Counting the Cost of FIRE:

Overcoming Barriers to Sustainable Experimentation Facilities

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Abstract. Sustaining European experimental facilities for Future Internet research is a significant challenge for testbed providers, funding bodies, and customers who depend on their long-term availability. To date, sustainability plans for experimental facilities have been dominated by abstract notions of business value and unclear business models. We argue that this fails to recognise that cost accountability is the critical element necessary to drive efficiency, irrespective of whether revenue is provided from public or commercial sources. Only through cost accountability can facilities make operational management decisions that are aligned with performance metrics and assess the financial viability of business plans. In this paper we demonstrate how cost modelling and usage accounting can be used to support operational and sustainability decisions for a federated cloud experimentation facility.

Keywords: Future Internet Socio-Economics, sustainability, cloud, Future Internet Research and Experimentation, business modelling.

1 Introduction

The research and development of products and services for the Internet is an increasingly complex endeavour. This is especially true for disruptive technologies that impact current Internet business models. Investigating new ideas and verifying and validating systems as they grow in maturity from the laboratory to commercial deployments requires resources that are diverse, distributed, and of sufficient scale to test hypotheses and assumptions. The European Future Internet Research and Experimentation (FIRE) initiative offers a novel approach to European testbed provision that moves away from project- and industry-specific facilities to general purpose, reusable, experimentation platforms [1]. Facilities are being created across Europe to support a range of technical domains, from sensor networking to cloud computing and social and networked media [2][3][4]. More complex federations of testbeds supporting system-level research are also being explored [5]. FIRE projects bring together largely existing national assets and establishes advanced mechanisms to access and use those assets on a European scale. In essence, the investment creates a European

dimension for national facilities, enhancing their potential through new types of use and a broader range of users.

A common challenge for all facilities is to sustain a service offering to European researchers beyond the lifetime of the project funding. Sustainability requires a business model that can attract sufficient revenues to pay for the costs associated with a service over a target period. This does not imply a commercial business or “self-sustainability” where revenues are exclusively acquired from paying customers. Previous attempts to establish commercially-operated FIRE testbeds have been explored [6] but, to date, no such service has been launched. We recognise that research infrastructures such as FIRE cannot be operated purely on a commercial basis due to their complex and federated nature and the need to support fundamental research [7]. The challenge of sustainability is not unique to the FIRE programme; for example, EGI has developed funding structures to ensure long-term European-scale continuity [8].

Until now, the sustainability debate is almost exclusively focused on a qualitative assessment of business models: Who are the customers? Who is going to pay? What do customers want? The FIRE roadmap comments on financial aspects at a superficial level but fails to provide a cost structure or quantify costs in any way [9]. However, no business model can be investigated unless financial aspects such as cost structures and revenue models are developed, quantified and explored. Managing the cost performance of a business is an essential element, irrespective of whether it is commercially or publicly funded. We argue that the lack of cost accountability and operational performance monitoring is a major barrier to sustainability because:

- budget holders and potential investors do not have the necessary information to assess viability of business plans; and
- testbed providers do not have the decision-making tools to control costs and achieve satisfactory levels of operational performance to meet their targets

In this chapter we present a method to demonstrate that cost accountability, operational performance and business-planning tools deployed within the lifetime of a FIRE project can provide valuable insight into sustainability beyond the lifetime of the project. The work is being conducted in the BonFIRE project, which offers a multi-site experimentation service for research and development of novel cloud and networking products and services. In Section 2 we describe the value propositions for a cloud experimental facility and a strategy for transitioning revenue flows from investment to demand-driven payments. In Section 3 we describe the cost model for Testbed-as-a-Service (TaaS) and then how the model is used to build a cost accounting system for a federated facility. In Section 4, we show how the cost accounting model can be used to support operational performance decisions for the facility. Finally, in Sections 5 and 6 we describe our future work and conclusions.

2 A Value Proposition for a Cloud Experimentation Facility

The BonFIRE value propositions have been studied using value chain analysis in conjunction with Ostewalder & Pigneur's Business Model Canvas [10]. The primary proposition is an outsourced on-demand testbed infrastructure offering four key

capabilities: control, observability, usability and advanced cloud/network features (including cross-site elasticity, bandwidth on-demand). Uniquely, the facility offers capabilities to allow customers to explore cross-cutting effects of applications, clouds and networks, and to control and observe the behaviour of physical and virtualised infrastructure in ways that are not offered by existing public cloud providers. Capabilities are designed for testing and experimentation, rather than production runs, aimed at customers who do not have sufficient capital or requirement for long-term investment in dedicated testbed facilities. This includes SMEs, academic researchers, and research collaborations. As such, the facility is not a “mass” market service, but most users are largely self-supporting and the service is not tailored for each customer; this makes for an efficient use of the public investment in these research infrastructures.

We have developed a number of value propositions and analysed them to understand how value is created and flows from service providers to customers. The service delivery models are all built on the rapid-provisioning and self-service paradigm of cloud computing (Table 1).

Table 1. BonFIRE Service Delivery Models

Value Proposition	Description
Testbed-as-a-Service (TaaS)	Multi-site cloud service with testbeds centrally controlled by a broker
Infrastructure-as-a-Service (IaaS)++	The BonFIRE capability as a value-added service to existing IaaS services.
3rd Party Testbed Provision (3PTP)	Multi-site cloud service with testbeds hosted on 3 rd party commercial clouds and public funded facilities
Experiment-as-a-Service (EaaS)	Test and development service providing experiment design, running, and analysis using BonFIRE facilities

Although business model generation [10] and value chain analysis offer effective high-level thinking tools to explore the general attributes of a business model and to prioritise across different scenarios, they do not provide the *quantitative* analysis necessary to monitor and investigate the operating and financial performance of a facility. Facilities need to develop and operate cost accounting systems to explore internal operating dynamics of experiment costs, capacity planning, product mix, investment and, potentially, pricing, so that they can:

- account for, and predict, the total cost for a product (e.g. experiment or test); and
- determine either the level of investment is required from public funding to maintain a certain level of service or to explore possible profit margins if considering commercial business models.

An important challenge is that the investment cost reflected in the price to a customer is generally above what they would pay on the commercial market, and under these business drivers, facilities must constantly find ways to control and reduce costs. This

Fig. 1. Three-phase strategy, shifting the revenue flows

is not something most experimental facilities consider in their operations. Facilities need to understand how costs behave and how they respond to changes in volume, price and product mix.

In the remainder of this chapter we describe the BonFIRE cost accounting system and initial results for the TaaS service delivery model (as described in Table 1). The system is being deployed during BonFIRE's "open access" offer, in which facilities are available to selected users without cost but also without funding, as part of BonFIRE's three-phase strategy (Fig. 1) towards sustainability; this phase provides the opportunity to conduct a business investigation to understand in practice the operating dynamics of an experimental facility.

3 Cost Modelling and Accounting

In a *cost model*, costs are classified into categories, can be organised into fixed and marginal, and are allocated to business activities [11]. For the TaaS service delivery model, testbed providers offer both infrastructure and software services to customers. A testbed provider makes capital investments in infrastructure for compute servers, storage servers, networking equipment and connectivity. They then develop and operate software services supporting the capabilities of a testbed (provisioning, monitoring, etc.). The general activities of a TaaS provider would include: software development, maintenance and support; experiment training and support; infrastructure management; management of partnerships and suppliers.

A cost model, like most models of real world processes, is based on assumptions where ground truth data is not available. In a funded facility project, accurate data is not always available about the resources of each partner. However, we have developed a working model based on initial assumptions, which can be refined either through actual data collections or deeper dialog with domain experts; this enables us to start quantitative discussion about sustainability with related stakeholders.

The cost model we have developed (Table 2 & Table 3) is based on the annualised total cost of ownership for the cloud infrastructure. An inventory of fixed hardware assets is created for each site with depreciation period of three years, costed either based on information from the testbed provider or mid-range market prices. We assume that the total cost of the hardware has to be met by the testbed providers, as this is representative of starting a commercial business. In practice, there are cases where fixed assets are already partially or fully depreciated before entering service in the testbed. Network hardware is assumed at 20% of server costs.

We then consider other fixed costs for operating hardware infrastructure and facility services for each site. Hardware maintenance is assumed at 10% of initial server costs, power is calculated based on a function of nameplate rating, assumed data centre efficiency rating [12] and industrial energy costs for each European country [13]. Network connectivity is assumed at 500Mbps symmetrical leased line for each site. Space costs are assumed to be zero, because testbed providers already operate data centres. Operating system costs are assumed to be zero as the facility only supports Linux/Open Source operating systems.

Staff costs are incurred for systems administration, software development and support. Support costs are estimated at 1 FTE per month for each 20 users and vary depending on usage. Staff salary rates are assumed at market rates. Overhead costs are

Table 3. Annualised facility costs (Capital Depreciated over 3 years)¹

Cost Category	Site A	Site B	Site C	Site D	Site E	Site F	Total
Compute Hardware	7 000	7 497	1 030	3 251	1 353	566	20 698
Storage Hardware	2 777	829	21	2 850	1 036	249	7 761
Network Hardware	1 955	1 665	210	1 220	478	163	5 692
Total Hardware	11 732	9 992	1 261	7 321	2 868	978	34 151
Hardware Maintenance	3 520	2 997	378	2 196	860	293	10 245
Op. System	0	0	0	0	0	0	0
Space	0	0	0	0	0	0	0
Power	23 858	19 259	5 474	10 420	28 355	7 652	95 019
Systems admin	20 081	34 877	9 512	14 796	19 024	6 341	104630
Software development	29 530	29 530	29 530	29 530	29 530	29 530	177182
User Support	21 759	21 759	21 759	21 759	21 759	21 759	130555
Data Transfer	7 460	7 460	7 460	7 460	7 460	7 460	44 762
Total operational	106208	115883	74 114	86 162	106989	73 037	562393
Total Costs	117941	125875	75 375	93 483	109856	74 015	596544

¹ We emphasise that these are illustrations and do not represent actual costs of BonFIRE sites.

allocated to compute, storage, and networking on the basis of 60% of operational costs (excluding capital) are allocated to compute 20% to storage and 20% to networking². The annualised costs for a facility with six sites offering a total of 4.9 Million Core hours and 608600 GB-Months storage per year total €596K (Table 3).

We can see from the cost model assumptions that the headline cost could be subject to significant error and variation between sites. However, the existence of the model allows us to explore the relationships between different cost categories and to help improve the assumptions. Firstly, in the current model almost all costs are fixed costs - the only cost which varies by usage relates to the number of staff needed to support variable numbers of users. Secondly, hardware costs are small in comparison to the staff costs required to operate the service; this is typical of most facilities, and means that, when combined with the self-service model of BonFIRE, the facility can scale (e.g. increasing compute/storage capacity) without incurring significant increase in staff costs. At this level the cost model is useful for long term (annual) business planning, but becomes even more powerful when linked to facility usage data.

Each site maintains a set of physical servers, and each physical server can offer compute and/or storage resources to experimenters. Each compute server has a set of CPU's offering a number of cores. When an experimenter requests compute resources they ask for either a predefined or custom instance type. Each instance type defines a number of cores, the number of vCPUs presented to the guest image, and memory (Mbytes) for each core. An experimenter can allocate a single, multiple, or fractions of a core. Each VM is considered a compute resource and consumes a proportion of the overall capacity.

The *resource model* defines the types of resources and how they are characterised in terms of metrics; currently, we define basic usage metrics: Core hours and Storage GB-months. For example, a VM running for 3 hours with 50% of a core incurs a usage of 1.5 core hours. Having defined our cost model and resource model, we are able to develop tools to analyse and improve the operational performance of the facility.

4 Operational Performance Management

Operational performance management is concerned with tracking, analysing and planning facility operations in a way that maximises efficiency and the value delivered to customers. Service managers need information that can assist them in day- to-day decision-making as they work towards the facility's key performance indicators (KPIs). Key questions for a FIRE facility would include:

- What are the facilities' utilisation targets and have they been met?
- What are the facilities' expected demand patterns over the next month and do we have enough capacity?
- Where should we invest more resources?
- How much will an experiment cost?

² Currently, network usage is not measured. We have allocated network costs to compute costs in our calculations.

Table 4. Weekly snapshot of facility performance using a box score chart

KPI	Site A	Site B	Site C	Site D	Site E	Site F	Total
Operational							
Core Hours Used	2306.63	2785.83	115.869	5458.03	2995.47	0.000	13661.8
Storage Hours Used	5289.05	0.000	0.000	21797.4	21179.3	0.000	48265.9
Core Utilisation	13.202	12.955	2.155	33.842	11.578	0.000	14.47
Storage Utilisation	0.123	0.000	0.000	1.937	1.051	0.000	0.566
# Site Allocations	104	36	9	188	138	0	475
Capacity							
Site Core Capacity	17472	21504	5376	16128	25872	8064	94416
Permanent Core Capacity	17472	21504	5376	16128	25872	8064	94416
Site Storage Capacity	4283328	840000	53760	1125600	2016000	201600	8520288
Permanent Storage Capacity	4283328	840000	53760	1125600	2016000	201600	8520288
Finance							
Cost per core hr	0.78	0.70	10.05	0.26	0.56	0.00	0.67
Cost per storage GB month	63.75	0.00	0.00	12.93	14.87	0.00	34.97
Cost for network	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Costs allocated to core	1806.19	1959.02	1164.06	1411.56	1681.20	1137.67	9159.70
Costs allocated to storage	461.89	461.65	285.45	386.19	431.42	285.69	2312.30

To answer such questions, a facility must define KPIs and relate them to the cost and resource model, whilst continuously tracking KPIs during facility operations. We use a technique from lean accounting called the Box Score Chart to provide a weekly

Fig. 2. Core hour cost vs. utilisation for each testbed site

snapshot of the facility performance [14]. The box score chart incorporates operational, capacity and financial KPIs.

At the centre of the chart (Table 4) we calculate the capacity of each site for the weekly reporting period, for example, Site A offers 17.4K core hours and 4.2 million Storage GB-hours. We can optionally track capacity that is productive (online) and unproductive (offline) due to failures or planned maintenance. We then define operational KPIs including core hours and storage hours used and as a proportion of total capacity. We know from the costs allocated to compute and storage for a given period and therefore we can calculate the cost for core and storage during the week. For Site A, core usage is 2306 core hours, capacity is 17422 core hours and costs of €1.8k, giving 13.2% utilisation for the week at a cost of €0.78 per core hour.

Understanding the utilisation KPIs is a powerful tool to maximise the efficient use of facilities, reducing the cost of experiments and moving to sustainability of the facility. Matching capacity to demand is essential because resources that are not used are a cost. A clear way to see this is from the high level utilisation targets as shown in Fig. 2. Here we see that costs vary between sites largely due to economies of scale,

Fig. 3. Experiment cost distribution for observed experiments in one week

Fig. 4. Monthly forward loads with different distributions of experiment types

where Site C offers less capacity than Site E. We also see that core hour costs reduce significantly between 10% and 40% utilisation but there is a diminishing return for the increase in utilisation beyond 60%. Commercial providers operate at utilisation above 70%, but FIRE facilities are not expected to achieve this.

By incorporating dynamic costs into the model we can calculate per-experiment costs and investigate how these costs change from week to week with the variation in utilisation. Fig. 3 shows a distribution of costs for 400 experiments run in a weekly reporting period. We can see that 95% of experiments cost less than €50.

The previous discussion has focused on the current performance of the facility, but to verify the viability of a business model, “what if” scenarios are needed to explore different future operational conditions. We use business model simulation to investigate the relationship between experiment types, forward loads, utilisation, cost, and revenue.

To do this, we first defined a set of experiment types with varying size and duration ranging from a small 1-day experiment using 10 cores (240 core hours) to a large 1-month experiment using 100 cores (73K core hours).

Using these load types, the next stage was to explore the dynamics of the facility under different forward load scenarios over a monthly period. Fig. 4 shows a set of possible loads with various mixtures of experiment types: for example, Load 1 consists of many small experiments whereas Load 3 is a few large experiments. The goal is to investigate how costs behave for different experiment distributions; for example, we can set a target utilisation level, say, 30% or 70% (the loads shown in Fig. 4 give 30% utilisation) and show costs and revenues under each set of experiment loads.

In Fig. 5 we show the costs and the revenue at €0.15 per core hour. We can see that at 70% utilisation the facility is approaching break-even whereas at 30% utilisation the facility is not even recovering half of its costs.

Fig. 5. Modelled revenue and costs assuming €0.15 per core hour in loads of 70% & 30%

Of course, this is still a very simple model and only shows revenue from pay-per-use; however, it is indicative of our approach and of the choices that will be necessary to place the testbeds on a sustainable basis.

5 Future Work

The initial model has been applied to our Testbed-as-a-Service value proposition, that is, BonFIRE's current operational setup. The model assumptions will be continuously validated and improved using actual data collected throughout the open access period of the project to improve the accuracy of results. The model will also be extended to include value-added services such as brokering, elasticity-as-a-service and bandwidth-on demand. The advanced cloud features offered by the facility at the end of the project need to be evaluated in terms of cost of maintenance and value to customers, so as to prioritise the capabilities based on the demand of customers.

All-in-one services such as TaaS are familiar to research centres and academic providers, who tend to operate with high levels of mutual trust and where universal service for a target research community is often a key requirement. However, the TaaS model presents challenges for commercial operators in terms of both the balance of control between the broker and testbeds, and the distribution of revenues. Our next steps are to extend the model to explore the commercially oriented value propositions, IaaS++ and 3rd party test-site provision. We are working closely with a commercial cloud provider, Wellness Telecom, who offer a BonFIRE site to explore infrastructure on demand from a 3rd party. This work will explore the balance between permanent and on-demand capacity. Finally, the work will be taken forward in the EC Fed4FIRE project, which will include to a diverse set of infrastructure resources including sensor and wireless networks, presenting the challenge of specialised assets and fewer of economies of scale.

6 Conclusions

In this paper we have presented an approach to cost accounting and operational performance modelling for experimental facilities that aims to provide facility operators and investors with information necessary to make financial planning and business decisions. It is clear that if experimentation facilities such as FIRE are to offer long-term sustainable services, greater consideration of financial aspects is necessary. No amount of business modelling using purely qualitative analysis will be sufficient to operate a facility in a way that maximises the benefits for the Future Internet research community. Establishing cost accountability and operational management tools that are linked to performance metrics is an essential and missing element in many publicly funded facilities today. The initial models presented in the paper are a starting point, but just by their very existence the debate is changing from the intractable challenge of “sustainability” to a reasoned discussion about quantified revenues and an understanding of ways in which specific levels of investment can deliver a level of capacity and service.

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