

Model-Based Data Centre Costing Approach

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Abstract
Data centres form a key part of the infrastructure upon which a variety of information technology services are built. They provide the capabilities of centralized repository for storage, management, dissemination and networking of data and information organized around a particular body of knowledge or pertaining to a particular business. The increasing demand for data storage and compute resources has driven the growth of large data centres: the massive server farms that run many of our present day internet and e-commerce applications with its attendant significant investment capital outlay and ongoing operating costs. This makes a critical examination of costs associated with building, operating and upgrading data centres imperative. For this cost model to meet the requirements of stakeholders it must capture the multidimensional complexities in power delivery, cooling, and required levels of redundancies for a specific service level agreement. However, non factoring of major total cost of ownership (TCO) parameters like amortization and maintenance costs for power, cooling and information technology resources in the cost model for data centres have questioned the reliability of this cost model, hence necessitate a research of this nature. To attack the problems identified above, I adopted a more accurate data centre construction cost model developed at HP Labs and adopted by the Uptime Institute Inc., to serve as a business intelligence tool for measurement and prediction of TCO and return-on-investment analysis.
Keywords: Data centres, cost model, service level agreement, TCO.

1 INTRODUCTION

For many years, the data centre industry has used dollars per square foot ($\$/ft^2$) of computer room space to benchmark the construction cost of a data centre. This approach has led many data centre owners to reduce the amount of space in an attempt to control project costs [1]. This approach generally produces disappointing results because it is based on a false premise. After reviewing 16 actual construction projects to identify their primary cost drivers, The Uptime Institute, Inc., developed a new and more accurate data centre construction cost model. This innovative data centre cost model emphasizes the "engine" capacity and functionality aspects of a data centre, in addition to the cost of space itself. In this model the key cost drivers are: power and cooling density (measured in total kW, watts per square foot or per square metre, i.e., W/ft^2 or W/m^2) or kW/cabinet), the Tier of functionality (Tier III Concurrently Maintainable, etc.) and the amount of computer room floor space (cabinets or space (ft^2 or m^2)). Many businesses operate outside of safe capacity thresholds with little or no room to expand [2 - 4].

According to IDG, the average data centre is 9 years old. The question is: As a business analyst, how can you avoid making major mistakes when entering the build and upgrade world of data centre business? The key lies in the methodology you use to design and build your data centre facilities. According to [2], [3] and [4] poor planning leads to poor use of valuable capital and can increase operational expenses, hence decreasing returns on investment.

In 1941, the successful revolution of data processing (DP) was started and hence the development of data centres (DaC). For the first time ever, engineer Konrad Zuse constructed an automatic computing machine – the Z3 – for the four basic arithmetic operations plus finding roots using electro-magnetic switches only from the world of telecommunications. This automatic machine in the "computing room", the living room of his parents, weighed more than a ton and had the gigantic power demand of 4,000 watts. The pioneer know-how of Zuse KG was integrated into the Siemens AG in 1967 and even today, it reflects our endeavour to push progress in DP technology and its related infrastructure.

The further development of information and communication technology (ICT) using electron tubes, magnetic storage devices and later semiconductor components has led to a world-spanning spread of data centres in science, industry and administration. In this way, the requirements regarding security and performance of the appertaining infrastructure were pushed upwards. The expansion of electronic data transfer, the networking of electronic media and, last but not least the spread of the Internet, in particular the "world wide web" developed at CERN (Conseil Europeen pour la Recherche Nucleaire) – the European Council for Nuclear Research, at the end of the 1980s generated a service sector in the field of data centres which grew dramatically and produced a growing demand for total availability and security of information, [8].

Modern data centres began in the 1960s as central locations to house huge mainframe computers and the associated storage devices and other peripherals [9]. Many definitions have been used to describe "data centres" such as [10], [11], [12], and [13]. Data centre, according to the online encyclopaedia (Wikipedia, 2014) is a facility used to house computer systems and associated components, such as telecommunications and storage systems, with their redundant or backup power supplies, data communications connections, environmental controls (e.g., heating, ventilation, air conditioning – HVAC, and fire suppression systems) and security devices. The main functions of a data centre facility are to centralize and consolidate information technology (IT) resources, house network operations, facilitate e-commerce and to provide uninterrupted services to clients on pay-per-use basis. These characteristics of data centres makes them much desired by large corporations that are involved in handling mission-critical, financial and analytics data processing applications, such as derivatives forecasting, risk and decision analytics and Monte Carlo simulations [6]. They may be, above all, highly functional buildings, but their design is evolving quickly, fuelled not only by the ever increasing need for efficiencies, infrastructure convergence and shared services, but also by the rapid growth, adoption and use of cloud-based computing solutions by top global information technology companies like Amazon.com, eBay, HP/EDS, IBM, Microsoft, Google, Salesforce.com, Oracle, Facebook and Yahoo! Inc respectively. Recent research report released by the Swiss-based World Economic Forum at Davos in collaboration with McKinsey and Co. [14] entitled, "The Risk and Responsibility in a Hyperconnected World," reveals that major information technology trends, including Massive Analytics, Cloud Computing and Big Data, can create between US $9.6 trn and US $21.6 trn in value for the global economy. According to International Data Corporation, global IT spending is somewhere in the region of over US $3.7 trillion (£2.3 trillion), and data centres, according to The Gartner group in its April 2014 forecast, will take up to US $143 bn by end of 2014 representing a 2.3 per cent increase from 2013 which closed at US $140 billion [14], [15] and [16], a high proportion of this expenditure is on servers, networking and storage devices which need to be housed in data centre facilities, due to the above reasons and myriad of others it makes a project of this type important so as to understand the underlying costs and complexities involved in developing such critical IT facilities and their underlying business models.

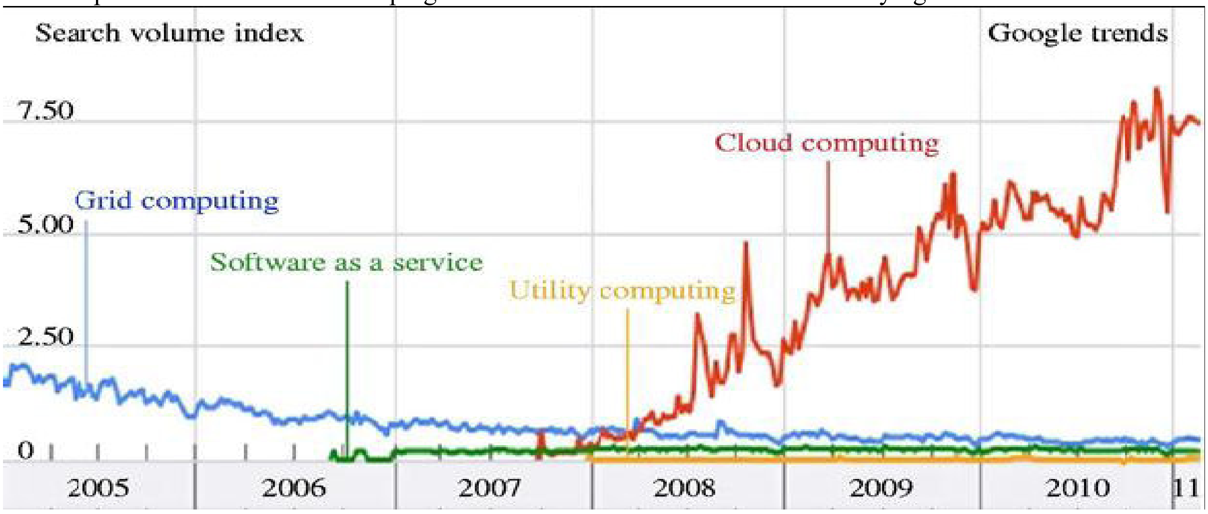

Figure. 2.1: Growth of cloud computing paradigm since 2005 (Source, Wikipedia, 2014).

Due to the explosive growth of data and the growing need to satisfy these data compute, storage and networking needs, it gave rise to the development of data centre facilities, which are houses that keeps storage servers for intensive computational purposes on pay-per-use basis. These data centres represent a significant investment in capital outlay and operating costs. These costs are spread on key components like: servers, power, network and building, as well as redundancies. The capitally-intensive nature of data centre facilities, has made it imperative for organizations to outsource their data centre and computing needs to independent service providers so as to leverage on the economies of scale of outsourcing such services and concentrate on their core business functions, [17].

According to *Cloud in Africa: Reality Check 2013 research study1*, released by World Wide Worx and Cisco. Nigeria lags substantially behind South Africa and Kenya with only 36 per cent of businesses currently using the Cloud via data centres, while about 50 per cent and 48 per cent of South African and Kenyan medium and large-scale businesses were already using cloud services. A significant 44 per cent of Nigerian businesses during the study said they will embrace the Cloud in the coming year, bringing the total in the country to 80 per cent by the end of 2014. This compares to 24 per cent of organisations in Kenya and only 16 per cent in South Africa, saying they will be taking up Cloud in 2014. According to the study, the key to the rapid adoption of Cloud computing in Nigeria and Kenya was found in the growing confidence that IT decision-makers have in the environment. "Even where confidence is not high, distrust in Cloud has almost entirely disappeared," revealed the report. Cisco Global Cloud Index Projected Cloud traffic is expected to dominate data centres in the third annual Cisco Global Cloud Index (2012 - 2017), [48], as shown below:

- Annual global data center IP traffic will reach 7.7 zettabytes by the end of 2017. By 2017, global data center IP traffic will reach 644 exabytes per month (up from 214 exabytes per month in 2012).
- Global data center IP traffic will nearly triple over the next 5 years. Overall, data center IP traffic will grow at a compound annual growth rate (CAGR) of 25 per cent from 2012 to 2017.
- Annual global cloud IP traffic will reach 5.3 zettabytes by the end of 2017. By 2017, global cloud IP traffic will reach 443 exabytes per month (up from 98 exabytes per month in 2012).
- Global cloud IP traffic will increase nearly 4.5-fold over the next 5 years. Overall, cloud IP traffic will grow at a compound annual growth rate (CAGR) of 35 per cent from 2012 to 2017.
- Global cloud IP traffic will account for more than two-thirds of total data center traffic by 2017.

In this paper, I reviewed related research works on data centre cost model by industry experts and researchers, with a view to identify the major cost drivers in a data centre cost model, and the mathematical relationship between them so as to provide an analytical framework or cost estimation model for effectively predicting and measuring the total cost of ownership(TCO) for data centres which will serve as a business intelligence tool for return-on-investment and profitability analysis, as well as other business decision processes, hence deepening understanding of the cost drivers of data centres, which provides insight into opportunities to control costs, [6].

2 LITERATURE REVIEW

Extensive research works have been done by experts and enthusiasts in modeling the cost of planning, developing and operating data centres. The first of such effort was an independent research commissioned and underwritten by IBM Deep Computing Capacity on Demand (DCCoD) team led by Koomey, Brill, Turner, Stanley, and Taylor in 2006, which produced a white paper titled: A Simple Model for Determining True Total Cost of Ownership for Data Centres. The research paper was published by the *Uptime Institute* In 2007, which is the global think tank on data centre-related issues [6]. There are no recognized standards for measuring the total cost of ownership (TCO) of the physical infrastructure of data centres and their support equipment. Simple cost models of summing the various CapEx and OpEx items do provide insight into total cash outlay, but they do not account for the utilization of the equipment and operating and maintenance costs, [18]. Previous TCO calculation efforts for data centres [1], [18] and [19] have been impressive, but generally have been incomplete and imperfectly documented, due to their use of total cost of ownership model or approach in isolation of other important cost parameters, hence ignores equipment and infrastructure operating, maintenance and amortization costs due to depreciation. These works have been impressive in providing insight into what it takes to build and operate a data centre, but generally limited due to their imperfect documentation and inability to capture the multidimensional complexities of data centre performance using cost metrics like: dollars per kW, dollars per square foot, watts per square foot, cost to build per square foot, dollars per kW, respectively. In all the researched literature on data centre cost modeling, the works of [1] and [19 - 30] were outstanding, more analytical and broad-based in that they came up with a more innovative and radical approach that involves combining the various data centre cost modeling parameters, so as to factor in the various amortization, operation and maintenance costs of the key cost drivers like: space, power, cooling and operations respectively.

3 KEY COST DRIVERS IN A DATA CENTRE COST MODEL

The following are the major cost parameters in a data centre facility viz:

- **Cost of Space:** The cost of land is directly connected to real estate prices and this varies greatly according to the geographic location of the data center. A comprehensive data center cost model must account for such variation in real estate price.
- **Recurring Cost of Power:** The electricity costs associated with continuous operation of a data center are substantial; the direct cost of drawing this power from the grid should be included. It is valued at about 10-15 per cent of total cost of the data centre.
- **Maintenance, Amortization (Depreciation) of the Power Delivery, Conditioning and Generation**: Data centers are a critical resource with minimally affordable downtime. As a result, most data centers are equipped with back-up facilities, such as batteries/fly-wheel and on-site generators. Such back-up power incurs installation and maintenance costs. In addition, the equipment is monitored continuously, and costs associated with software and outsourced services must be included.
- **Recurring Cost of Power required by the Cooling Resources:** The environment internal to the data centre must be maintained at a sufficiently low temperature for optimal rack operation. Since the electrical power consumed by the compute resources is dissipated as heat, an adequate cooling infrastructure is required for data centre operation. State-of-the-art cooling resources tend to require almost as much power as that dissipated by compute resources to affect heat removal; this is a substantial addition that should be factored into a data centre cost model.

- **Maintenance and Amortization (Depreciation) of the Cooling Resources**: Like the power system, data centres usually have backup chillers or air-conditioning units. The operation and maintenance (O&M) costs associated with the cooling infrastructure can be significant. In addition, the equipment is monitored continuously, and costs associated with software and outsourced services must be included.
- **Utilization of Critical Space**: The data centre is a critical facility, and therefore care is required to "right" provision the data centre resources. Sub-optimal operation (through "over-provisioning" or "under-provisioning" the available space) effectively raises the cost of ownership for a given data centre. Table. 5.1 below provide a rough guide to associated costs and assumptions made while determining the total cost of ownership for such facilities. Costs are amortized, i.e., one time purchases are amortized over reasonable lifetimes. By amortizing, we obtain a common cost run rate metric that we can apply to both one time purchases (e.g., for servers) and ongoing expenses (e.g., for power), [21].

Table 3.1: Guide to where costs go in the data centre

AMORTIZED COST	COMPONENTS	SUB-COMPONENTS
~45%	Servers	**CPU, memory, storage systems**
~25%	Infrastructure	**Power distribution and cooling**
~15%	Power Draw	**Electrical utility costs**
~15%	**Network**	**Links, transit, equipment**

Source: [21]

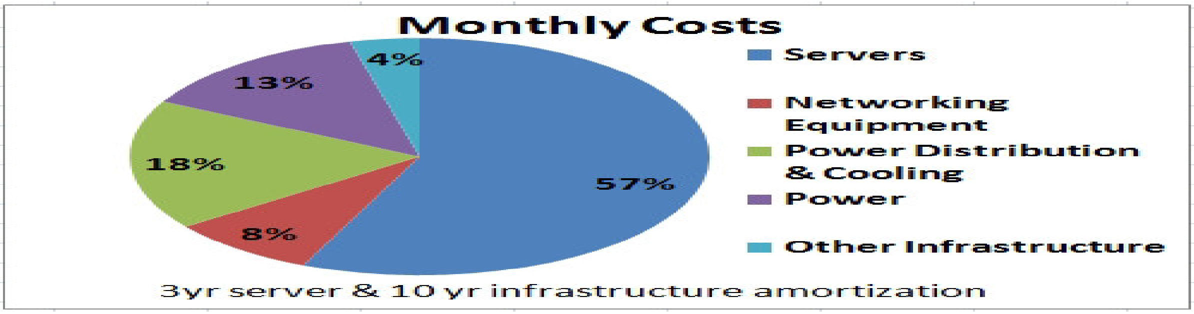

Figure.3.1: Pie-chart showing percentage that the various cost drivers takes in a typical data centre.

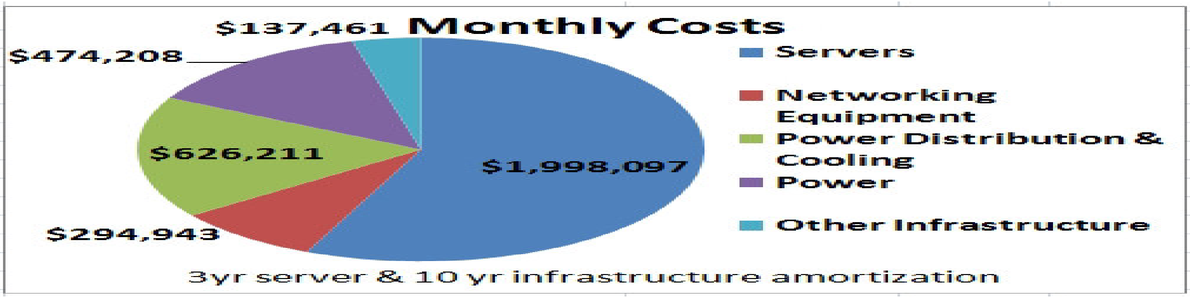

Figure.3.2: Pie-chart showing amounts of money (in US $) that the various cost drivers takes in a typical data centre.
Source: http://mvdirona.com/jrh/TalksAndPapers/PerspectivesDataCenterCostAndPower.xls

4 Data Centre Cost Modeling Assumptions

To determine the true total cost of ownership of data centres and express it on a per-rack basis requires a significant amount of data, including capital, engineering, installation, and operating cost data for the various elements of physical data centre or network room infrastructure, as well as design-related parameters such as: sq.feet per rack, watts per rack, utilization schedule, expected lifetime, redundancy options, et cetera. The typical data centre was defined to be one exhibiting the following characteristics in other to determine the TCO:

Table 4.1: Data Centre Cost Modeling Assumptions values

No.	PARAMETERS/VARIABLES	VALUES
1.	**Power Rating**	10MW
2.	**Power Density**	50W/ft^2
3.	**Life Cycle**	10 Years
4.	**Average Rack Power**	1500W
5.	**Redundancy**	2N
6.	J_1	1.33
7.	K_1	1.33
8.	K_2	1.0
9.	L_1	1.5
10.	**NOI**	\$50/ft^2
11.	$U_{\$, A\&M}$ **(Power)**	0.072/W
12.	$U_{\$,grid}$	\$100 MWh
13.	$A_{data\ centre}$	20,000 ft^2
14.	**% Occupancy**	50%
15.	$U_{\$, A\&M}$ **(Cooling)**	\$0.036/W

In order to model the total cost of ownership of a typical data centre, the following cost assumptions were made as shown in Table 3.1.3 below [6]:

Table 4.2: Data centre cost modeling assumptions for key cost drivers

#	COST COMPONENTS	VALUES		REMARKS
1.	Size of Facility (Critical Load)	8,000,000		***[Chosen to get ~50k servers -- As PUE improves, critical load goes up without total load changing]***
2.	Cost of Power ($/kwh):	\$0.072		***[Can range between just under \$0.03 and over \$0.15 depending upon region]***
3.	Cost Per Critical Watt in $/W	\$9.00		***[Uptime institute says \$12.50/W for tier II: http://uptimeinstitute.org/wp_pdf/%28TUI3029A%29Cost_ModelDollarsperkWPlusDollars.pdf]***
4.	Facilities Amortization:	120		**(10 Years)**
5.	Watts/Server	165		
6.	Cost/Server ($)	\$1,450.00		
7.	Server Amortization (months)	36		**(3 years)**
8.	Network Amortization (months)	48		***[4 years: most use 5 years today but this is trending down with move to commodity net gear and I think it'll be 3 years soon]***
9.	Annual Cost of Money (%):	5%		
10.	Average Load Critical Usage (%):	80%		***[Average % of provisioned power used]***
11.	Power Usage Effectiveness (PUE)	1.45		
12.	Power & Cooling Infrastructure (%)	82%		***[% of infrastructure that is power & cooling-- Christian Belady @ msft], [Excluding network egress charges, operating system and application stack costs all of which are workload & approach dependent]***

(Source: http://mvdirona.com/jrh/TalksAndPapers/PerspectivesDataCenterCostAndPower.xls).
(Note: All costs are in 2014 dollars, i.e., US \$1=165.76 Naira)

5 MODELING THE DATA CENTRE SPACE

The real estate value for commercial properties is typically estimated as the ratio of two parameters [43, 44]:

- **The Net Operating Income (NOI) per month**, which is usually calculated as the difference between gross income and operating expenses (without including debt service costs such as amortization, depreciation and interest), and
- **The Capitalization Rate ("cap rate"),** which is conceptually similar to the P/E (price/earnings) ratio in the stock market [Sivitinades, P., Southard, J., Torto, R. G., Wheaton, W. C., 2001,]. A P/E of 40 means the stock is selling at 40 times its current value, or it will take an investor 40 years to get his/her money back; similarly, the capitalization rate is a representation of the ratio of current valuation to expected return [Barclay Associates, 2004]. A cap rate of 10% is typical for most income property, although cap rates ranging from 9% to 13% may often be encountered [Simpson, J., Simpson, E., 2003]. Thus, the real estate value of a commercial property can be given as:

$$\mathbf{Price}_{\text{real estate}} = \frac{\mathbf{NOI}}{\mathbf{Cap\ Rate}} \quad \text{.......} \quad \mathbf{5.1}$$

Equation 5.1 is based entirely on the real estate value. For a data center, however, a difference is made between the *total space, active space,* and *leased space* [Blount, H. E., Naah, H., Johnson, E. S., 2001, Evans, R., 2003].The total property value of a data centre may include the real estate necessary for the plant chillers, power generation systems, and other auxiliary subsystems; however, operating income is typically only realized in that portion of the data centre which is populated with computing equipment [Ron, Kalich., and Gautam, Barua., 2002]. Thus, the level of occupancy in a given data centre should be included in the calculation of Eq. 5.1:

$$\mathbf{Cost}_{\text{space}} = \frac{(\mathbf{NOI/ft^2})\,(\mathbf{A}_{\text{data centre}})\,(\mathbf{\%\ Occupancy})}{\mathbf{Cap\ Rate}} \quad \text{.......} \quad \mathbf{5.2}$$

5.1 MODELING BURDENED COST OF POWER DELIVERY

While tenants in a rented house are billed based on number of rooms they are occupying, a data centre client-a given system housed in a given rack-requires conditioned power on a continuous basis, and has special requirements for cooling. In addition to the electricity costs for power from the grid, the power delivery system in a data center includes conditioning, battery back-up, on-site power generation, and redundancy in both delivery as well as generation. Depreciation (amortization) and maintenance costs are associated with the infrastructure required to enable each of these functions. Indeed, data centre experts often talk about conditioned power cost being three times that of grid power [42]. Thus, rather than just the direct cost of power delivery, a *burdened* cost of power delivery should be considered as follows:

$$\mathbf{Cost}_{\text{power}} = \mathbf{U}_{\$,\text{grid}}.\mathbf{P}_{\substack{\text{consumed}\\ \text{hardware}}} + \mathbf{K}_1\mathbf{U}_{\$,\text{grid}}.\mathbf{P}_{\substack{\text{consumed}\\ \text{hardware}}} \quad \text{.......} \quad \mathbf{5.3}$$

Where the power burdening factor K1 is a measure of the increased effective cost of power delivery due to amortization and maintenance costs associated with the power delivery system. It should be noted that depreciation is relevant to the maximum (rated) power capacity of the data centre, i.e. if a data centre is built and had equipment commissioned to operate at 10 MW, then the amortization costs will be derived from the capital necessary to enable a 10-MW delivery system. Thus, a data centre being operated at lower capacities inherently fails to adequately recover initial investment. Therefore, a penalty for sub-optimal operation should be inherently included in the K1 factor, which can be given as follows:

$$\mathbf{K}_1 = \frac{\mathbf{J}_1\mathbf{U}_{\$,\text{A\&M power}}}{\mathbf{U}_{\$,\text{grid}}} \quad \text{.......} \quad \mathbf{5.4}$$

Where J_1 is the capacity utilization factor, which is given as:

$$\mathbf{J}_1 = \frac{\mathbf{Installed\ (Maximum)\ Capacity\ [Watts]}}{\mathbf{Utilized\ Capacity\ [Watts]}} = \frac{\mathbf{P}_{\text{rated}}}{\mathbf{P}_{\text{consumed power}}} \quad \text{.......} \quad \mathbf{5.5}$$

From Eq. 5.4 K1 is the ratio of the realized (weighed) amortization and maintenance costs per Watt of power delivered to the direct cost of electricity (per Watt) drawn from the grid. This can be calculated on a monthly basis. J1 weighs the amortization costs by measuring the level of utilization of the conditioned space in the data center. Combining Eqs. 5.3, 5.4 and 5.5 we have:

$$\mathbf{Cost}_{\text{power}} = \mathbf{U}_{\$,\text{grid}}.\mathbf{P}_{\substack{\text{consumed}\\ \text{hardware}}} + \mathbf{U}_{\$,\,\text{A\&M}}.\mathbf{P}_{\substack{\text{rated}\\ \text{power}}} \quad \text{.......} \quad \mathbf{5.6}$$

Equation 5.6 gives the costs associated with power delivery to the data centre in terms of direct electricity costs ($U_{\$,grid}$) and indirect electricity costs (burdening factors, represented by $U_{\$,A\&M}$).

5.2 BURDENED COST OF COOLING RESOURCES

In addition to the power delivered to the compute hardware, power is also consumed by the cooling resources, [46 and 47]. Amortization and maintenance costs are also associated with the cooling equipment, so that the cost of cooling can be given as:

$$\mathbf{Cost_{power} = U_{\$,\ grid}.P_{cooling} + K_2U_{\$,grid}.P_{cooling}} \quad \ldots\ldots \quad \mathbf{5.7}$$

The load on the cooling equipment is directly proportional to the power consumed by the compute hardware. Representing this proportionality in terms of the load factor L1, we get:

$$\mathbf{P_{cooling} = L_1 . P_{\substack{consuned\\hardware}}} \quad \ldots\ldots \quad \mathbf{5.8}$$

Substituting Eq. 5.8 into Eq. 5.7:

$$\mathbf{Cost_{cooling} = (1 + K_2)\ L_1\ U_{\$,grid}\ P_{\substack{consumed\\hardware}}} \quad \ldots\ldots \quad \mathbf{5.9}$$

Where the cooling burdening factor **K_2** is a representation of the amortization and maintenance costs associated with the cooling equipment per unit cost of power consumed by the cooling equipment. As with the power delivery system, the **K_2** cost is based on the maximum (rated) power capacity of the data centre, i.e. if a data centre is built to operate at 10 MW, then the amortization costs will be derived from the capital necessary to enable the cooling system necessary for a 10-MW load. Thus, a data centre being operated at lower capacities inherently fails to adequately recover initial investment. Therefore, a penalty for sub-optimal operation should be included in the **K2** factor, which can be given as follows:

$$\mathbf{K_1 = \frac{J_1 U_{\$,A\&M\ power\ cooling}}{U_{\$,grid}}} \quad \ldots\ldots \quad \mathbf{5.10}$$

Where J_1 is the capacity utilization factor given by equation 5.5. It should be noted that the capacity utilization penalty of Eq. 5.10 is different from the load factor penalty of Eq. 5.8 in the sense that L_1 is non-optimal because of *design* inefficiencies in the cooling system, while J_1 is non-optimal because of *operational* inefficiencies in the data centre. Combining Eqs.5.5, 5.9 and 5.10:

$$\mathbf{Cost_{cooling} = U_{\$,grid}\ L_1\ P_{\substack{consumed\\hardware}} + U_{\substack{\$,A\&M\\cooling}}\ J_1L_1\ P_{\substack{consumed\\hardware}}} \quad \ldots\ldots \quad \mathbf{5.11}$$

5.3 OVERALL MODEL FOR COST OF SPACE, POWER AND COOLING

Since the key cost drivers in a typical data centre has been modeled [Eq. 5.2] as well as the recurring costs for burdened delivery of power [Eq. 5.3] and cooling [Eq. 5.9]. The next challenge is to determine the total cost of ownership for our hypothetical data centre. This (TCO) can be determined by changing the cost of space into a per month recurring cost estimate, this is to enable summation with the power + cooling costs. As a first-order estimate, we consider that the reason the data center space becomes more valuable than any other commercial property is because it is enabled by burdened power delivery and cooling resources. However, the costs for cooling and power are accounted for separately, i.e. if K_1, K_2, L_1 etc were all zero, then the value of the data center should become identical to that of any commercial real estate [19, 20, 30, 42]. Thus, the average $\$/ft^2$ commercial rates for the market can be used as a basis for determining the value of the data centre real estate. (The appropriate $\$/ft^2$ value will depend on the cap rate and other considerations discussed earlier in Eq. 5.1 to Eq. 5.2.) That is:

$$\mathbf{Cost_{space} \approx (\$/ft^2)\ (A_{data\ centre})\ (\%\ Occupancy)} \quad \ldots\ldots \quad \mathbf{5.12}$$

Where the $\$/ft^2$ is the average income per unit area that might be realized each month for a commercial property specific to the geographic area under consideration. Combining Eqs. 5.3, 5.9, and 5.12, the overall cost for data center space and power is obtained as:

$$\mathbf{Cost_{\substack{space\\cooling\\power}} = [(\$/ft^2)\ (A_{data\ centre})\ (\%\ Occupancy)]}$$

$$\mathbf{+\ [(1 + K_1 + L_1 + K_2L_1)\ U_{\$,grid}\ P_{consumed}]} \quad \ldots\ldots \quad \mathbf{5.13}$$

The first term in the above model represents the cost of the real estate, while the second term represents the combined costs of power for hardware and power for cooling equipment. Amortization costs as well as penalties for inefficient utilization of critical data center resources is captured in the multiplying factors K_1, K_2, and L_1. The remaining costs of operation, including personnel, licensing and software, are analyzed in the next section. The equation can be further simplified to cost out space in terms of critical space used in ft^2 as:

$$\mathbf{Cost_{space\ power\ cooling} = (\$/ft^2)\ (A_{critical,}\ ft^2) + (1 + K_1 + L_1 + K_2L_1)\ U_{\$,grid} * P_{consumed}} \quad \ldots\ldots \quad \mathbf{5.14}$$

5.4 DATA CENTRE MANAGEMENT AND OPERATING COSTS

Data Centre Management refers to the role of an individual within the data centre (data centre manager) who is responsible for overseeing technical and IT issues within the data center. This includes computer and server operations, data entry, data security, data quality control and management of the services and applications used for data processing. Data center management integrates into other IT systems for complete data synchronization including virtual systems, proprietary systems, and automation. Data center management requires a number of tools, IT policies and strategies to create and maintain a secure and efficient data center. It also entails monitoring and managing the performance of servers in a data centre. Data centre management aims to optimize the performance of data centre servers by tracking key metrics, such as CPU load and memory usage, for each server. Data centre management may require administrators to have visibility into both virtual and physical servers in the data centre, [19, 20, & 30].

5.4.1 CALCULATING THE TOTAL COST OF OPERATING AND RUNNING A DATA CENTRE

Here a summation of the total cost of operating and managing a data centre will be obtained viz:

5.4.2 PERSONNEL AND SOFTWARE COSTS

The objective of this project report is to focus on the physical space, power and cooling costs. However, in order to estimate the total cost, an estimate of personnel and software costs is not only necessary, but critical. The personnel costs associated with management of heterogeneous set of applications and physical compute, power and cooling resources across the data center needs to be captured. The emergence of utility models that address the heterogeneity at a centralized level enables one to normalize the personnel cost to the number of active racks in the data centre. Furthermore, in standard instances, there is a clear segregation of installations resulting from the need for physical security or due to high power density deployment of uniformly fully loaded racks, [19, 20, 30, & 42].

5.4.2.1 PERSONNEL COSTS

Personnel cost may be considered in terms of number of information technology (IT) facilities and administrative resources utilized per rack per month. These are internal personnel (excluding those covered by preventive maintenance contracts for power and cooling equipment) utilized per rack in a data center. Including costs for the average number of IT personnel per rack (M_1), the average number of facilities personnel per rack (M_2), and the average number of administrative personnel per rack (M_3), the total personnel costs are obtained as follows:

$$\mathbf{Cost_{personnel\ per\ rack} = (M_1 + M_2 + M_3)\ Savg = M_{total}\,.\,S_{avg}} \quad \ldots\ldots \quad \mathbf{5.15}$$

5.4.2.2 DEPRECIATION OF INFORMATION TECHNOLOGY EQUIPMENT

In a managed services contract, the equipment is provided by the data centre operator, and thus the total cost of operation must account for IT equipment depreciation. Assuming a rack full of industry standard servers, the list cost of IT equipment can be determined using manufacturer's list price. Using straight line depreciation, the cost of depreciation of a rack full of industry standard servers may be determined on a monthly basis as follows, [19, 20, 30, and 42]:

$$\mathbf{Cost_{depreciation\ per\ rack} = IT_{dep} = \frac{Rack\ Purchase\ Cost}{Lifetime\ of\ rack\ (usually\ 3\ years)}} \quad \ldots\ldots \quad \mathbf{5.16}$$

5.4.2.3 SOFTWARE AND LICENSING COSTS

In a managed services contract, data centre personnel administer the installation of the operating system (OS), patches and resources for load balancing. The user's only responsibility may be to manage the application on the server. The personnel and hardware cost associated with the data centre side of the cost is captured in sections 5.6.2.1 and 5.6.2.2, respectively. However, the software and licensing costs must also be applied to determine the overall cost. A first order strategy is to look at the total licensing cost, and the number of racks being utilized for IT purposes, and determine the cost on a per rack basis as follows, [19, 20, 30, 42]:

$$\mathbf{Cost_{software\ per\ rack} = \sigma_1 = \frac{Total\ licensing\ costs}{R}} \quad \ldots\ldots \quad \mathbf{5.17}$$

5.2.2.4 TOTAL COST OF RACK OWNERSHIP AND OPERATION

Combining Eqs.5.15, 5.16 and 5.17, the total costs of data centre operation/management can be estimated as, [19, 20, 30, and 42]:

$$\mathbf{IT\ Operation\ Cost_{total} = R\ (M_{total}\ S_{avg} + IT_{dep} + \sigma 1)} \quad \ldots\ldots \quad \mathbf{5.18}$$

Combining Eq. 5.18 with Eq. 5.14, the desired total data centre cost model in terms of critical space used in ft^2 will be:

$$\mathbf{Cost_{total} = (\$/ft^2)\ (A_{critical,}\ ft2) + (1+ K_1 + L_1 + K_2L_1)*U_{\$,grid}\ {}_*P_{consumed\ hardware} + R*(M_{total}S_{avg} + IT_{dep} + \sigma 1)} \quad \text{.......... 5.19}$$

6 CONCLUSION

Due to the explosive growth of data and the growing need to satisfy these data compute, storage and networking needs, it gave rise to the development of data centre facilities, which are houses that keep storage servers for intensive computational purposes on pay-per-use basis. These data centres represent a significant investment in capital outlay and operating costs. These costs are spread on key components like: servers, power, network and building, as well as other information technology redundancies. This research has successfully identified and modeled the critical cost parameters in a data centre.

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