WHITE PAPER

A Simple Model for Determining True Total Cost of Ownership for Data Centers

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Executive Summary

Data centers are mission-critical components of all large enterprises and frequently cost hundreds of millions of dollars to build, yet few high-level executives understand the true cost of building and operating such facilities. Costs are typically spread across the IT, networking, and facilities/corporate real-estate departments, which makes management of these costs and assessment of alternatives difficult. This paper presents a simple approach to enable C-suite executives to assess the true total costs of building, owning, and operating their data center physical facilities (what we are here calling the True TCO). The business case in this paper focuses on a specific type of data center facility: a high-performance computing (HPC) facility in financial services. However, the spreadsheet model (available for download at http://www.uptimeinstitute.org/TrueTCO) can be easily modified to reflect any company's particular circumstances. Illustrative results from this true data center TCO model demonstrate why purchasing high-efficiency computing equipment for data centers can be much more cost effective than is widely believed.

This Paper

1. **Presents a simple spreadsheet tool for modeling the true total cost of ownership (True TCO) that can be used by financial analysts and high-level managers to understand all the components of data center costs, including both capital and operating expenses (CapEx/OpEx).**
2. **Documents assumptions in a transparent way so that others can easily understand, use, and critique the results.**
3. **Suggests that purchasers of servers and other IT hardware explore options for improving the efficiency of that equipment (even if it increases the initial purchase price) to capture the substantial**

Introduction

A data center is one of the most financially concentrated assets of any organization, and holistically assessing its True TCO is no mean feat. These costs are typically spread across organizations in the IT/networking and facilities/corporate real-estate departments, which makes both management of these costs and assessment of alternatives a difficult task.

We present a schematic way to calculate, understand, and rationalize IT, networking, and facilities CapEx and OpEx in a "typical" data center. Analysis of a prototypical data-center facility helps business owners evaluate and improve the underlying efficiency and costs of these facilities or assess the cost-effectiveness of alternatives, such as off-site computing, without the confidentiality concerns associated with revealing costs for a particular facility. It also provides an analytical structure in which anecdotal information can be cross-checked for consistency with other well-known parameters driving data center costs.

Previous TCO calculation efforts for data centers (Turner and Seader, 2006 and APC, 2003) have been laudable, but generally have been incomplete and imperfectly documented. This effort is the first to our knowledge to create a comprehensive framework for calculating both the IT and facilities costs with assumptions documented in a transparent way. The contribution of such "open-source" transparency, combined with the spreadsheet model itself being publicly available free from the *Institute's* web pages, will allow others to use and build on the results.

For simplicity, we focused this inquiry on a new high-density HPC data center housing financial and analytics applications, such as derivatives forecasting, risk and decision analysis and Monte Carlo simulations. We choose this financial services HPC example because such applications are both compute-intensive and growing rapidly in the marketplace.

Data and Methods

The data center in our example is assumed to have 20 thousand square feet of electrically active floor area (with an equal amount of floor area allocated to the cooling and power infrastructure).[1] A facility housing HPC analytics applications has a greater footprint for servers and a lesser footprint for storage and networking than would a general-purpose commercial data center and would be more computationally intensive than typical facilities (which usually run, on average, at 5 to 15 percent of their maximum computing capacity).

In our example, we assume the facility is fully built-out when it goes on line in 2007. In most real-world data centers, there's a lag between the date of first operation and the date that the new facility reaches its full complement of installed IT equipment. For the purposes of this paper, we ignore that complexity. We also focus exclusively on the construction and use phases of the data center and ignore costs of facility decommissioning and materials and equipment disposal. (As this tool is used and refined over time, we anticipate that financial managers may want to add additional capabilities to the model to capture complexities such as these that have an impact on their capital planning and decision-making.)

Table 1 (see page 5) shows the calculations and associated assumptions. The table begins with the characteristics of the IT hardware, splitting it into servers, disk and tape storage, and networking. The energy use and cost characteristics of this equipment are taken from a review of current technology data for data centers housing financial HPC programs.

The site infrastructure CapEx and OpEx for power and cooling of data centers are strongly dependent on reliability and concurrent maintainability objectives, as best represented by their Tier level. Tier III and IV facilities certified to the *Institute's* standards for computing and data availability are the highest reliability data centers in existence, and their site

[1] We also assume that the data center has 30-foot ceilings and that the electrically active floor area is equal to the raised floor area.

infrastructure costs reflect that reliability and resiliency. (Non-technical managers who wish to understand the de facto industry standards embodied in the Tier Performance Standards protocol for uninterruptibility should refer to the *Institute* white paper *Tier Classifications Define Site Infrastructure Performance* (Turner, Seader, and Brill, 2006)).

Turner and Seader (2006) developed infrastructure costs (including cooling, air handling, backup power, power distribution, and power conditioning) for such facilities after a review of sixteen recently completed large-scale computer site projects. They expressed those costs in two terms, one related to the power density of the facility and the other related to the electrically active floor area. The costs per kW are applied to the total watts (W) of IT hardware load and then added to the floor-area-related costs to calculate site infrastructure costs.

Other significant costs must also be included, such as architectural and engineering fees, interest during the construction phase, land, inert gas fire suppression costs, IT build-out costs for racks, cabling, internal routers and switches, point-of-presence connections, external networking and communications fees, electricity costs, security costs, and operations and maintenance costs for both IT and facilities. The spreadsheet includes each of these terms as part of the total cost calculation, documenting the assumptions in the footnotes to the table.

Results

Total electrical loads in the facility are about 4.4 MW (including all cooling and site infrastructure power). The computer power density, as defined in Mitchell-Jackson et al. (2003), is about 110 W/ft^2 of electrically active floor area. Total computer-room power density (which characterizes total data-center power) is double that value, which indicates that for every kW of IT load there is another kW for cooling and auxiliary equipment. Servers, which are the most important IT load in this example, draw about 16 kW per full rack (actual power, not rated power).

Total installed costs for this facility are $100M+/-, with about 30 percent of that cost associated with the initial purchases of IT equipment and the rest for site infrastructure. Total installed costs are about $5,000/ft^2 of electrically active floor area (including both IT and site infrastructure equipment). On an annualized basis, the most important cost component is site infrastructure CapEx, which exceeds IT CapEx (see *Figure 1*), a finding that is consistent with other recent work in this area (Belady 2007). About one quarter of the total annualized costs are associated with OpEx, while three quarters are attributable to CapEx.

On a per electrically active floor area basis, total annualized costs are about $1,200 per square foot per year. If these total costs are allocated to servers (assuming that the facility only has 1U servers) the cost is about $4,900 per server per year (which includes the capital costs of the server equipment).

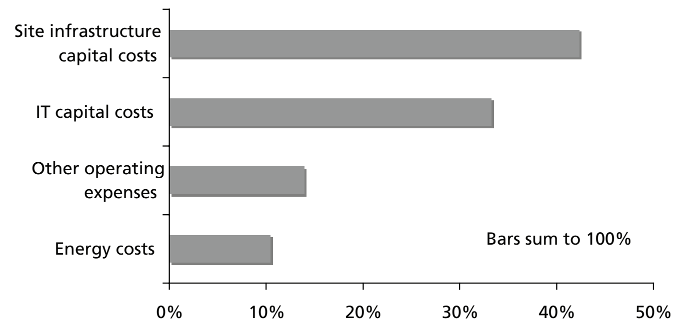

Figure 1: Annualized cost by component as a fraction of the total

Assessing the Business Case for Efficiency

One important use of a model such as this one would be to assess the potential benefits of improving the energy efficiency of IT equipment. The cost of such improvements must be compared against the true total cost savings, not just the energy savings, and the avoided infrastructure costs would justify much more significant investments in efficiency than have been considered by the industry heretofore. Most server manufacturers assume that they compete for sales on first costs, but server customers who understand the True TCO are justified in demanding increased efficiency, even if it increases the initial purchase price of the IT hardware.

For example, a hypothetical 20 percent reduction in total server electricity use in this facility would result in direct savings of about $90 per server per year in electricity costs, but would also reduce capital costs of the facility by about $10M (about $2,000 per server, compared to a street cost for each server of about $4,500). This $10M is approximately 10 percent of the built-out, fully commissioned cost of our base-case facility. So the direct site infrastructure savings from IT efficiency improvements in new facilities can be substantial and would justify significant efficiency improvements in IT equipment. Put another way, approximately 25 percent more revenue-generating servers could be operating in a facility that reduced total server power use by 20 percent.

Of course, purchasing efficiency is only possible if there are standardized measurements for energy use and performance (Koomey et al. 2006, Malone and Belady 2006, Nordman 2005, Stanley et al. 2007, The Green Grid 2007). The Standard Performance Evaluation Corp. (SPEC) is working on a standardized metric for servers scheduled for release by the end of 2007 (http://www.spec.org/specpower/). Once such metrics are available, server manufacturers should move quickly to make such standardized measurements available to their customers, and such measurements should facilitate efficiency comparisons between servers.

Future work by the *Institute* and others on this True TCO model will likely assess costs for many classes and all four computing availability Tiers of data centers. This model, as currently specified, focuses only on HPC for financial services in a Tier III facility—data centers designed to serve other industries and markets will have different characteristics.

The servers in general business facilities consume (on average) smaller amounts of power per server and operate at much lower utilization levels. Until there are prototypical models for each general business type and Tier-level of data center, managers should experiment with this model by plugging in their known or planned characteristics. The exercise of gathering the initial data may be frustrating, but if there's anything like $10M in saved costs at stake, the near-term ROI payback for the frustration may make it well worth it.

The model should also be modified to allow different floor-area allocations per rack, depending on the type of IT equipment to be installed. For example, tape drives can be much more tightly packed (from a cooling perspective) than can HPC 1u server racks. Such a change will also allow more accurate modeling of existing or new facilities that have a different configuration than the one represented in *Table 1* (see page 5).

Additional work is also needed to disentangle the various components of the kW-related infrastructure costs, which account for about half of the total installed costs of the facility. The original work on which these costs are based (Turner and Seader, 2006) did not disaggregate these costs, but they have such an important effect on the results that future work should undertake such an effort.

Conclusions

This paper compiles and consolidates data-center costs using field experience and measured data, and summarizes those costs in a simple and freely available spreadsheet model. This model can be used to estimate the true total costs of building a new facility, assess potential modifications in the design of such a facility, or analyze the costs and potential benefits of offsite computing solutions. In this facility, site infrastructure capital costs exceed the capital costs of IT hardware, a result that will surprise many CFOs and CIOs; that fact alone should prompt an examination of the important financial and operational performance implications and tradeoffs in the design, construction and operation of large-scale data centers.

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Table 1: Simple model of true total cost of ownership for a new high density data center

Download the working version of the True TCO Calculator at http://www.uptimeinstitute.org/TrueTCO

Energy and power use/costs	Units	Servers	Disk storage	Tape storage	Networking	Totals	Notes
% of racks		80%	8%	2%	10%	100%	1
# of racks		160	16	4	20	200	2
# of U per rack		42	42	42	42	42	3
% filled	%	76%	76%	76%	76%	76%	4
# of U filled		5120	511	128	638	6397	5
Power use/filled U	W	385	200	50	150	340	6
Total power use/rack	kW/rack	12.3	6.4	1.6	4.8	10.9	7
Total Direct IT power use	kW	1971	102	6	96	2176	8
Total electricity use							
IT (UPS) load	kW	1971	102	6	96	2176	8
Cooling	kW	1281	66	4	62	1414	9
Auxiliaries	kW	690	36	2	34	761	10
Total power use	kW	3942	204	13	192	4351	11
Electric power density							
IT load	W/sf elect. Active	99	5	0	5	109	12
Cooling	W/sf elect. Active	64	3	0	3	71	12
Auxiliaries	W/sf elect. Active	35	2	0	2	38	12
Total power use	W/sf elect. Active	197	10	1	10	218	12
Total electricity consumption							
IT load	M kWh/year	16.4	0.9	0.1	0.8	18.1	13
Cooling	M kWh/year	10.7	0.6	0.0	0.5	11.8	13
Auxiliaries	M kWh/year	5.7	0.3	0.0	0.3	6.3	13
Total electricity use	M kWh/year	32.8	1.7	0.1	1.6	36.2	13
Total energy cost							
IT load	M $/year	1.11	0.06	0.00	0.05	1.23	14
Cooling	M $/year	0.72	0.04	0.00	0.04	0.80	14
Auxiliaries	M $/year	0.39	0.02	0.00	0.02	0.43	14
Total electricity cost	M $/year	2.23	0.12	0.01	0.11	2.46	14
Capital costs (Cap Ex)							
IT capital costs							
Watts per thousand $ of IT costs	watts/thousand $	86	30	6	100		15
Cost per filled U	k $/U	4.5	6.7	8.3	1.5		16
Cost per filled rack	k $/rack	189	280	350	63		17
Total IT costs	M $	23.0	3.4	1.1	1.0	29	18

Table 1 continued

Other capital costs	Units	Servers	Disk storage	Tape storage	Networking	Totals	Notes
Rack costs	k $/rack	3	3	3	3		19
External hardwired connections	k $/rack	5	5	5	5		20
Internal routers and switches	k $/rack	5	5	5	5		21
Rack management hardware	k $/rack	3	3	3	3		22
Rack costs total	M $	0.48	0.05	0.01	0.06	0.6	23
External hardwired connections total	M $	0.80	0.08	0.02	0.10	1.0	23
Internal routers and switches total	M $	0.80	0.08	0.02	0.10	1.0	23
Rack management hardware total	M $	0.48	0.05	0.01	0.06	0.6	23
Cabling costs (total)						1.3	24
Point of Presence (POP)	M $					3.5	25
kW related infrastructure costs	M $	46.9	2.4	0.2	2.3	51.8	26
Other facility costs (elect. active)	M $					5.2	27
Interest during construction	M $					4.0	28
Land costs	M $					0.50	29
Architectural and engineering fees	M $					2.9	30
Inert gas fire suppression	M $					1.0	31
Total installed capital costs	M $					101.8	
	$/sf elect. active					*5091*	
Capital costs with 3 year life	M $					29	32
Capital costs with 15 year life	M $					72	33
Annualized capital costs	M $/year					19.1	34
Annual operating expenses (Op Ex)							
Total electricity costs	M $/year	2.2	0.1	0.01	0.1	2.5	35
Network fees	M $/year					0.5	36
Other operating expenses							37
IT site management staff	M $/year					0.39	38
Facilities site management staff	M $/year					0.52	39
Maintenance	M $/year					0.42	40
Janitorial and landscaping	M $/year					0.16	41
Security	M $/year					0.70	42
Property taxes	M $/year					0.72	43
Total other operating expenses	M $/year					2.91	
Total operating expenses	M $/year					5.9	44
Total Annualized costs							
Total	M $/year					25.0	45
Per unit of electrically active floor space	$/sf/year					1249	46

Assumptions (Note: All costs are 2007 dollars. Contact JGKoomey@stanford.edu with questions or comments)

1. **Fraction of racks allocated to different categories based on** *Uptime Institute* **consulting experience and judgment for high performance computing in financial applications.**
2. **Number of racks calculated based on 20ksf electrically active floor area, 100 square feet per rack, and percentage breakdown from previous row.**
3. **Racks are standard (6.5 feet high with 42 Us per rack).**
4. **% of rack filled based on** *Institute* **consulting experience.**
5. **The total number of Us filled is the product of the number of racks times total Us per rack times the % filled.**
6. **Energy use per U taken from selective review of market/technology data. Server power and costs per watt assumes IBM X-3550 1U system.**
7. **Energy use per rack is the product of the total number of Us filled times watts per installed U.**
8. **Total direct IT energy use is the product of watts per rack times the number of racks of a given type.**
9. **Cooling electricity use (including chillers, fans, pumps, CRAC units) is estimated as 0.65 times the IT load .**
10. **Auxiliaries electricity use (including UPS/PDU losses, lights, and other losses) is estimated as 0.35 times IT load.**
11. **Total electricity use is the sum of IT, cooling, and auxiliaries. Cooling and auxiliaries together are equal to the IT load (Power overhead multiplier = 2.0).**
12. **Electricity intensity is calculated by dividing the power associated with a particular component (eg IT load) by the total electricallyactive area of the facility.**
13. **Total electricity consumption is calculated using the total power, a power load factor of 95%, and 8766 hours/year (average over leap and non-leap years).**
14. **Total energy cost calculated by multiplying electricity consumption by the average U.S. industrial electricity price in 2007 (6.8 cents/kWh, 2007 dollars).**
15. **Watts per thousand 2007 dollars of IT costs taken from selective review of market and technology data. Server number calculated assuming IBM x3550 1U server as described in next note.**
16. **Cost per filled U taken from selective review of market and technology data. Server street cost calculated assuming IBM x3550 1U server with 8 GB RAM, two dual core 2.66 GHz Intel processors (19.2 GFLOPS max/server).**
17. **Cost per filled rack is the product of the cost per U and the total # of Us per rack (42).**
18. **Total IT costs are the product of the number of filled Us and the cost per filled U.**
19. **Rack costs are the costs of the rack structure alone.**
20. **External hardwired connections costs are** *Institute* **estimates.**
21. **Internal routers and switch costs are** *Institute* **estimates.**
22. **Rack management hardware costs are** *Institute* **estimates.**
23. **Total costs for racks, hardwired connections, and internal routers and switches are the product of the cost per rack and the number of racks.**
24. **Cabling costs totals are** *Institute* **estimates.**
25. **Point of presence costs are** *Institute* **estimates for a dual POP OC96 installation.**
26. **kW related infrastructure costs (taken from Turner and Seader 2006) are based on Tier 3 architecture, $23,801 per kW cost. Assumes immediate full build out. Includes costs for non electrically active area. Construction costs escalated to 2007$ using Turner construction cost indices for 2005 and 2006 (http://www.turnerconstruction.com/corporate/content.asp?d=20) and 2007 forecast (http://www.turnerconstruction.com/corporate/content.asp?d=5952). Electricity prices escalated to 2007$ using the GDP deflator 2005 to 2006 and 3% inflation for 2006 to 2007.**
27. **Other facility costs are based on $262 per square foot of electrically active area (taken from Turner and Seader 2006. Costs are in 2007 $, escalated as described in the previous footnote).**

28. Interest during construction estimated based on total infrastructure and other facility capital costs assuming a 7% real interest rate for one year.
29. Land cost based on $100,000 per acre, 5 acres total.
30. Architectural and engineering fees are estimated as 5% of kW related infrastructure costs plus other facility costs (electrically active). Cost percentage is based on personal communication with Peter Rumsey of Rumsey Engineers, 9 July 2007.
31. Cost for inert gas fire suppression are *Institute* estimates ($50/sf of electrically active floor area).
32. Capital costs with three year life include all IT equipment costs (which include internal routers and switches).
33. Capital costs with 15 year lifetime include all capital costs besides IT costs (these costs also include rack, cabling, and external hardwire connection costs).
34. Capital costs are annualized with the capital recovery factor calculated using the appropriate lifetime (three or 15 years) and a 7% real discount rate.
35. Total electricity costs include both IT and infrastructure energy costs (see notes 11, 12, 13, and 14).
36. Network fees are *Institute* estimates.
37. Other operating expenses based on *Institute* estimates for a Midwest mid-size town location. Benefits are assumed to be equal to 30% of salary.
38. IT site management staff costs assume $100k/yr salary, 3 people per shift, 1 shift per day.
39. Facilities site management staff costs assume $100k/yr salary, 3 people per shift, 1 shift per day.
40. Maintenance costs assume non-union in-house facilities staff, $80k/yr salary, 4 people per shift, 1 shift per day.
41. Janitorial and landscaping costs assume $4/gross square foot of building area per year (based on *Institute* estimates).
42. Security costs assume $60k/yr salary, 3 people per shift, 3 shifts per day.
43. Annual property taxes estimated as 1% of the total installed capital cost of the building (not including IT costs).
44. Total operating expenses include electricity costs, network fees, and other operating expenses.

About the Author

Jonathan Koomey, Ph.D., is a Senior Fellow of the *Institute* and Co-Chair of the *Institute* Design Charrette 2007: Data Center Energy Efficiency by Design held October 28-31, in Santa Fe, NM (http://www.uptimeinstitute.org/charrette) for which this paper serves as an important philosophical underpinning.

Dr. Koomey is a Project Scientist at Lawrence Berkeley National Laboratory and a Consulting Professor at Stanford University. Dr. Koomey is one of the leading international experts on electricity used by computers, office equipment, and data centers, and is the author/co-author of eight books and more than 150 articles and reports on energy and environmental economics, technology, forecasting, and policy. He has also published extensively on critical thinking skills.

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Appendix A: Details on the Cost Calculations

Site infrastructure costs total $23,800 to $26,000 per kW of useable UPS output (2007 dollars) for Tier III and IV facilities, respectively (Turner and Seader 2006). An additional $262/ft² of electrically active floor area (2007 dollars) must be added to reflect the floor-area related costs.

Costs from the Turner and Seader (2006) data (in 2005 dollars) were adjusted to 2007 dollars using Turner Construction Company cost indices for 2005 and 2006 (http://www.turnerconstruction.com/corporate/content.asp?d=20) and the Turner 2007 forecast (http://www.turnerconstruction.com/corporate/content.asp?d=5952). Please note: There is no relation between the author Turner and the Turner Construction Company.

The electricity price is the projected U.S. average price for industrial customers from the U.S. Energy Information Administration Annual Energy Outlook 2007 (US DOE 2007) corrected to 2007 dollars using the GDP deflator from 2005 to 2006 and an assumed inflation rate of 3 percent for 2006 to 2007.

To calculate annualized investment costs, we use the static annuity method. The capital recovery factor (CRF), which contains both the return *of* **investment (depreciation), and a return** *on* **investment, is defined as:**

$$CRF = \frac{d(1+d)^L}{((1+d)^L-1}$$

In this formula, d **is the real discount rate (7 percent real) and** L **is the facility or IT equipment lifetime (three and 15 years for the IT and site infrastructure equipment, respectively.). The CRF converts a capital cost to a constant stream of annual payments over the lifetime of the investment that has a present value at discount rate d that is equal to the initial investment. This annualization method gives accurate results for the annualized lifetime IT costs as long as any future purchases of IT equipment (after the first cohort of equipment retires after three years) has the same cost per server in real terms.**

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About the Uptime Institute®

Since 1993, the Uptime Institute, Inc. (*Institute***) has been a respected provider of educational and consulting services for Facilities and Information Technology organizations interested in maximizing data center uptime. The** *Institute* **has pioneered numerous industry innovations, such as the Tier Classifications for data center availability, which serve as industry standards today.**

At the center of the *Institute's* **offering, the 100 global members of the Site Uptime Network® represent mostly Fortune 100 sized companies for whom site infrastructure availability is a serious concern. They collectively and interactively learn from one another as well as from** *Institute***-facilitated conferences, site tours, benchmarking, best practices, and abnormal incident collection and analysis.**

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