics and those which are novel in the cloud service analytics literature. Its novelty partially stems from the fields such as *business management*, and also emerges as a result of recognizing service client, service provider and service regulator *analytics* requirements. Thirty-five metric attributes for each of the several hundred metrics have been distinguished. The ontology and the measurements can be made consumable for businesses through Business Intelligence and data science software, and customized dashboards can be produced for case, as the metric ontology is multi-faceted and is customised given the use-case at hand in order to gain business advantage. A detailed practical example regarding the development of an Elasticity trust mark for the benefit of cloud users, cloud service providers and the regulators has been provided.

**Index Terms**—service science, cloud computing, metrics, ontology, performance measures, business management, complex systems

## I. INTRODUCTION

NIST (National Institute of Standards and Technology) defines cloud computing as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction” [1], [2]. Clouds massively provide computing resources over a network (typically the Internet [3]) and put resources at optimal use for processing. As the grocery giants such as Walmart amass their buying/production power to

buy/produce value products, sometimes with high quality, the same (or quite better, quality-wise) can be done for computing services by creating giant service-marts. This is particularly important as massive amount of data is generated annually in scale of a zeta-byte ( $10^{21}$  bytes) [4] and *big data* is growing in terms of volume and variety with more velocity [5], which needs to be kept and processed in a cost effective and optimal way by many public and private parties. Cloud computing is an increasingly popular solution and is a trend setter for science and technology together with *big data* [6].

Clouds can be private or public. Private clouds can be customized for the owner's best use and can be self-managed from the scratch [7] while public clouds can save costs as the resources are shared optimally by a number of clients. Clouds are created and are competing according to different models and none has dominated the market so far. Among the challenges cloud computing faces are the complexities and technical details which result in Performance Unpredictability and the need for ensuring Business Continuity [8].

A cloud is elastic and scalable. Clouds provide Software as a Service (SaaS), Platform as a Service (PaaS), Infrastructure as a Service (IaaS) and Data as a Service (DaaS), usually to numerous clients (the *XaaS* family, *X* being an abbreviation for any kind of important and desired service on the cloud, is increasingly becoming wider and wider). IaaS is the provision of virtual servers, storage and networking for infrastructure managers, PaaS is the provision of platforms such as databases and OS for the software developers, while the SaaS is the provision of software such as CRM for the less-technical clients. BPaaS (Business Process as a Service) has also been suggested as a higher level on top of SaaS for provision of out of the box business models [9]. The idea is: an out of the box business model would still need to be tailored for the real business, but it would take less effort than needed for the other lower level software usually provided at the SaaS layer, making the cloud service a more *agile business change solution*.

In Cloud Computing it is important to provide a pool of computing resources in different service and usage levels (IaaS, PaaS and SaaS), with the aim of improving on a number of QoS metrics and business metrics, such as service cost, elasticity, security, flexibility of services, accessibility of services and so on.

While data analytics applications hosted in a cloud environment are well-suited [10], cloud computing analytics itself has not been developed as much for the benefit of cloud service providers and cloud service regulators. Without offering measurement-guided service improvements, a cloud business will not be managed well and the cloud computing challenges cannot be addressed. In the competitive service market, you have a good cloud only if you address more computing challenges and improve service quality based on a better analytical model, it is not just a matter of the cloud hardware and software parts working together for accommodating VMs using over-simplified monitoring software.

In the other hand, clients want to know what happens to their data and to the cloud services, given the different situations and scenarios, from legal scenarios to computational, now and in future. They want to know the business impact and the sound decision options they have, which arise from such an understanding. This, too, highlights the importance of measuring and analysing the cloud and strongly motivates the already important research regarding the cloud computing metrics, namely measuring Quality of Service (in its broad definition addressing the mentioned challenges), Quality of Experience and the relevant business (and even legal) metrics. We can infer that there are three categorically important viewpoints regarding the cloud metrics:

- a. Service provider view
- b. Service user view
- c. Regulator view

There are numerous software tools and a number of underlying models which try to explain and measure cloud performance, each from a different viewpoint, but the fact that no comprehensive and full-coverage software or model exists which thoroughly cover the three categories of viewpoints is a major shortcoming we will address.

Criticisms aside, the combination of the features and metrics of the existing cloud monitoring and measurement software can help much with cloud management. Examples of the existing tools and their metrics:

Cloud Harmony is an interesting software which can report test results according to several metrics such as upload and download speeds, page loads, latency, CPU and multi-threading on several major services [11].

Cloudstone is “a toolkit consisting of an open-source Web 2.0 social application (Olio), a set of automation tools for generating load and measuring its performance in different deployment environments” [11]. It includes a dollars per user per month metric. [11]

Cloud CMP, developed by Duke University and Microsoft Research, “pits cloud against cloud”, assessing computation, storage, and network services, then

estimates performance and cost of an application if it's deployed on a particular provider [11].

CloudSleuth assess response time and availability on popular cloud service providers. The tests are run from locations in 50 states of the US and from 75 international locations [11].

CloudStatus evaluates Amazon Web Services and Google App Engine.

Iperf can test the quality of the network by creating TCP and UDP data streams and measuring the throughput of a network that is carrying them [12].

In this paper, we will provide a *background* and we also explore the *methodology* (Section II) and *improvement opportunities on the state of the art* (Section III) which then culminates in a novel *cloud analytics and measurement model* (Section IV). We report the *implementation of the model* in form of an ontology, *web of metrics* (Section V) and elaborate on how the *enterprises can benefit* from this metric ontology (Section VI), followed by *practical business use examples* (Section VII). The paper is eventually *concluded* and hints for *future work* are mentioned (Section VIII).

## II. METHODOLOGY

Our study of metrics, business intelligence software and analytics literature has led us to two trends which are important for methodological studies:

- 1) **Business advantage** is, directly or indirectly, the ultimate motivation for driving the development and assessment of measurement tools and theories (from the monitoring agents to the business intelligence software)
- 2) **Artificial Intelligence** has gained and is gaining more and more importance in extracting business value from metric data. There's a bold AI trend in analytics software and the next generation analytical brains such as IBM's Watson.

In Artificial Intelligence, hybrid methods which combine different algorithms to achieve better results than the best single algorithm, have a record of success, making hybrid approaches a generic approach for trying to enhance what's at hand. In Natural Language Processing, sometimes over fifteen algorithms are combined to achieve a few percent of more performance<sup>1</sup>.

More data can have the same or even better effect than combining algorithms in Artificial Intelligence. In fact, modest lower performance AI algorithms have shown better performance than the best of algorithms in their class when the amount of data fed to the modest algorithm has been increased.

This pattern of ‘more calculation methods combined, plus more data fed, probably brings significantly better results’ has been gone as far as collecting data/algorithm pieces which would be assumed disposable [15].

The importance of the finding that benefitting from the data and algorithms which were assumed to be disposable

<sup>1</sup> For example, for NLP problems such as Word Sense Disambiguation where the disambiguation accuracy according to a well-balanced gold standard has been about 65 to 70 percent for best hybrid algorithms (according to the Senseval-3 gold standard).

can lead to better results, can go beyond the classic Artificial Intelligence, to AI applications in analytics and business problems, including putting Cloud Computing analytics to work for business advantage.

Therefore, we have tried to create a more complete taxonomy of cloud computing metrics compared to the rivals such as the Carnegie Mellon taxonomy, which would play the parallel to more algorithms in hybrid AI approaches (as every metric is a calculation formula looking at the cloud from a specific measurement view point. Such a formula is in fact a tiny algorithm). It is interesting that each of these tiny algorithms attracts its own data flow (naturally, as a metric) which would make the analytics model not only more ‘calculation method’ rich (algorithm rich) but also more data rich.

Then we have turned the taxonomy to an ontology by defining over thirty attributes for every metric which would further define relationships between metric types, qualities and uses (on top of the simple hierarchy of a taxonomy).

We compare the resulting metrics with Carnegie Mellon taxonomy to prove it is more complete, while the fact that our work has been put into an ontological format with thirty five attributes for each metric is unique (not found in classic taxonomies) and has an umbrella model for ontology development (which is again unique). While the umbrella ontology development method is itself a contribution, the benefits of an ontological view to the metrics over a mere taxonomical view is also argued in next sections to justify the effort.

For the different parts mentioned in earlier paragraphs, we have to argue that this specific accumulation of more calculation methods (metrics) and the related data streams can bring the sort of advantage seen in AI (such as NLP) frequently. The question of *more performance* resulting from more algorithms and data in classic AI is parallel to (and in this case turned into) *more business value* as a result of definition of more metrics and more metric data streams compared to the limited number of main stream metrics in rivals (most notably the Carnegie Mellon SMI). Therefore we have to argue in the next sections that, whether by example or by a thorough “implementation and data gathering”, such a gain of business advantage based on such less important/less main-stream metrics which we have introduce for measuring the cloud, on top of the Carnegie Mellon metrics, does exist.

The argument by thorough “implementation and data gathering” is more desirable but much more expensive to furnish. It’s a part of our future aim, while providing existence argument by business example together with the assuring fact of the experienced strength of this approach as published in AI field [15] plus the fact that AI tools used for metric analysis are soaring and the Cloud Analytics and AI fields are tightly bound, will modestly do the purpose anticipated from the argument.

One methodological shortcoming of this *existence-by-example* proof approach is while we show the extra metrics and metric attributes resulted by our model can work to the advantage of businesses, therefore

contributing to the cloud analytics body of knowledge in a systematic and practical way, we have not proved yet that every extra metric or metric attribute we have introduced has such a notable use, as the example does not use all the metrics and attributes (but provides a *usage example* and an *idea* of how *such kind of a usage* happens in other cases).

### III. AN OUTLINE OF IMPROVEMENT OPPORTUNITIES ON THE STATE OF THE ART

Li *et al.* [16] research focus on ninety-seven metrics in Performance (sixty-seven metrics), Economics (twenty-five) and Security (five metrics) categories. Not addressing the Assurance and Usability categories of metrics (which we will address later) is one of the issues resolving which can move this good research further. There are also more useful metrics in the Security and Economics categories which are important for the concerned use cases. The metrics which are considered minor or negligible for use-case *A* can be very important for use-case *B* and researchers tend to focus on the subset of metrics which is more aligned to their expertise, which can manifest itself in a metric system not accommodating some/many of the use cases. For example, risk management metrics for cloud federation is the focus of a research by Arias-Cabarcos *et al.* [17] which distinguishes between pre/post federation stages to quantify risk in form of 21/16 metrics (in different levels) respectively. Such examples show how vast the potential metric pool actually is: in order of hundreds if not thousands, rather than the tens of metrics [16], [18] or fewer [14] presented in existing work.

Hu *et al.* [14] build on the SERVQUAL system [14] as can be seen in Fig. 1. A number of metrics in the Performance, Usability and Security categories are addressed in their research. To notice the importance of evaluation of customer support is a positive contribution here.

Cloud service quality evaluation system

| First grade indexes | Second grade indexes  | External metric   |
|---------------------|---|---|
| Rapport (Ra)        | Training system (Ra1)<br>Customized service (Ra2)<br>Customer support (Ra3)   | Training hours<br>Information pushing frequency<br>Selection results in SLA   |
| Responsiveness (Rb) | Dynamic scalability response (Rb1)<br>Disaster recovery time (Rb2)<br>Technology support availability (Rb3)   | Response time<br>Response time<br>Non-support times in commitment   |
| Reliability (Rc)    | Elastic service availability (Rc1)<br>Service accuracy (Rc2)<br>Budget control (Rc3)  | Available uptime percentage<br>Failure frequency<br>Selection results in SLA  |
| Flexibility (Rd)    | Multi-client access adjustment (Rd1)<br>Extra resources allocation (Rd2)<br>Data migration (Rd3)  | Multi-client variation balance<br>Coverage of resources <sup>a</sup><br>Amount of data migration <sup>b</sup>   |
| Security (Re)       | Data backup (Re1)<br><br>Fault recovery strategy (Re2)<br>Regular security audit (Re3)<br>Anti-virus tool (Re4)<br>Data secrecy (Re5)<br>Access control (Re6) | Image backup frequency <sup>a</sup><br>Database backup frequency <sup>b</sup><br>Selection results in SLA<br>Selection results in SLA<br>Selection results in SLA<br>Selection results in SLA |

#### Notes

<sup>a</sup> means the metric in IaaS

<sup>b</sup> mean the metric in PaaS.

Selection results in SLA means the metric can be identified directly by comparing the selection results with reality

Figure 1. A new QoS evaluation system based on SERVQUAL system [13], reproduced from [14].

Fig. 2 shows the Carnegie Mellon University's cloud analytics metric hierarchy which is one of the best we have seen [18]. It has several ten metrics. A cloud computing metric system may contain many metrics (in our case, a few hundred). Most use-cases may focus on one to ten percent of these metrics. The current research mostly focuses on the famous performance and security metrics accompanied by an emerging trend in usage of *business* group of metrics. We have gathered and extended a list of simple and complex *metrics* which has gradually become more complete in comparison to the existing [14], [16], [18], [19] state of the art. We categorised our metrics into a *default* hierarchy represented in the form of a *web of metrics* hosted by the metric Wiki. Thirty-five attributes for each metric were identified to form our *ontology* of metrics for cloud performance measurement and analysis. Ontologies offer the means of explicit representation of the meaning of different concepts, for example in form of attributes, together with the concept relationships [20]. Some of the ontology attributes have been *filled in* according to the papers, or our experience, while the others remain as *place holders*.

Web of metrics is a straightforward platform for development of the metric ontology, which can be consumed by cloud monitoring programs while the development is going on by crowds working on the Wiki. It means that as we develop the web of metrics on our wiki, it can be instantly consumed by programs which recognise its simple and straightforward format, making the distance between the cloud analytics research and its application much shorter. Finally, a performance measurement *messaging format* for the cloud is proposed, in a common JSON format, for which the required messaging serialization/deserialization *code* is already publicly available. A relevant program which recognises the format has been developed.

To our knowledge, there is no standard metric hierarchy and there is no complete and comprehensive monitoring/evaluation tool covering all the aspects of cloud analytics. We are trying to make our metric list more complete for example compared to Carnegie Mellon's SMI [18], using various sources in the literature and our own ideas, while we recognize the fact that a zero weight might be assigned to some of our listed metrics and attributes in some specific analysis (use-case) context. This is a confirmation of the under-investigated fact that *the pool of attributes and metrics is quite large while a specific analysis may only require some of the metrics and attributes*. It is interesting that the researchers whose papers we have studied or with whom we have worked each have their own perspective towards the cloud metrics, which is (often considerably) different from the others. As stated, this has its roots in their experience and the use-cases for which they wish to consume the cloud metrics. For example, throughput, delay, delay jitter and packet loss are the metrics used to assess Quality of Service by Charfi *et al.* for their research on high throughput WLANS [21].

We concluded that while no specific metric viewpoint should be imposed, as we face a multi-facetted concept

here, we should introduce a *default* viewpoint, which is comprehensive enough to cover most of the use-cases. Hosting this default viewpoint on a public Wiki platform would enable different researchers or businesses to define their own portal, hierarchy or viewpoint upon this unique and comprehensive ontology. As measurement systems must be designed to serve the intended use [22], if the default representation of web of metrics is not suitable enough for a use-case, one can easily produce a custom view to the metric web using the desired combination of the web links to the metrics, to suit the purpose. Big chunks of the hierarchy can be directly adopted without any change by linking to the topmost desired parent node, which makes the work highly re-usable for different use-cases with few clicks.

Now let's have a closer look at the metrics and the contributions which can be made over the state of the art in terms of comprehensiveness and wider coverage of the metrics by the metric ontology. Here we mention the shortcomings seen in the SMI (and in many cases, other classifications) and then in the next section we introduce a more complete novel classification of metrics which address the shortcomings. Because of the limitation in space, only two levels or sometimes three levels of the metric hierarchy are shown out of the four to six existing levels, as we do not plan to present all the several hundred metrics in this article.

Security assessment and secure service provision is still seen as a challenge for cloud computing. The Information Systems Audit and Control Association (ISACA) did a survey and found that 45% of those taking part in ISACA's first annual IT Risk/Reward Barometer survey feel quite concerned about the risks of cloud computing [23]. Just 10% of respondents' organizations planned to use cloud computing for mission-critical IT services and about one in four (26%) did not plan to use it for any IT services [23]. To assess the security aspect of cloud with enough metrics and to perform a proper analysis of how these metrics relate to one another through an ontology is an improvement opportunity over state of the art.

Our Security category is richer than SMI in terms of holding more comprehensive security sub-categories while a number of what SMI categorises under *security* are in fact a small part of the large under-investigated category we call *assurance*, which should be separated (see Section V).

Assurance, concerned with undeliberate threats, does also contribute to lack of trust among potential clients. "Risk" is the only part of the "Assurance" super metrics represented by SMI, pointing to another improvement opportunity.

As we can see in Fig. 2, Carnegie Mellon SMI has reduced a huge "Business" category of metrics (super metric) to merely a "cost" category. This is not enough and is yet another improvement opportunity.

In our view, it is neater to refer to the *raw* capabilities of the cloud (such as CPU clock speed, MIPS or FLOPS speed) as "Performance" and to categorise *the way the cloud can utilise the raw resources* as "Usability".

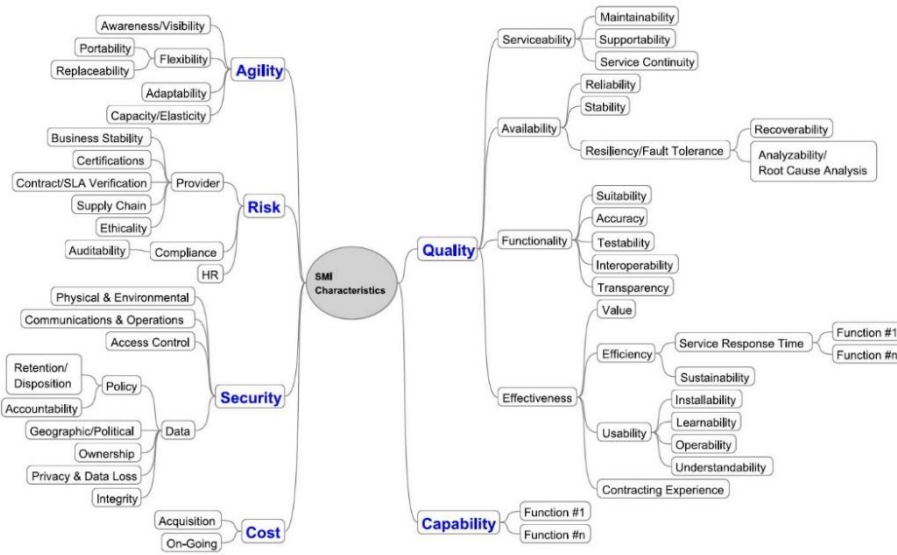


Figure 2. SMI categorization by Carnegie Mellon University.

In SMI (see Fig. 2), “Capability” represents existence of a number of functions, each of which is in fact a way the raw resources of the cloud can be used in a specific functional form, which is a part of the “Usability” in our ontology. SMI also has a usability group under effectiveness which is itself under Quality. Therefore some parts of the SMI “Quality” partially captures “Usability” and the other parts of the SMI Quality such as Availability captures raw resource metrics which we categorise in the ontology as “Performance”. SMI realisation of Quality is partially good as the term Quality is referred to in the research literature and business use cases frequently, but aren’t security, business, assurance and ... all qualities which we expect from the cloud? Therefore, we think the following top-level classification is a better default view for the ontology with more coverage (as will be shown):

**Quality (or QoS):** a holistic term including all the six metric categories: Performance, Usability, Security, Assurance, QoE/Environment and Business.

**Performance:** raw resources and technical capabilities of the cloud (bare-metal inclination of metrics)

**Usability:** the way the raw resources and technical capabilities are used in the cloud (the *qualities* which help you to use the raw cloud resources for computation and put it at the service of the client).

**Security:** the *qualities* which *secure* you (your data/software) in the cloud, by taking care of the deliberate threats.

**Assurance:** the *qualities* which *assure* you regarding the cloud function, by taking care of undeliberate threats.

Please see Fig. 3 for the definitions, including the definitions of the fifth and sixth categories.

|                         |  |
|-------------------------|--|
| 1 - Performance         | , a super-metric of the resources and technical capabilities we have in the cloud  |
| 2 - Usability           | , a super-metric of how we utilise the resources and technical capabilities we have  |
| 3 - Security            | , a super-metric of how we avoid deliberate harm   |
| 4 - Assurance           | , a super-metric of how we assess different sorts of self-harm in the complex cloud ecosystem to inform (assure) the cloud clients and assist the cloud provider managers with preventing harm |
| 5 - Environment and QoE | , a super-metric of the external aspects surrounding the cloud   |
| 6 - Business            | , a super-metric of higher level external or internal aspects of the cloud in close relation to the market   |

Figure 3. A snapshot of the entry-point to our metric ontology (web of metrics, in a custom Wiki format).

#### IV. NOVEL CLOUD ANALYTICS MODEL: DESIGNED PROCESS FOR ACHIEVING ADVANCED ONTOLOGY-ENABLED CLOUD ANALYTICS

Ontology of cloud computing metrics can provide a thorough understanding of what can be measured and what are the attributes of the metrics. To put the ontology to business use will be the next step.

A novel model for cloud measurement should put forward an ontology of metrics and the process/rules using which such ontologies can effectively be created and evolved without suffering from the mentioned shortcomings. The model should also pave the way of metric ontology use by realizing the rules governing an effective use of the ontology, from software manifestation to business use (gaining return on investment).

A part of the novelty of the model lies in its high regard for the business side and its facilitation of fast-tracking of cloud metrics added to the Wiki (by the research community), to the BI/ERP/BPMS software which consume the up-to-date Wiki (ontology) and put it to effective daily use by enterprises. This is a business contribution in harmony with collective intelligence and crowd sourcing.

Regarding the model, there are a number of questions and challenges to be answered, which give rise to a *process* using which the ontology is created and used:

**Ontology language/format:** different languages can be considered for the specification of ontologies, including DAML, OIL, RDF and RDFS, WSML or OWL [20]. The ontology languages such as OWL (Web Ontology Language) have a higher expressive power than the simpler knowledge representation structures such as Semantic Nets (information graphs with information associated to nodes and edges), but development and usage of such ontologies is more time consuming. For the first stage of the project, there will be no desirable use of such higher expressive powers languages such as OWL. The solution would be to start with the light-weight yet information-rich ontology (such as a semantic web defined on a wiki) and transform it to more complex ones when a good use of such expressive power is sought (use of theorem prover, ...). The process of initiating and evolving an ontology should take this into account (see Fig. 4).

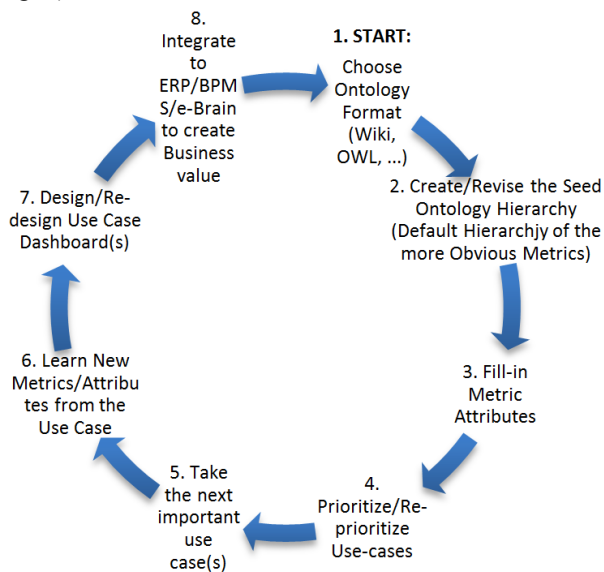


Figure 4. Novel cloud analytics process: *Continuous* (multiple-iteration) process to achieve a novel analytics and measurement model in form of a *useful* and *valuable* metric ontology. Some of the eight steps are skipped where not applicable to the iteration concerned, e.g. a decision to change the ontology format does not happen frequently and the creation of seed ontology may therefore be omitted if a new format has not been chosen. The other example is where there's an importance tie or a dependency for "next important use case", in which case a group of the cases are chosen in the concerned iteration.

**Ontology ease of use:** we implement the light weight ontology on a Wiki, which means it can be developed from different sites around the world by different developers/researchers and it can be fed into the BI and

other kinds of software instantly as it is developed. It is easily produced and is an easily consumable solution.

**Ontology attributes for the metrics:** the metric attributes should represent the more static aspects of each metric such as formulation complexity as well as the dynamic aspects such as the metric trend. A metric node in ontology has 30+ attributes.

**Ontology's scope and coverage:** the ontology is aimed to be comprehensive enough to cover different use-case, from the viewpoint of client, provider and regulator of the cloud services. It covers issues from performance and usability to security and assurance. Business and QoE and environmental aspects of the service provision are also covered.

The ontology creation and evolution process support a wide coverage ontology created based on use priority (steps 4 and 5 of the process in Fig. 4).

**Revisiting the metric ontology's advantage over the existing metric categories and metric systems:** the first contrast is comprehensiveness of the different measurement categories through the inclusion of the viewpoints of different entities interested in cloud service quality, as we mentioned.

Other more limited models suggested for cloud measurement can be specific to an aspect of cloud such as SLAs or can be specific to a certain approach of measurement such as Wu *et al.* [24] which breaks down the model of SLA measurement to four consecutive stages of Quantization, Grading, Normalization and Weighted Summing of user/provider metrics in different cloud layers (29 parameters in total for calculation, from CPU capacity to Privacy).

The second point of contrast is a design suitable for fast-tracking technical developments and scientific studies of metrics to the business level and to put it to enterprise use. Consumption of the ontology by Business Intelligence enabled software and enterprises and by ERP systems right from the development Wiki is supported. To support this, the first point of contrast we mentioned earlier should have existed and the whole design should be fine-tuned. An example of business use of the ontology appears in Section VII.

**On the metric ontology's business advantage:** the phrase to summarize this is 'decision making at different levels and for different uses'. From automated decision making by the cloud monitoring software or the BI-informed meticulous decision by business consultants in the cloud service sector (provider view) to deciding what service to use from which provider and how (client view) to decide how to govern and standardize and regulate the cloud service market (regulator view), a reliable and comprehensive measurement model is designed and implemented in form of an ontology and is ready to be put into practical use.

## V. A NOVEL CLOUD ANALYTICS MODEL: ONTOLOGY IMPLEMENTATION (WEB OF METRICS)

Fig. 3 shows the first Wiki page, the entry point for the *web of metrics*, including the top-level metric categories

we call *super-metrics*, which can be drilled down to lower level metrics (four to six levels deep).

We call these metric categories *super metrics*. It is important to note about the super metrics:

1. It is useful to add the whole category (super-metric) by a click to analysis dashboards, based on the usefulness of their underlying metrics. Those of their sub-metrics which are not required may be un-ticked.

2. We have different *views* towards the ontology for any (group of) *use case(s)*. While an ordinary metric can become *super* (*topmost* level) in a *customized view* based on its usage/importance for specific use case(s), in the default view, the *hierarchical* superiority is often the basis to determine these topmost super metrics. Simply, they are the most general metrics and are the hierarchically topmost *composite metrics*. Occasionally, important and popular metrics may be placed one level higher to make them more accessible when browsing the ontology.

3. We have seen researchers missing useful metrics relevant to their goals as they do not use a well-defined thorough default categorization of the metrics. To rely only on one's own knowledge of the concerned field (e.g. security) is not usually the best option. Sometimes risks arising from both *Security* and *Assurance* issues (each corresponding to a super-metrics) are not well distinguished and thoroughly represented as the researcher inclines towards the one they better know (which is usually *security*).

**Composite metrics:** metrics consisting of a number of other metrics. Super-metrics are composite metrics, while most of the composite metrics are not super-metrics. Usually, the value of a composite metric is calculated based on the directly underlying metrics.

The super metrics are the default first layer. They are numbered, as well as their sub-metrics, to make tracking of and reference to the metrics easier.

#### A. Metric Descriptions

Following are the first two levels of the ontology metrics out of the few hundreds of metrics categorized in totally six levels.

Going through every new use case usually adds a number of new metrics to the group and can sometimes result in re-arranging the default metric hierarchy of the ontology.

**On the selection criteria, rationale and validation:** in a nutshell, the rationale is to have as much useful metrics for the business (client/provider/regulator) as we can, to support a wide range of use cases. Every useful metric is added, while obvious metric compositions or the redundant ones are not selected (e.g. some of the *y* per *x* sort of metrics, such as *clients joined per hour* while we already have the per *day* one. Or better: we add the per *time unit* one instead of all). The validation is done by being able to design the use scenario for the business and provide the argument why it works. The validation reaches its peak when some businesses implement and use the scenario and the benefits are measured rather than justifiably argued.

**Measurement formula:** each of the following metrics has thirty-five attributes including the metric formula(e), which are populated (given value) in the metric Wiki.

**Example proving existence of novel business use in the extra metrics compared to the rivals:** the metric number 4.11.1 has been explained in terms of the formula and validation (business use scenario and the associated arguments) in Section VII of the paper.

The *Performance* super-metric consists of the following metrics (1.2 means the second sub-metric of the super metric number 1 in the default hierarchy of our metric ontology):

- 1.1 Load Balancing
- 1.2 Scalability
- 1.3 Elasticity
- 1.4 Main Hardware Parts
- 1.5 Throughput
- 1.6 Response Time
- 1.7 Performance Agility of the Cloud
- 1.8 Application-oriented Benchmarks
- 1.9 Task-oriented Benchmarks
- 1.10 Operating System
- 1.11 Cloud Load (Committed Resources)
- 1.12 Available Resources
- 1.13 Machine Type
- 1.14 Reserved Resources

The *Usability* super-metric consists of the following metrics:

- 2.1 User-friendliness of the Interface
  - 2.2 Cloud Availability
  - 2.3 Cloud Provider Availability
- Examples:
- 2.3.1 Support Level/Quality
  - 2.3.2 Service Continuity
  - 2.4 Flexibility
  - 2.5 Usability Agility

The *Security* super-metric consists of the following metrics:

- 3.1 Cloud Access
- 3.2 Data Encryption
- 3.3 Security Gateway
- 3.4 Cloud Hardware Environment Security
- 3.5 Cloud Management Environment Security
- 3.6 Vulnerability Management
- 3.7 Security Incidents Index

The *Assurance* super-metric consists of the following metrics:

- 4.1 Reliability
- 4.2 Disclosure Balance
- 4.3 Legal and Moral aspects
- 4.4 Updates
- 4.5 Unplanned maintenance
- 4.6 MTTR (Mean Time to Recover)
- 4.7 MTBF (Mean Time between Failures)
- 4.8 Data Integrity
- 4.9 Assurance Agility
- 4.10 Cloud Service Insurance
- 4.11 Trust Marks, Such as:
  - 4.11.1 Elasticity Trust Mark (the definition, measurement method and use of which will

be explored as an example in Section VII, showing its novel business use as a sample of the numerous useful metrics not found in rivals)

#### 4.12 SLA

The *Environment and QoE* super-metric consists of the following metrics:

- 5.1 Internet/network service delivery chain
- 5.2 Cloud Readiness of Clients
- 5.3 Client machine performance
- 5.4 Usage date/time/place

The *Business* super-metric consists of the following metrics each of which is itself a big category. The categorization is to some extent parallel to the ITIL (Information Technology Infrastructure Library) service life-cycle stages.

- 6.1 Business Design
- 6.2 Business Strategy
- 6.3 Business Operation
- 6.4 Business Change
- 6.5 Business Evaluation

#### B. An Overview of the Ontology Node Attributes

To create a simple ontology we need the ontology nodes (metrics) and node relationships and the metric attributes defined for each node. There's no need to make it more complicated at this stage, as there's no considerable desired usage for the further ontological complexity and high order logics anytime soon in BI/ERP/BPMS applications. As the web of metrics shows the relationship between metrics, we continue by defining the attribute structure of the ontology nodes (metrics), which are added and populated for every metric in the web of metrics.

Besides the categorical (hierarchical) metric relationships in the web of metrics, the attributes 7 and 8 also define another type of relationship between metrics (another type of *edge* between *nodes* of the ontology *graph*): the calculation relationship. The *Hierarchical relationships* shown in the links of the web of metrics do not always capture *calculation relationships* (we say not always, as in many cases a weighted sum of the underlying metrics is a good approximation of the parent metric in the ontology, making it an easier hierarchical calculation).

Every metric link leads to an attribute page of the following format plus the links to the sub-metrics of the metric (shown in form of a metric code and a metric name clicking on which leads to a page with similarly structured attributes plus sub-metrics page). Given the node relations (metrics linked together on the wiki) and the attribute definitions for each node, the ontology of metrics is formed.

Attributes can be *dynamic* or *non-dynamic*. Dynamic attributes, such as the metric *trend*, change based on the metric value, while non-dynamic ones such as the *metric description* change occasionally (usually by human).

The selection criteria for the list of attributes is novelty and business use together with preserving the comprehensiveness of the ontology. We do not omit attributes just because a smaller group of users may use

them (because in that case the ontology would not support the relevant use cases well), but to the contrary, a mindful expansion of the attribute structure is recommended as an avenue for future research.

The novel attributes structure for each metric:

##### 1. **Metric description** - non-dynamic

Description in few simple and concise sentences.

##### 2. **Formula(e) or calculation algorithm(s) for the metric** - non-dynamic

Description precisely turned into one (or more) precise calculation ideas.

##### **Novelty/use:**

1) There can be more than one formula which we allow to be selected for the calculation.

2) Sometimes the calculations can be complex and a reference to the calculation code (algorithm) is provided here.

##### 3. **Relevance to the cloud layers:** - non-dynamic

We define four flag attributes (on/off) for cloud metrics in the Ontology, making it corresponding to: BPaaS, SaaS, PaaS and IaaS. A view based on this categorisation will be one of the many usages.

**Novelty/use:** automatic categorisation of metrics (layer-wise)

##### 4. **Weight in processing tasks** - non-dynamic

For example, what is the weight/importance of memory latency (node) to Online Transaction Processing tasks. It may only be one default/average weight at the beginning for different tasks. Later, it can include a case-based list of weights.

The default weight can be set in comparison to the weights of the metrics at the same hierarchical level.

##### **Novelty/use:**

1) Automatic calculation of the parent metric from the underlying metrics based on the task at hand (weighted average)

2) Also it can be used to prioritize metrics.

##### 5. **Weight for a SaaS or private software** - non-dynamic

For example, what is the weight/importance of memory latency (node) to SAP BI software. Can be default/average weight or a one-by-one list of weights.

**Novelty/use:** metric prioritization, automatic metric suggestion for specific use

##### 6. **Formulation complexity** - non-dynamic

An idea of the level of complexity of the metric: Low, Average, High, Very High.

Example: the metrics which have a formula constituting of more metrics, or those which are not easy to quantify are examples of more complex metrics, such as Elasticity Trust Mark (will be discussed in details in Section VII).

**Novelty/use:** prioritization, automation

##### 7. **Nodes which are used in this node's formula** - non-dynamic

Node IDs to be mentioned.

**Novelty/use:** metric calculation, ontology structure outline, metric use/importance statistics

##### 8. **Nodes which use this node in their formula** - non-dynamic

Node IDs to be mentioned.

**Novelty/use:** metric calculation, ontology structure outline, metric use/importance statistics

9. **Strengths of the metric** - non-dynamic

**Novelty/use:** part of the concise metric SWOT analysis.

10. **Opportunities associated with the metric** - non-dynamic

**Novelty/use:** part of the concise SWOT analysis.

11. **Weakness of the metric** - non-dynamic

**Novelty/use:** part of the concise metric SWOT analysis.

12. **Threats and risks of the metric** - non-dynamic

**Novelty/use:** part of the concise SWOT analysis.

13. **Target for the metric if any** - non-dynamic

What threshold is assumed to be excellent/good/bad/disastrous, given the metric calculation? Default/usual target or a case-based list.

**Novelty/use:** automatic metric monitoring and alarms, automatic decision making

14. **QoE flag** - non-dynamic

Whether a metric is in QoE category or not (Yes/No).

15. **Service phase** - non-dynamic

Describes which service lifecycle phase a specific process is primarily associated with (based on ITIL: service strategy, service design, service transition, service operation and continual service improvement).

**Novelty/use:** ITIL support (especially good for businesses the services of which are run based on ITIL)

16. **Processes** - non-dynamic

Describes the associated key business processes, relevant to the metric, within each aforementioned phase of the ITIL service lifecycle (each phase has a number of relevant processes to each of which a number of metrics can be associated. We are interested in the cloud analytics aspect of these metrics).

**Novelty/use:** ITIL support (especially good for businesses the services of which are run based on ITIL)

17. **Link to other processes** - non-dynamic

We should explore and document how relevant processes 'may' link to other service processes within different lifecycle phases.

**Novelty/use:** ITIL support (especially good for businesses the services of which are run based on ITIL)

18. **Roles and responsibility** - non-dynamic

**Novelty/use:** for the purpose of offering various analytical lens through a BI tool, we should be mindful of who to present what metrics, with what level of details. If we identify who would be responsible for various service phase processes, it helps us to automatically suggest the information to display at various managerial/user levels, which can then be customized further by the manager/user.

19. **Critical success factors** - non-dynamic

These are the factors relevant to the *healthy* value of the metric which is vital to the success of service execution in an organisation.

**Novelty/use:** the healthy metric value (which should be defined in terms of numerical criteria such as a threshold) is linked to the successful execution of the relevant services which is important for business success.

20. **Business focus flag** - non-dynamic

This acts as a checkbox to report whether the metrics is primarily business-centric.

21. **IT focus flag** - non-dynamic

This acts as a checkbox to report whether the metrics is primarily technology-centric.

22. **Service provider flag** - non-dynamic

This acts as a checkbox to report whether the metrics is primarily service provider-centric.

**Novelty/use:** supporting the 360 degrees view of the metrics encompassing the service provider, service client and the service regulator.

23. **Service client flag** - non-dynamic

This acts as a checkbox to report whether the metrics is primarily service client-centric.

**Novelty/use:** supporting the 360 degrees view of the metrics encompassing the service provider, service client and the service regulator.

24. **Service regulator flag** - non-dynamic

This acts as a checkbox to report whether the metrics is primarily service regulator-centric.

**Novelty/use:** supporting the 360 degrees view of the metrics encompassing the service provider, service client and the service regulator.

25. **Metric ITIL flag** - non-dynamic

The Information Technology Infrastructure Library (ITIL) is a set of practices for IT service management (ITSM) that focuses on aligning IT services with the needs of business.

This indicates the source of the metrics, which is 1 (true) if the metric is directly taken from ITIL.

26. **Ease of calculation** - non-dynamic

How easy/hard it is to calculate the metric in practice: Easy/Intermediate/Hard.

**Novelty/use:** one novel use is in calculating the time complexity and required time of updating the metric value updates. Some metrics such as Elasticity Trust Mark are calculated using a rather complex code instead of a simple formula, as will be mentioned in Section VII, while a regulator might need to update many of such metrics based on AI and statistical time series functions for many service providers. In this case knowing the time it takes may be useful.

27. **Tolerance for variation from target** - non-dynamic

**Novelty/use:** tolerance criteria and thresholds for variation of the metric from the Target, if any target is set at all, can help with automatic alarms and automatic decision making (to be used by the organizational ERP, BPMS or Artificial Brain for Management system).

28. **Metric code in the default ontology hierarchy** - non-dynamic

**Novelty/use:** a unique metric identifier label including the default hierarchical classification, Such as 2.5.1 (namely first sub-metric of the fifth metric of the second super metric in the ontology).

29. **Frequency of measurement** - non-dynamic

How frequently the metric is measured: nano-second, micro-second, millisecond, second, minute, hour, day, week, month or annual.

**Novelty/use:** auto alarms / auto decision making.

### 30. **Range for the metric** - non-dynamic

Validity range of the result of metric assessment, in format of a set such as: [1, 100] or [Low, Med, High]

**Novelty/use:** validity checks

### 31. **Variance from target** - dynamic

Variance of the metric from the Target (if target is set).

**Novelty/use:** helps with automatic alarms and automatic decision making.

### 32. **Metric status** - dynamic

Whether a metric is within the *desired* range or not (Green/Red). A marginal status may also be defined (Orange/Blue for a metric value which is marginally outside/inside the desired range)

**Novelty/use:** helps with automatic alarms and automatic decision making.

### 33. **Metric trend** - dynamic

Metric trend in form of a number (preferred) or desirability colour (Green/Red). A marginal status may also be defined (Orange/Blue). In the dashboards, the number and colour can be both shown (imagine a car speedometer with coloured areas).

**Novelty/use:** helps with gauge visualizations, automatic alarms and automatic decision making.

### 34. **Measurement time-stamp at source** - dynamic

Measurement time for the metric at the measurement source (machine), which can include the date as well.

**Novelty/use:** helps with keeping a more complete metric log/history and with automatic decision making.

### 35. **Measurement time-stamp at destination** - dynamic

Measurement time for the metric at the point where the measurement is recorded (perhaps a BI database), which can include the date as well.

**Novelty/use:** helps with keeping a more complete metric log/history and with automatic decision making.

## VI. A NOVEL CLOUD ANALYTICS MODEL: HOW CAN ENTERPRISES BENEFIT FROM THE MEASUREMENT MODEL AND THE WEB OF METRICS

Web of metrics has also brought the idea of introduction of monitoring systems built based on a comprehensive metric ontology, to a widely used Business Intelligence system such as IBM Cognos or an ERP/BI system such as the one produced by SAP (also BPMS group of software). This way a massive number of clients and businesses who already use such popular software, can integrate cloud service analytics to their business decision making tools. Each business as a whole, the business units, or every executive individually can get a customized dashboard according to their need, a customized hierarchical view towards the metrics, serving specific use-cases relevant to different roles within each business/department/job. This is a requirement [22] which other cloud measurement alternatives [18], [19] do not seriously consider, which limits their usability.

For every business, a route leading to Quality of Service excellence should be carefully taken by benefitting from advanced analytical means such as web of metrics and the BI/ERP/BPMS tools which support it:

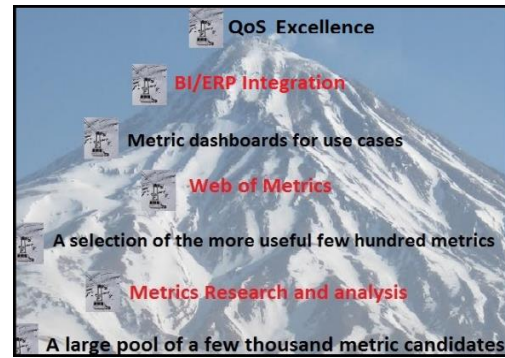


Figure 5. A route to the quality of service excellence peak.

The following explanations help with understanding Fig. 5:

**Metrics Research and analysis:** determining the relevant metrics that can be exploited effectively from a pool of thousands of candidates.

**Web of metrics:** constructing interconnected *relationships* between metrics and creating the *attribute set* for each metric is central to the production of a wiki-based ontology which can be used for monitoring, analysis and control software. It is based on a model which bridges the cloud measurement and analysis divide from the technology to the business.

**BI/ERP Integration:** we have identified the need to focus efforts on developing software which, will assess Cloud service environments, present it in dashboards which can be drilled into, and pro-actively comes up with suggestions for improvement of the services or actions which can be executed, through a business control system (ERP/BPMS), which it has been integrated to.

**QoS Excellence** is eventually possible through the analytical Brains, the next generation of the present BI, ERP and BPMS software which integrate many algorithms to gain further advantage over such classic software. IBM's Watson seem to follow the same route of excellence in future, but it has not been used for such a thorough support of the cloud computing analytics yet. IBM's acquisition of the SPSS company (SPSS has a large tool-box of statistics, AI and time-series tools applicable to BI data) and its heavy investment on Watson shows that enterprises active in the BI field may gradually move towards creating the more complete Artificial Brains.

**Problem of Different Ontological Viewpoints:** there is different viewpoints towards what a useful hierarchy of metrics is and what attributes of which metrics is needed. This arises from different business and technical needs and the different experience of people who want to use the metrics.

**Ontology Customization and Pattern Recognition Tool:** to solve the problem of different ontological view points, and to solve it in a fast manner, it is good to provide a customization tool to help ontology users define what they want from the ontology for their use-case(s) in a self-service fashion.

The tool can recognize common customization patterns and provide a default offer of customization based on

asking a number of questions in the first step. In the next steps, the offer can be taken or further customized.

Benefits of metric ontology integration to Business Intelligence tools:

- Wide *usability*, high *user-friendliness* and wide *compatibility* across a large number of businesses/uses through the renown BI tools (which can often be programmed to use the ontology)
- Providing cloud service analysis *dashboards* for *fit-to-purpose* analytics serving different *business levels and roles*: companies, departments and individuals
- Integrated access to *mathematical and statistical tools*, for example for Time-series Analysis
- Integrated access to *Artificial Intelligence tools* which help with suggesting metric-aware business actions, which can be executed through a business controller system (ERP, BPMS or Artificial Brain for Management)

## VII. BUSINESS USE EXAMPLE

A simple example of a metric ontology informed action<sup>2</sup> in such a *Pro-active ERP/BPMS system we have mentioned*, which benefits from the metric ontology integration, is to call the reserve *phone sales* staff of an e-tailer (online retailer) via the ERP software automatically if the BI analysis of the cloud metrics anticipates a cloud service outage for some time. Time series analysis, statistical tools or artificial intelligence tools within the BI software can be used to analyze the metric information. As *customer satisfaction* is the second most important business driver (after *product value*) for some of the e-tailers such as the electronics e-tailers, it is important for the e-tailer business (run on a cloud) to take necessary pre-cautions. Customer satisfaction is at risk if a cloud service outage results in online orders to be served via long queues of phone sales. Development of such pro-active systems taking care of such situations (e.g. calling reserve staff when needed or make other required decisions) based on thorough analysis of many metrics, will be necessary for the next generation of BI/ERP/BPMS systems which we call Artificial Brain for Management. The idea is not limited to the cloud analytics and the cloud-relevant ERP/BPMS actions and will probably be a major interdisciplinary research (and practice) route in fields such as Artificial Intelligence, Business Intelligence, Enterprise Resource Planning, Business Process Management Systems, Business Transformation and e-Government.

More sophisticated examples could also be introduced. We introduce a group of them here to shed more light on the sort of business uses which the ontology is able to support.

Use cases which put the ontology to practice can be categorized to low-level and high-level. While a low-

level use case is concerned with low level performance metrics usually used in close connection to the hardware and in resource monitoring systems, high level use cases represent the use of metrics for business, legal or complex technical purposes. Here, we provide an example of how the ontology which is implemented based on the model can be used for addressing high-level business problems less addressable by the rival metric categorizations and taxonomies: the problem of *trust*.

One of the advantages of using cloud services which needed for the daily operations of a business is to serve sudden service request jumps, for example as a result of an ad going viral. *Elasticity* is a second level metric (a sub-metric of the 'Performance' super-metric) in our metric ontology which measures this and can be calculated from the underlying lower level hardware-related metrics in the metric hierarchy. Sometimes a weighted average of the underlying metrics simply gives us the number for the higher-level parent (the precise formulae appear in the web of metrics). Then, the calculation can be made consumable to enterprises by being turned into an *Elasticity* trust mark metric (a part of the "trust mark" metric which is itself classified under the *Assurance* super-metric).

The umbrella *trust mark* sub-metric in the *Assurance* super-metric covers this group of specific cases relevant to *trust*. The ongoing trend of ontology extension for covering different use-cases is a part of our novel model for cloud computing service measurement. The model accounts for the multi-faceted, use-case-rich and multi-entity (client-provider-regulator) concept of measuring the service.

Trust marks are on/off metrics, the value of which can be determined in a static (long-term) or dynamic (real-time) form.

To know whether to give a company an Elasticity trust mark badge or not, the trend of cloud load in the past should be considered and the probabilities of demand jumps in the future calculated. First derivative, second derivative, third derivative and ... of the cloud load for different cloud parts (RAM, HDD/SSD, Network, CPU) can tell us the probability of not being able to accommodate for future demands based on the present growth, while we can also consider the information fed-in by the company consultants (for example, special circumstances such as the time an ad, which might go viral, is being placed and may affect the calculation if not properly considered). This, when formulated, provides an estimation of *the chance of not being elastic enough* to serve the client needs *in the future x units of time*.

From the business and marketing point of view, by determining the right probability and number of days, for example by:

"Ensuring the chance of failure to provide required elasticity is below one in a million for every *ordinary* company which is hosted in the cloud for ten years"

we can tell clients/providers that when you get this Elasticity trust mark, it means *you have airplane-level safety* regarding demand jump risks (airplane-level safety coming out of six sigma management, which might be

<sup>2</sup> By "metric ontology informed", we mean the analytics based on the ontology's metric hierarchy, the associated metric value recordings in the concerned cloud(s) and the other values from *attributes*.

translated into failure chance of less than one in a million).

To go all the way from technicality of the hardware to the business and marketing advantage of trust marks would require formulating and defining a number of factors and game determiners, but the model and the developed ontology supports this *out of the box* by appropriate additional metrics, attributes and the usage flexibilities of a Wiki based ontology. All in all, this is an advantage over the aforementioned rival metric sets and the corresponding over-simplified models.

The Elasticity trust mark badge will be the topmost and the only part of this business use case's dashboard. It can appear for example on a cloud provider website and can be drilled into by clicking on it to see the underlying parts and the calculations inside. At this level, there's no complex BI automation or automatic customization. We have just shown how the ontology can be practically useful for business.

Although the *Elasticity* concept is open to definition and therefore sensitive to the specific use/context at hand, a basic and common definition is: "The ability of system to effectively accept 'sudden' resource demand jumps", for example demand jump as a result of an ad going unexpectedly viral. This concept may be formulated this way in the metric ontology:

$$\text{Elasticity} = (\text{Reserved Resources} / \text{Committed Resources}) \times 100$$

The resources are assumed to simply be CPU, RAM, HDD and Network. The amount of these resources can be summed up (weighted sum) to calculate the total.

Now, after all this, we have to address the question of how much "reserved resources" are enough to give us the *Elasticity* sort of *Assurance* (represented by an Elasticity trust mark), resulting in trust mark badge eligibility. This will guide the *cloud service provider* to avail the required resources to keep its trust mark badge.

In summary, the probability of a company, hosted in the cloud, facing an Elasticity failure, during every  $x$  years, should be less than one in million. We calculate the probability using the 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> (and so on) derivatives of cloud load data over time. It tells us the realistic worst case for demand jump based on the historical load data. Challenges which arise:

- 1) **Problem:** Creating toy companies can cheat the system as they don't have failures.  
**Solution:** give "weight" to the companies or define an "average company".
- 2) **Problem:** Young clouds without enough data are hard to predict  
**Solution:** Wait for the cloud to work for few years under supervision to give it a trust mark badge or perform qualitative research and give a provisional badge.
- 3) **Problem:** Mathematical problems such as this one should be solved: "Relying on witnessing a long record of consecutive numbers and assuming it is reliable to predict future, and by calculating the

discrete derivatives (1<sup>st</sup>, 2<sup>nd</sup>, ...) of this number list, which shows growth patterns, what is the probability that a number greater than  $x$  appears in the next  $y$  numbers?"

**Solution hint:** Peak Demand Forecasting is a similar research route which has previously been explored in fields such as Inventory Management (in Operations Research) and Network Infrastructure demand forecasting. There also exist similar problems studied in FOREX (Foreign Exchange) Analysis.

In Inventory Management, there are variables which resemble the reserved resources concerned by Elasticity in cloud computing: Item Ordering Costs, Item Holding Costs, Ordering Lead Time and Item Shortage Cost.

Peak demand forecasting does not solely focus on the highest feasible demand level but on the range and likelihood of all feasible levels that demand might peak at in any given period [25].

So, toy companies mentioned in challenge number 1 are translated as (deliberate) *noise*, young cloud data scarcity in challenge number 2 go to the *forecasting with less historical data* and the math problem mentioned in challenge 3 will find its siblings in the literature, e.g. *forecasting literature theorems*.

There are also heuristic ways of estimating the probability of hitting certain cloud load jumps, without precisely calculating it from the past data. For example, the variables of a Gaussian (normal) distribution can be calculated given the past data and any deviation from such a normal distribution is assumed to be noise, i.e. assuming that demand for cloud resources follows a normal distribution (which tells us the chances of hitting a certain jump in demand, which we want to not fail to accommodate unless the chance is less than one in a million for  $n$  companies over  $t$  units of time).

## VIII. CONCLUSIONS AND FUTURE WORK

Apart from addressing the practical forecasting and formulation challenges mentioned in the last part of the previous section, completing the several thousand *attribute* entries of our ontology (about 35 attributes for each metric) can lead us to the next version of the web of metrics, which is expected to stay the leading cloud metric ontology worldwide. We have designed it on an easily extendable Wiki platform. Completing the ontology is possible by linking the relevant papers and research to the ontology's attribute entries and to come up with solutions where there's still no published research to fill in a metric *attribute place holder*. In such cases the attribute can be filled in using surveys and other indirect methods of estimation (preferably crowd source enabled, such that people use the *web of metrics* for research and be encouraged to complete this resource like they complete Wikipedia. Wikipedia is currently much under-contributed in terms of cloud metrics. Introduction of the metric wiki can drive the *Wikinomial* resources to the ontology project).

Quantitative assessment of the results of use of the ontology, and quantitative comparison of usefulness of different its parts (different metrics, different metric attributes), based on the real world implementation of the model across businesses, is an interesting research route which demands vast resources and can be made feasible by popularity of the metric ontology, if (when) it is *used* and *completed* publicly, particularly by the cloud performance community.

We are also working on the application of this research in the Smart City field, including suitability of DLT services and APIs for interoperability and data exchange between stakeholder systems, which is to be reported in subsequent publications.

#### CONFLICT OF INTEREST

There is no known conflict of interest as far as the authors are aware.

#### AUTHOR CONTRIBUTIONS

The research and writing work were primarily done by Armin Shams, while significant advice and editing notes from the other co-authors, is received and used.

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