Data Center Cost Models

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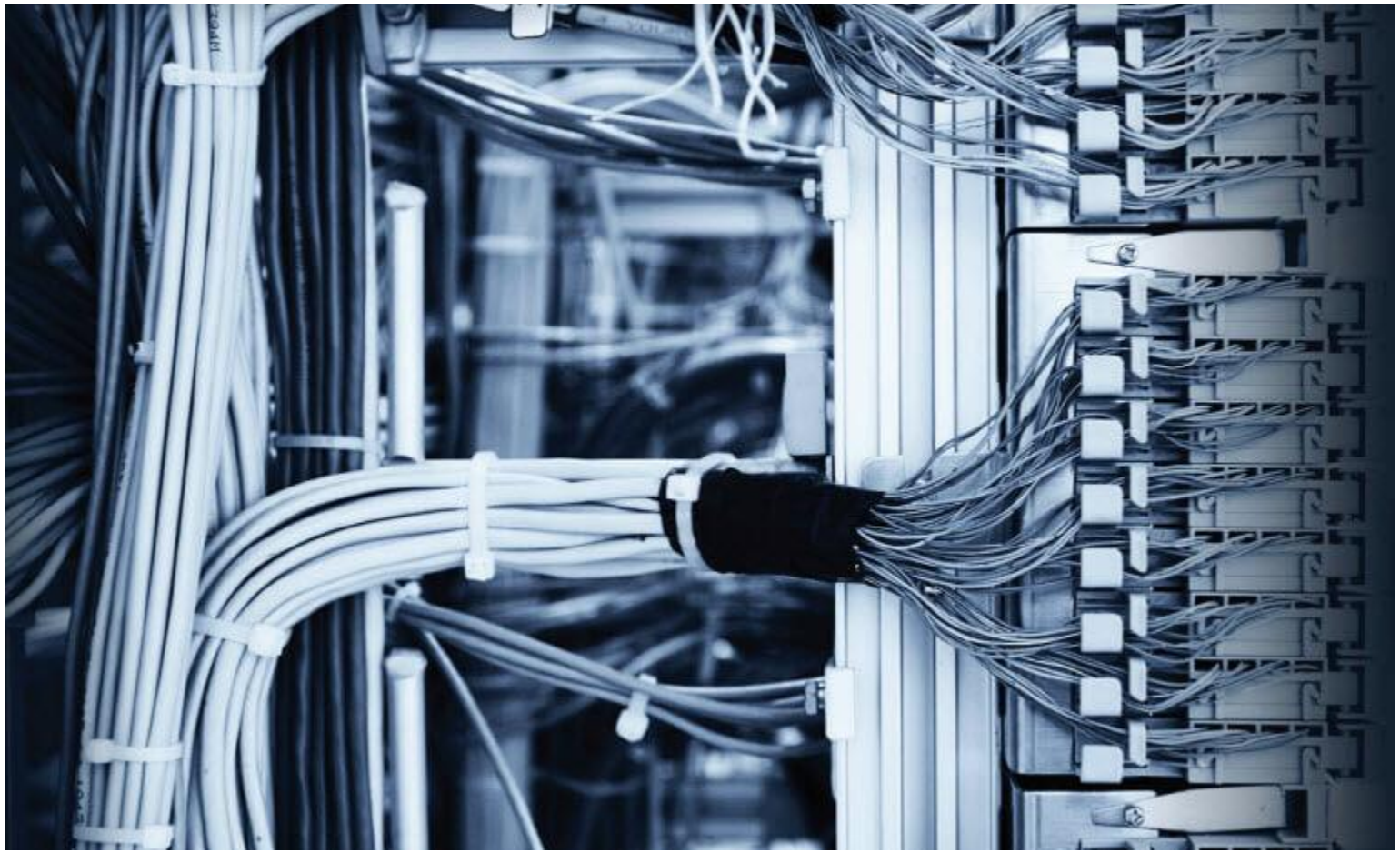


- To better understand the potential impact of energy-related optimizations, total cost of ownership (TCO) of a Data Center (DC) needs to be examined.

CAPEX and OPEX

- CAPEX refers to investments that must be made upfront and that are then depreciated over a certain time frame.
  - Examples are the construction cost of a DC or the purchase price of a server and other network equipment.
- OPEX refers to the recurring monthly costs of actually running the DC.
  - Examples are electricity costs, repairs and maintenance, salaries of on-site personnel, and so on.

Barroso, Luiz André, Jimmy Clidaras, and Urs Hölzle. "The datacenter as a computer: An introduction to the design of warehouse-scale machines." *Synthesis lectures on computer architecture,* 2013.

CAPEX Breakdowns

- It includes:
  1. DC construction amortized cost, (C_{DC}^{A});
  2. DC construction loan interest (C_{DC}^{L});
  3. server amortized cost (C_{S}^{A});
  4. Other network equipment's amortized cost, e.g., Top of Rack switch (ToR) amortized cost (C_{SW}^{A});
  5. Server loan interest (C_{S}^{L});
  6. ToR switch loan interest (C_{SW}^{L}).

Unit to Use

- DC costs are often expressed in **U.S. dollars per watt** of critical power.
- Critical power is defined as the peak power level that can be provisioned to IT equipment.
- Cost in terms of dollars per square foot is less useful since:
  1. there is no standard definition of what space to include or exclude in the computation
  2. all of the DC's primary components—power, cooling, and space—roughly scale linearly with watts

DC Construction Amortized Cost C_{DC}^{A}

- It includes the cost of land acquisition/collocation, power and cooling system, etc.
- It varies widely depending on design, size, location, and desired speed of construction. Adding reliability and redundancy makes DCs more expensive.
- Very small or very large DCs tend to be more expensive
  - the former because fixed costs cannot be amortized over many watts;
  - the latter because large centers require additional infrastructure such as electrical substations.

DC Construction Amortized Cost C_{DC}^{A}

Cost/W	Source
$12–25	Uptime Institute estimates for small- to medium-sized datacenters; the lower value is for "Tier 1" designs that are rarely used in practice [155]
$9–13	Dupont Fabros 2011 10 K report [43] contains financial information suggesting the following cost for its most recent facilities (built in 2010 and 2011 - see p 39 for critical load and p 76 for cost): $204 M for 18.2 MW (NJ1 Phase I) => $11.23/W $116 M for 13 MW (ACC6 Phase I) => $8.94/W $229 M for 18.2 MW (SC1 Phase 1) => $12.56/W
$8-10	Microsoft's investment of $130 M for 13.2 MW ($9.85/W) capacity expansion to its data center in Dublin, Ireland [105] Facebook is reported to have spent $210 M for 28 MW ($7.50/W) at its Prineville data center [49]

Tier I: $10,000/kW of useable UPS output
Tier II: $11,000/kW of useable UPS output
Tier III: $20,000/kW of useable UPS output
Tier IV: $22,000/kW of useable UPS output

DC are classified into four Tiers based on different redundancy levels of capacity systems, distribution paths, power system, etc.

Turner, W. Pitt, and John H. Seader. "Dollars per kW plus dollars per square foot are a better datacenter cost model than dollars per square foot alone." *Uptime Institute White Paper*, 2006.

DC Construction Amortized Cost C_{DC}^{A}

- Critical power: max power to power IT equipment.
- For example, a DC with 20 MW of generators may have been built in a 2N configuration and provide only 6 MW of critical power plus 4 MW to power chillers. Thus, if built for $120 million, it has a cost of 120/6 = $ 20/W, not 120/20= $ 6/W.
- **DC construction amortized cost** depends on the duration over which the investment is amortized. Typically, DCs are depreciated over periods of 10–15 years.
- For example, if we depreciate the $ 20/W DC over 12 years, **DC construction amortized cost** is 20/12/12/30**=** $ 0.0046/W per day.

DC Construction Loan Interest C_{DC}^{L}

- If a loan is taken out to finance construction the $ 20/W DC at an interest rate of 8%, the daily interest payment would be 20*8%/12/12/30 = $ 0.00037/W

Server Amortized Cost (C_S^A)

- Server costs are computed similarly, except that servers have a shorter lifetime and thus are typically depreciated over 3–4 years.
- Critical power for server is its peak power.
- For example, a $4,000 server with an actual peak power consumption of 500 W costs 4000/500=$8/W. Depreciated over 4 years, the **server amortized cost** becomes 8/4/12/30**=**$0.0056/W per day.
- Other network equipment's amortized cost, e.g., Top of Rack (ToR) amortized cost (C_{SW}^A) can be calculated in same fashion.

Server Loan Interest (C_S^L);

- If a loan is taken out to finance construction the $8/W server at an interest rate of 8%, the daily interest payment would be 8*8%/4/12/30 = $ 0.00044/W
- ToR switch loan interest C_{SW}^L can be calculated in the same fashion.

OPEX Breakdowns

- It includes:
  1. demand-side electricity costs
  2. support-side electricity costs
  3. other operational cost (C_O)

Demand-side and Support-side Electricity Costs

- Demand side refers to IT equipment such as servers, switches, etc.
- Support side refers to cooling system, lighting, Uninterruptable Power Supply (UPS), etc.
- Support-side electricity costs are counted as overhead of demand-side electricity costs by using Power Usage Effectiveness (PUE) metric.
- Industrial electricity costs are expressed in cents/kilowatthour

Census Division and State	Residential		Commercial		Industrial		Transportation		All Sectors	
	November 2016	November 2015	November 2016	November 2015	November 2016	November 2015	November 2016	November 2015	November 2016	November 2015
New England	**18.86**	**18.54**	**15.02**	**14.63**	**11.96**	**12.14**	**7.19**	**8.69**	**15.94**	**15.61**
Connecticut	19.66	20.04	16.45	15.27	12.82	12.97	8.99	11.04	17.27	16.88
Maine	16.24	16.20	12.46	13.02	9.16	8.96	--	--	13.02	13.06
Massachusetts	19.15	18.35	14.89	14.60	12.89	13.19	5.26	6.75	16.02	15.59
New Hampshire	19.11	18.15	14.67	14.39	12.33	12.62	--	--	15.96	15.48
Rhode Island	18.17	18.62	14.48	14.54	13.47	13.25	19.23	19.29	15.80	15.97
Vermont	17.84	17.67	14.78	14.63	9.91	10.11	--	--	14.62	14.49
Middle Atlantic	**15.82**	**16.00**	**12.11**	**12.30**	**6.82**	**6.98**	**10.26**	**11.19**	**12.23**	**12.35**
New Jersey	15.29	15.32	11.76	12.04	9.66	9.69	8.39	9.37	12.75	12.86
New York	17.75	18.23	13.99	14.04	5.87	5.87	11.23	12.14	14.08	14.19
Pennsylvania	14.24	14.20	9.15	9.50	6.78	6.98	7.27	8.32	10.08	10.20
East North Central	**13.29**	**13.37**	**10.03**	**9.93**	**6.98**	**6.87**	**7.20**	**7.38**	**9.94**	**9.85**
Illinois	12.86	13.27	8.77	8.99	6.34	6.45	6.91	7.18	9.21	9.47
Indiana	12.42	12.03	10.36	9.84	7.53	6.85	11.35	10.30	9.71	8.97
Michigan	15.46	14.63	10.99	10.51	7.15	6.81	12.10	11.64	11.14	10.62
Ohio	12.22	13.11	10.04	10.22	6.67	7.11	8.00	7.83	9.55	10.02
Wisconsin	14.40	13.93	10.77	10.47	7.59	7.25	15.00	16.67	10.72	10.38
West North Central	**11.80**	**11.36**	**9.19**	**8.85**	**6.63**	**6.49**	**8.72**	**8.61**	**9.15**	**8.83**
Iowa	12.00	11.16	8.78	8.09	5.20	5.13	--	--	7.72	7.37
Kansas	13.16	12.83	9.87	9.96	7.23	7.49	--	--	9.97	10.00
Minnesota	13.15	11.87	10.22	9.06	7.17	7.03	10.16	9.54	10.11	9.27
Missouri	10.79	11.25	8.43	8.71	6.36	6.00	7.17	7.38	8.98	9.01
Nebraska	10.73	10.36	8.48	8.24	6.87	6.92	--	--	8.48	8.34
North Dakota	10.30	9.19	9.08	8.45	8.44	7.84	--	--	9.12	8.41
South Dakota	11.71	11.10	9.50	9.08	7.44	7.07	--	--	9.79	9.36
South Atlantic	**11.65**	**11.72**	**9.27**	**9.30**	**6.19**	**6.19**	**7.90**	**7.91**	**9.63**	**9.65**
Delaware	13.87	14.47	10.07	10.68	7.42	8.13	--	--	10.90	11.56
District of Columbia	13.71	13.71	11.77	12.03	8.64	9.06	9.43	9.21	11.99	12.09
Florida	11.30	11.56	9.23	9.43	7.88	8.01	8.51	9.19	10.13	10.39
Georgia	10.93	10.50	9.76	9.19	5.46	5.25	4.66	4.37	9.07	8.61
Maryland	14.33	14.89	11.04	10.60	7.79	8.28	7.90	7.88	12.12	12.00
North Carolina	11.22	11.39	8.37	8.40	5.74	5.86	8.44	8.15	8.89	8.85
South Carolina	12.54	12.81	10.09	10.16	5.55	5.65	--	--	9.17	9.02
Virginia	11.52	11.47	7.81	8.13	6.62	6.83	7.82	7.60	8.95	9.16
West Virginia	11.72	10.73	9.76	9.13	6.79	6.24	--	--	9.09	8.41
East South Central	**11.34**	**11.08**	**10.35**	**10.14**	**5.85**	**5.69**	--	--	**9.07**	**8.84**
Alabama	12.29	11.39	11.33	10.51	5.99	5.46	--	--	9.41	8.71
Kentucky	11.01	10.85	9.71	9.56	5.52	5.50	--	--	8.35	8.22
Mississippi	11.04	11.43	9.95	10.27	6.03	6.26	--	--	8.85	9.17
Tennessee	10.95	10.81	10.23	10.15	5.93	5.88	--	--	9.44	9.27
West South Central	**10.57**	**10.84**	**7.69**	**7.97**	**5.23**	**5.26**	**5.84**	**5.57**	**7.81**	**7.90**
Arkansas	10.08	10.12	8.02	8.25	5.72	6.09	11.70	9.45	7.78	8.00
Louisiana	9.16	9.15	8.61	8.50	5.13	5.24	9.60	7.56	7.37	7.30
Oklahoma	9.40	10.39	6.80	7.23	4.62	4.84	--	--	6.89	7.32
Texas	11.11	11.38	7.62	7.95	5.29	5.23	5.59	5.43	8.06	8.13
Mountain	**11.50**	**11.21**	**9.28**	**9.25**	**5.74**	**5.95**	**9.85**	**9.80**	**8.85**	**8.76**
Arizona	11.66	11.24	9.64	9.46	5.71	5.54	9.23	7.96	9.54	9.17
Colorado	12.16	11.72	9.90	9.86	7.26	7.14	10.15	9.96	9.81	9.68
Idaho	10.08	9.34	7.90	7.57	5.75	5.74	--	--	8.14	7.78
Montana	11.06	10.79	10.22	10.13	4.75	5.05	--	--	8.78	8.71
Nevada	11.80	12.70	7.73	8.94	3.16	5.21	7.34	8.51	7.21	8.09
New Mexico	11.98	11.77	9.55	9.74	5.65	5.92	--	--	8.79	8.92
Utah	10.71	10.63	8.55	8.12	5.58	5.65	9.94	9.95	8.19	8.02
Wyoming	11.30	11.11	9.78	9.24	6.85	6.63	--	--	8.20	7.90
Pacific Contiguous	**14.75**	**14.24**	**12.77**	**13.02**	**9.22**	**8.98**	**7.89**	**8.40**	**12.64**	**12.52**
California	17.97	17.33	14.37	14.76	12.03	12.07	7.83	8.37	15.02	15.03
Oregon	10.75	10.68	8.93	8.84	6.38	6.04	9.34	9.25	9.03	8.88
Washington	9.51	9.41	8.49	8.49	4.73	4.47	9.24	9.00	7.85	7.71
Pacific Noncontiguous	**25.08**	**23.98**	**22.18**	**21.28**	**20.29**	**19.42**	--	--	**22.45**	**21.51**
Alaska	21.18	20.04	18.26	17.39	16.15	15.54	--	--	18.80	17.92
Hawaii	28.48	27.15	25.90	24.64	21.89	20.76	--	--	25.03	23.83
U.S. Total	**12.75**	**12.71**	**10.25**	**10.30**	**6.64**	**6.61**	**9.04**	**9.63**	**10.10**	**10.05**

Google DCs

- Berkeley County, South Carolina
- Council Bluffs, Iowa
- Douglas County, Georgia
- Jackson County, Alabama
- Lenoir, North Carolina
- Mayes County, Oklahoma
- Montgomery County, Tennessee
- The Dalles, Oregon

https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a

Other Operational Cost (C_o)

It includes costs on repairs and maintenance, salaries of on-site personnel, etc.

- It is harder to characterize because it depends heavily on operational standards (e.g., how many security guards are on duty at the same time or how often generators are tested and serviced) as well as on the DC size (larger DCs are cheaper because fixed costs are amortized better).
- Costs can also vary depending on geographic location (climate, taxes, salary levels, etc.) and on the DC design and age.
- Typical operational costs for multi-MW DCs in the United States range from $0.02 to $0.08/W per month.

Formulation

- Power consumption for server: P_1^d
- Power consumption for other network equipment: P_2^d
- Electricity Cost: C_1

$$C_1 = \sum_{d \in \mathrm{N}} (P_1^d + P_2^d) \cdot 24 \cdot \mathrm{h} \cdot EP_d \cdot U_d$$

- Cost other than electricity: C_2

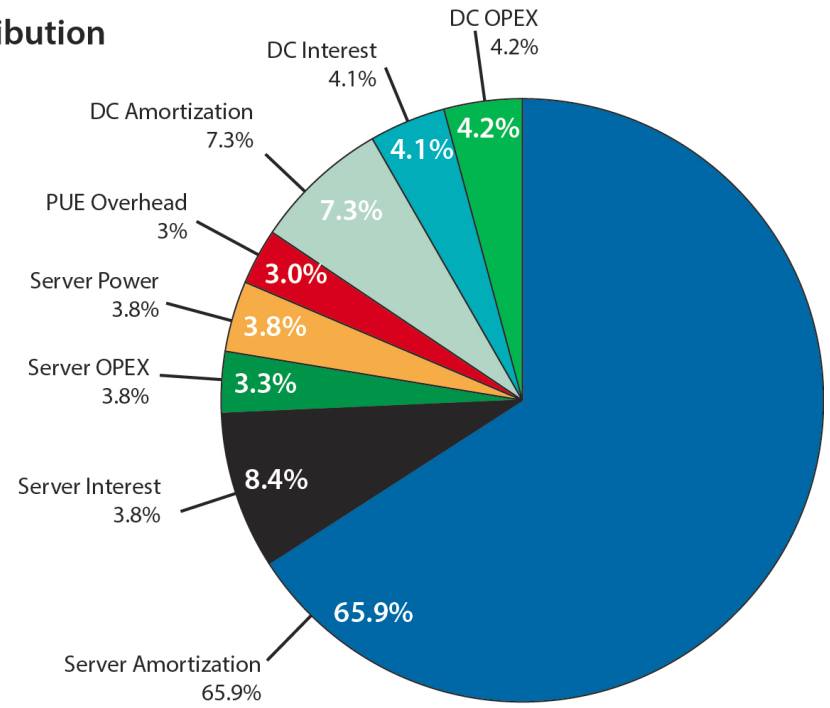
$$C_2 = \sum_{d \in N} \left\{ \left(C_S^A + C_S^L \right) \cdot Max_{DC} \cdot P_1^d + \left(C_I^A + C_I^L \right) \cdot \frac{Max_{DC}}{N_R} \cdot P_2^d + \right.$$

Case Studies

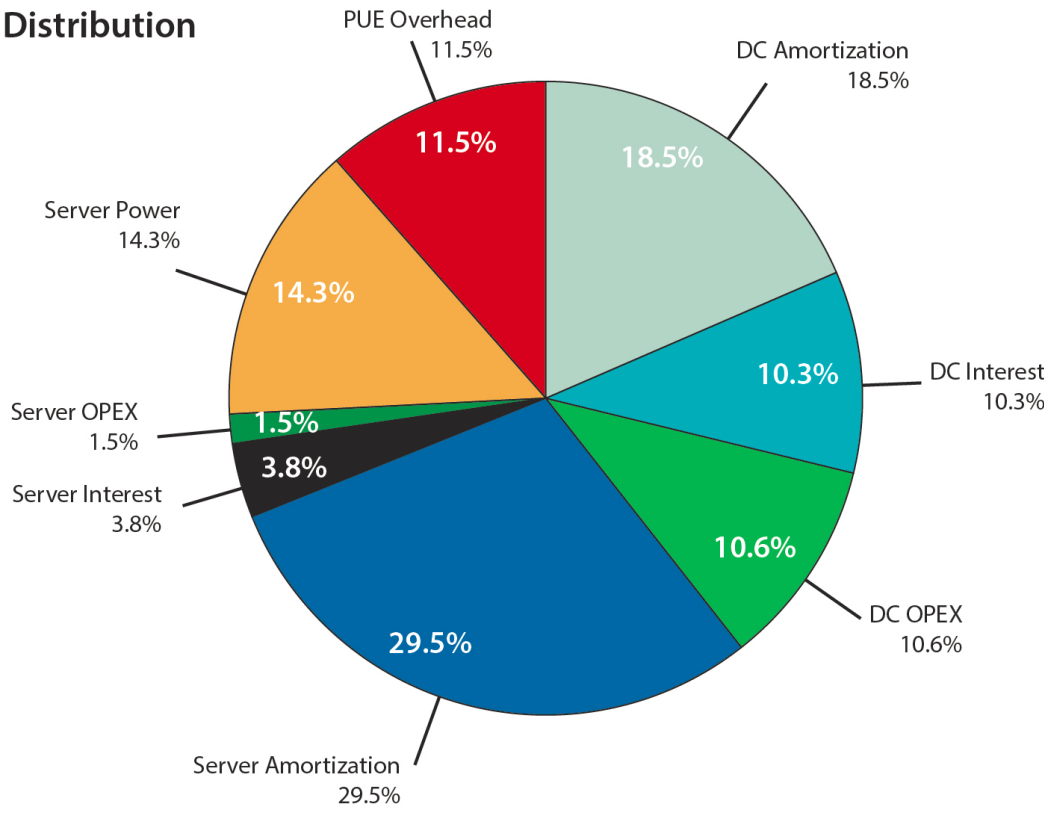
- Dell PowerEdge R520 with 2 CPUs, 48 GB of RAM and four disks. This server draws 340 W at peak and costs approximately $7,700 as of 2012.
- The cost of electricity is the 2012 average U.S. industrial rate of 6.7 cents/kWh.
- The interest rate a business must pay on loans is 8%, and we finance the servers with a 3-year interest-only loan.
- The cost of DC construction is $10/W amortized over 12 years.
- DC Opex is $0.04/W per month.
- The DC has a power usage effectiveness (PUE) of 1.8, the current industry average.
- Server lifetime is 3 years, and server repair and maintenance is 5% of CAPEX per year.
- The server's average power draw is 75% of peak power.

Case Studies

Case A Cost Distribution



Case B Cost Distribution



If a cheaper, faster, higher-powered server consuming 500 W at peak and costing only $2,000 in a location where electricity cost is $0.10/kWh.

The Cost of Public Cloud

- Instead of building your own DC and server, you can rent a virtual machine from a public cloud provider such as Google's Compute Engine or Amazon's EC2.
- Two possible cost schemes:
  - on-demand instance. For example, an AWS "High Memory Quadruple Extra Large" instance costs $1.80/h as of January 2013.
  - Contract. For example, $6,200 plus $0.28/h with a three-year contract.
- Which to choose depends on how you are going to use the server instance.