WHITE PAPER

Cost Model: Dollars per kW plus Dollars per Square Foot of Computer Floor

By W. Pitt Turner IV, P.E. with Kenneth G. Brill

For many years, the data center industry has used dollars per square foot of computer room space to benchmark the construction cost of a data center. This has led many data center owners to reduce the amount of space in an attempt to control project costs. This approach generally produces disappointing results because it is based on a false premise. Originally, 16 actual construction projects were used by the Uptime Institute (Institute) to identify their primary cost drivers and develop a new and more accurate construction cost model. This model emphasizes the "engine" capacity and functionality aspects of a data center, in addition to the space itself. This white paper edition features refinements to the first edition, including an update to the cost model—based on four additional data center projects completed since.

The content of this white paper was jointly developed by ComputerSite Engineering.

Uptime Institute™

This white paper:

- Provides an update to the more accurate way of predicting the total budget required to build a new data center.
- Is originally based on 16 actual major projects, plus an update with 4 newer projects.
- Warns senior executives and project managers to be extremely cautious if their project budget is significantly less than the Institute's metric because the "savings" are most likely to result from reductions, often unstated, in infrastructure performance features or delivered capacity.
- Urges project managers to get seed funding to develop the project requirements and the budget/schedule that will be presented to senior management. This seed money enables the client to engage Tier* technology design, construction, and cost experts with multiple project experience and to develop the data center design concepts, capacities, and uptime performance objectives before they determine the project's budget and schedule for construction. This approach more easily incorporates overlooked areas, like transfer to operations, before making irrevocable commitments to senior management.

Data Centers Are Not Upgraded Office Buildings

When one examines data center detailed construction cost breakdowns, the mechanical/electrical systems will account for 70% or more of the construction cost (depending upon density and functionality). This is a distinctive departure from office buildings where mechanical/electrical systems are normally about 15% of the total cost of construction. This fundamental, functional difference between office buildings and data centers is the reason that the traditional office building construction cost benchmarking system of dollars per square foot or per square meter ($/ft^2 or $/m^2) is inappropriate for data center construction.

When designing a new data center, two management decisions will determine the cost of the mechanical and electrical systems, which in turn will drive the total project cost. These management decisions are a) the initial and ultimate design objectives for power and heat load density and b) the Concurrent Maintainability or Fault Tolerance functionality of the mechanical and electrical infrastructure. Both of these decisions are independent of the square feet in the computer room. Doubling density doesn't substantially affect the size of the computer room, but it does double the size and cost of the underlying mechanical/electrical infrastructure. Similarly, changing the Tier of functionality (from Tier II to IV, for example) can effectively double costs without adding any computer room space or increasing the usable UPS kW available for the computers.

Data Center Cost Drivers

Detailed analysis has shown that there are three primary construction cost drivers for a data center:

- Power and cooling capacity or density (total kW, kW/cabinet, or watts per square foot or per square meter [W/ft^2 or W/m^2])
- Tier of functionality (e.g., Tier III Concurrently Maintainable)
- Size of the computer room floor (space [ft^2 or m^2] or number of cabinets)

Consider (2) similar 20,000-ft^2 (1,900-m^2) computer rooms: the first is Tier II at 1.5 kW/cabinet (50W/ft^2, 538 W/m^2; 1,000 kW of redundant UPS for IT computers) and the second is Tier IV Fault Tolerant at 3 kW/cabinet (100 W/ft^2 1,077 W/m^2; 2,000 kW of redundant UPS for IT). The computer room floor sizes are identical in both cases. However, the gross building footprint, which includes the space for the mechanical/electrical infrastructure, is quite different: the first is about 26,000 ft^2 (2,400 m^2) gross and the second is about 40,000 ft^2 (3,700 m^2) gross. Even more importantly, the construction cost for the second case (higher-density Tier IV) solution is more than triple the cost of the first solution. This example illustrates a) how construction costs can change dramatically independent of the size of the computer room and b) why the traditional $/ft^2 ($/m^2) cost model should be avoided.

Institute's Data Center Construction Cost Model

The Institute's cost model appropriately reflects the unique characteristics of data centers.

The computer room component provides raw tenant space without any fit-out of functionality or power/cooling capacity. The cost of this raw space is independent of Tier level and includes a raised floor, building shell and core (incidental office space for facilities, lobby, rest rooms, conference room, interior partitions, loading dock, storage area, etc.), normal interior finishes, lighting, building HVAC for makeup air, fire detection and pre-action sprinklers, and other space items that are not related to kW or functionality Tier. The cost of fitting out the computer room with the "kW distribution and delivery equipment" (basically the power distribution and cooling units) is separately included in the kW component below.

What converts a raw computer room into a data center is the "behind the curtain" power and cooling engine that drives the computer room space. This engine is sized in kW by Tier level and provides for the installation of the underlying and redundant mechanical/electrical infrastructure capacity (measured in kW of uninterruptible power and cooling required by the computer and communication load), as well as the distribution equipment required to support the desired Tier of functionality. Cost components include utility switchgear, power distribution backbone switchgear, engine generators, UPS, batteries, PDUs, critical power distribution, chillers, pumping,

*For further information on Tier Levels and functionality, consult the Institute's white paper, *Tier Classifications Define Site Infrastructure Performance*.

piping, cooling units, thermal storage, and fuel system, plus the gross building space to house all of this equipment. Depending upon density, remember that the space for "back of the house" equipment for Tier IV will exceed the amount of computer room floor space it supports. At 3 kW/rack, the ratio is at least 1 to 1. At 9 kW/rack, the ratio can be more than 3 to 1.

The Institute cost model uses just two primary elements.

- The **"kW" component** by desired level of functionality:
  - Tier I: $11,500/kW of redundant UPS capacity for IT
  - Tier II: $12,500/kW of redundant UPS capacity for IT
  - Tier III: $23,000/kW of redundant UPS capacity for IT
  - Tier IV: $25,000/kW of redundant UPS capacity for IT
- The **"computer room" component**: In all cases, $300/ft^2 ($2,880/m^2) of computer room floor must be added to the "kW cost" shown above.

A third element may be useful as well. This element is the cost for "empty space" built with the original building but planned for future use. An example is a 10,000-ft^2 room constructed for a second UPS system when the initial UPS kW requirement is fully met with the first UPS system.

- The **"empty space" component** is added to the "kW cost" above: $190/ft^2 ($1,824/m^2).

Example Using Institute Cost Model

Returning to the earlier example of (2) computer rooms each 20,000 ft^2; the first, Tier II with 666 racks at 1.5 kW/rack (1,000 kW of UPS for computers) and the second, Tier IV Fault Tolerant with 666 racks at 3.0 kW/rack (2,000 kW of UPS for computers), the costs would be:

- Tier II @ 1.5 kW/rack = $18.5 Million
  - (20,000 ft^2 x $300/ft^2) + (1,000 kW x $12,500/kW)
- Tier IV @ 3.0 kW/rack = $56.0 Million
  - (20,000 ft^2 x $300/ft^2) + (2,000 kW x $25,000/kW)

Important Assumptions, Conditions, Constraints, and Other Costs to Include

The Institute's cost model is based on 20 completed projects, each of which had extremely well-developed designs that are industry benchmarks. These projects actually delivered their promised capacity, redundancy, and functionality (Concurrent Maintenance and/or Fault Tolerance). This historical basis ensures that users of the Institute's model are, in fact, getting more accurate, complete, and all-inclusive costs than other alternatives, especially during the early project planning cycle when volunteers are providing free information without defining assumptions, requirements, and constraints.

The following assumptions, conditions, constraints, and other costs to include are important:

- This model is intended as a quick tool that can be applied very early in the planning cycle to accurately reflect the primary construction cost drivers.
- For the reasons to be outlined below, the tool may be only $^+/_-$30% accurate for a specific project, but will offer fairly accurate relative trade-offs within that project or between project options.
- The wide accuracy tolerance ($^+/_-$30%) is done with specific intent because it is not generally conducive to one's career to repeatedly go back to management for more project money. Experience indicates that the normal quick scope descriptions used very early in the project development process are usually incomplete, not very specific, and prone to assumption error. This sets the project up for a stream of incremental cost increases as the scope is made more complete and more specifics are developed.
- Costs are for 2007 construction. Future year costs should be inflated using the Engineering News Record (ENR) indexes.
- The cost model assumes a minimum of 15,000 ft^2 (1,400 m^2) of computer room in an architecturally plain, single-story building, with power backbone sized to achieve ultimate capacity with future installation of additional capacity components or systems. No allowance is made for offices, Command Centers/NOCs, etc.
- This cost model is based on 3.0 kW/rack with use of air cooling units on the raised floor. Adjustments need to be made for different cooling methods such as galleries.
- International demand for key commodities will continue to have a dramatic impact on data center cost variations. For example, in one recent 18-month period, both steel and copper increased 64%.
- Specific additions must be made to the building project cost from this model. These costs include items that are highly variable and are not included in the model: land, design fees, external program and project management fees, abnormal governmental permits or fees, interest during construction, inert gas fire suppression, exterior architectural enhancements, and abnormal civil, utility, site, or foundation costs. (These can add several millions of dollars to project cost.)
- Overall program costs must also be developed. (The *program* includes the building project, plus the IT, operations, and network costs to put the building to work as a data center.) These additions need to include: IT hardware costs, swing equipment, cabinets and structured cabling, communications, network and IT migration, transition to operations, tools and equipment for the facilities team, spare parts, etc.

- Location cost adjustments are necessary for high cost metropolitan areas such as New York, Chicago, or other abnormal construction cost areas.

Cautionary Note

Be suspicious of cost claims for functionality or capacity that are significantly less than that shown here. At least once a month, the Institute learns of grievous project mistakes made by the selective (mis)use of Institute white papers. It is not appropriate, nor wise, to base the financial success of any major multi-million-dollar project on free information (like that offered in this or other white papers). As a way to avoid these multi-million-dollar mistakes and unnecessarily foreshortened project life cycles, the Institute urges owners to obtain sufficient seed money to select the design and construction team and actually complete the conceptual design. The required seed money is normally between $300,000 and $1,500,000 depending on the size of the project. This approach permits the client to develop a realistic budget estimate based on early design assumptions incorporated into the project. This may not yield a complete design or exact cost estimate, but it will reduce uncertainty.

Availability, reliability, and power density goals should be confirmed before the design and construction team are selected. Specifics should be developed for the 16 site infrastructure subsystems that are required to achieve site availability; the initial and ultimate system capacities should be double-checked against Tier-level Certification requirements[*], as well as other Operational Sustainability[†] recommendations. These include site selection, staffing, training, and a number of other factors that should be addressed to assure ensuing operational success.

Conclusion

The primary drivers of data center construction cost are power and cooling capacity (or density), the Tier of functionality, and the size of the computer room. Traditional real estate cost models using cost per square foot imply that a square foot reduction will reduce total cost proportionally, which is not true. At current densities, cutting computer room space by 50% will reduce total cost by only 5%. To prevent sub-optimal decisions, this cost model is based on engine costs in kW plus square foot cost. As power and heat densities have increased, the costs of the mechanical and electrical infrastructure have become a bigger and bigger proportion of total construction cost. This trend is expected to continue. This cost model brings these factors explicitly into the cost equation.

Users are warned that the Institute's information is often tragically misapplied; owners, contractors, and equipment vendors make performance claims for their previous data center construction projects that are not supported by factual examination. To prevent career limiting mistakes, the Institute urges independent validation of capacity, redundancy, and functionality performance claims early in the project. If costs are dramatically lower than what is identified in this white paper, it is most likely that necessary systems and capacity are missing, and the resulting project will not be certifiable. Based on the Institute's experience, there is no "magic bullet."

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[*]The Institute offers a Tier Certification program that prospectively rates a future data center project by capacity and Tier Level for both design topology and for Operational Sustainability of the implementation. Based on actual execution and implementation, the Institute will provide a final certification. This methodology provides an owner with an independent perspective of the uptime effectiveness, Sustainability, and expected life cycle of their multi-million dollar investment.

The Institute has retained legal right to Certify sites to the Tier Classification System. The Institute has exclusively licensed ComputerSite Engineering, a management and engineering consulting firm, to perform inspection and validation utilizing the Institute's Tier Performance Standards and the Institute's comprehensive database of emerging industry problems and best design practices.

Only sites listed at www.uptimeinstitute.org/certifiedsites are Uptime Institute Tier Certified. Any site not listed by the Institute is self-certified. When submitted to the rigorousness of the Institute's standard, not all self-certified sites are found to be compliant to the desired Tier level. A lower-than-desired Tier level often results in the unnecessary waste of tens of millions of dollars.

[†]Operational Sustainability is the capability of a facility to deliver its performance objective over an extended period of time. Considerations include ease of operation, maintenance, and expansion. Sustainable sites have the ability to adapt and respond to business requirements over the long term.

Referenced and Related White Papers

The following white papers are referenced herein and can be found at uptimeinstitute.org/whitepapers:

- *Operational Sustainability and Its Impact on Data Center Uptime Performance, Investment Value, Energy Efficiency, and Resiliency*
- *Tier Classifications Define Site Infrastructure Performance*

Related Publications

Further information can be found at computersiteengineering.com/whitepapers:

- *Critical Environment Governance*
- *Critical Environmental Staffing Considerations*
- *Life Expectancy of Facilities Infrastructure*
- *Tier Technical User's Guide*

About the Authors

W. Pitt Turner IV, P.E. is a Distinguished Fellow and Senior Certification Authority for the Uptime Institute and a faculty member for the Institute's Site Uptime Network®. As a Principal of ComputerSite Engineering, Mr. Turner has personally guided billions of dollars in client site infrastructure investments. Prior to joining ComputerSite Engineering in 1993, Mr. Turner was Senior Project Manager for Pacific Bell's Fairfield Data Center; he was responsible for concept development, design, construction, and start-up for a 200,000-ft^2 facility. His work included the benchmarking of other data centers to help establish business-process improvements. He is a co-author of the Institute's Tier and Operational Sustainability white papers, among others.

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About the Uptime Institute

The Uptime Institute, Inc. is a pioneer in creating and operating knowledge communities for improving uptime effectiveness in data center Facilities and Information Technology organizations. The 100 members of the Institute's Site Uptime Network® are committed to achieving the highest levels of availability and many are Fortune 100 companies. Members learn interactively from each other as well as from Institute sponsored meetings, site tours, benchmarking, best practices, uptime effectiveness metrics, and abnormal incident collection and trend analysis. From this interaction and from client consulting work, the Institute prepares white papers documenting Best Practices for use by Network members and for the broader uninterruptible uptime industry. For the industry as a whole, the Institute publishes white papers, offers a Site Uptime Seminar Series, Site Uptime Symposium, and Data Center Design Charrette Series on critical uptime-related topics. The Institute also conducts sponsored research and product certifications for industry manufacturers. For users, the Institute certifies data center Tier level and site resiliency.

About ComputerSite Engineering

ComputerSite Engineering, Inc. is a data center engineering and management consulting firm working in close collaboration with the Uptime Institute to address technical aspects of contemporary data center issues. Independent of any Engineer-of-Record or manufacturer affiliation, ComputerSite Engineering's consulting teams help clients develop and execute solutions that are responsive to their unique business needs. Since 1985, ComputerSite Engineering has guided and justified data center investments for major organizations that require high levels of continuous availability to conduct business. ComputerSite Engineering's mission is to work with clients to ensure data centers are managed for uninterruptible uptime over sustained periods.

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