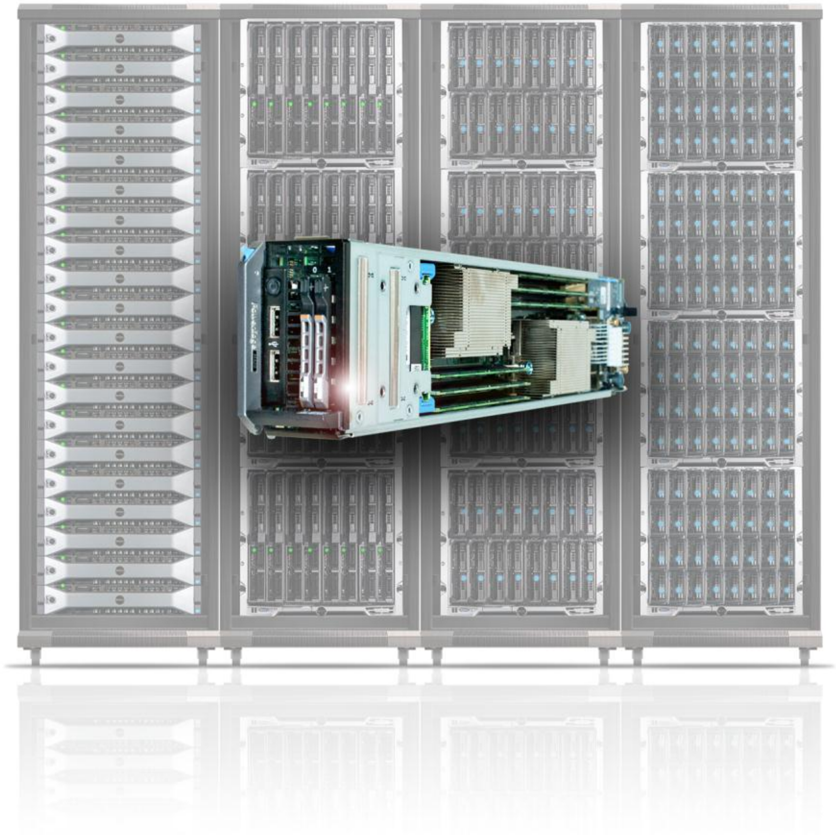
DELL AND THE VALUE OF DENSITY



A Principled Technologies white paper commissioned by Dell Inc.

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HIGH DENSITY SAVINGS

Dell™ PowerEdge™ high density server solutions give your business the potential to reduce CAPEX and OPEX through increased density.

Potential savings include:

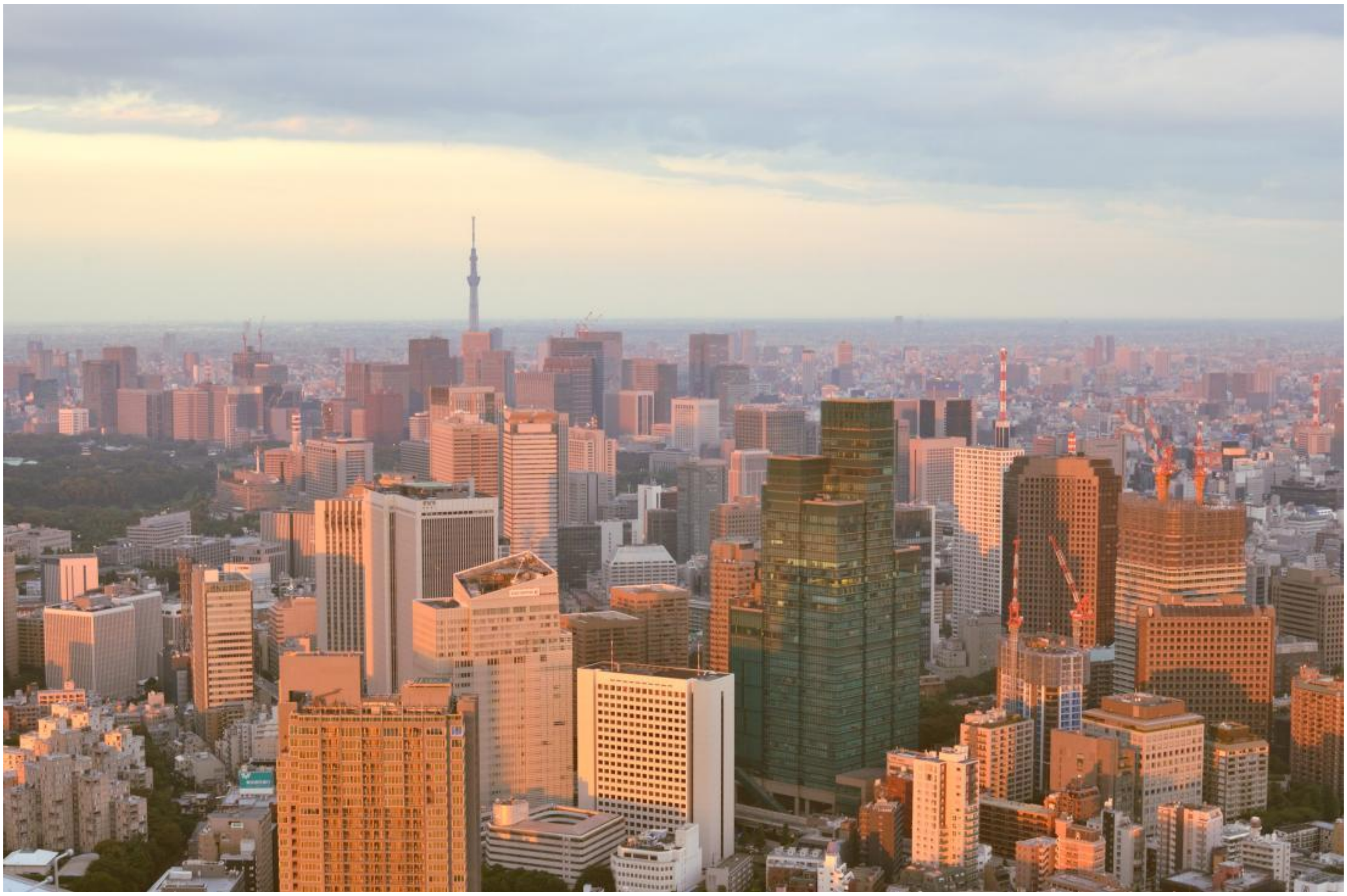
- The Dell PowerEdge M420, an ultra-dense quarter-height blade solution, could require 4.8x fewer racks for an equivalent number of processors, compared to a rack-based server solution. (pg. 21)
- The same study found that the M420 could result in a $2.5 million TCO savings over five years. (pg. 24)
- Consolidating legacy servers to current generation Dell PowerEdge 12G servers can provide as much as an 82% reduction in administration costs, and up to a 60% reduction in Microsoft® SQL Server® licensing costs. (pg. 12)
- Consolidating five legacy servers to a single PowerEdge server can provide up to $151,747 in total savings, including a 76 percent reduction in energy costs. (pg. 13)
- A high-density environment could yield $3.6M in savings versus a low-density environment over five years. (pg. 35)

EXECUTIVE SUMMARY

IT buyers face a dizzying array of choices, one of which revolves around a core issue in datacenter design – how physically dense should their datacenter be, and why? Today, businesses are implementing high-density computing solutions, such as the ultra-compact quarter-height Dell PowerEdge M420, to maximize return on investment and save management costs. Trends indicate that organizations will seek even higher densities in the future, using two approaches – a physical compaction of the datacenter and a logical compression achieved via virtualization. These related trends, coupled with the move towards greater power (kW) densities per rack, point to a dense compute future. Increasing physical measures of density, such as sockets per U or cores per rack, have the potential to improve the bottom line for companies.

Platforms such as the Dell PowerEdge M420 blade, which compresses up to 512 compute cores in a single 10U blade chassis, can help you realize this potential. For high-performance computing (HPC) environments or datacenters with a restricted physical footprint, this compression of compute power into smaller space is ideal. This is true even for customers who have already implemented blade server solutions – collapsing existing medium-density environments into smaller volumes can provide further advantages, such as providing the opportunity increased density with denser blade servers and new blade SAN storage technologies with no additional chassis costs.

In this paper, we define high density, discuss its relationship to the driving forces of virtualization and consolidation, and offer cost savings examples from various studies. We look at the entire density spectrum, including both rack servers and blade compute nodes, highlighting specifically the Dell hardware options and the enabling Dell technologies, such as iDRAC and Dell Lifecycle Controller, which make density with Dell a compelling choice.



The value of density

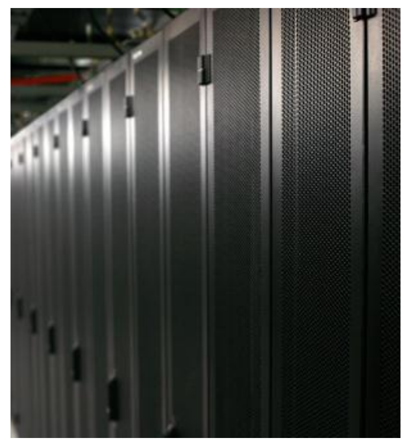
Doing more with less is a requirement if you want your business to thrive. Growing your business up to the sky is possible with ever-improving technology, which allows you to do more with less.

But growing a business is like growing a city. You reach boundaries where you can no longer grow outward—so you must either build up, or increase the usage density for the property you already have. In a city, that means building taller, more space-efficient places for people and businesses.

In a datacenter, you eventually face a similar decision—how do you increase your usage density without expanding physical datacenter space? With high-density computing infrastructure, you can shrink your server footprint and increase both your compute efficiency and costs savings for power and cooling.

Density – Top 5 benefits

What exactly is high density? At a physical level, it involves designing, building, and implementing compute infrastructure to occupy the smallest amount of physical space possible. Widening this definition beyond just physical compute power per square foot or sockets per rack unit (U), we can also define density from application and systems management perspectives. Using consolidation as a vehicle, companies can increase their logical density by collapsing many workloads and applications from legacy low-density solutions to fewer highly dense solutions using virtual machines (VMs). By reducing the number of physical servers and increasing the amount of work performed in less physical space, businesses can realize savings in management time, datacenter space, power and cooling costs, and even in systems management time and budget. We discuss and present multiple recent studies showing the benefits of consolidation in the Other consolidation studies to consult section below.



Benefits of increased server densities and consolidated workloads include the following:

- Consolidation efficiencies and performance benefits: Many studies show that simple consolidation exercises not only have the benefits listed below, but have the potential to dramatically increase performance for the organization.
- Capitalizing on generational improvements in hardware and systems management: Generational improvements in hardware let businesses take advantage of consolidation through virtualization and increase density in server deployments. Processor, RAM, and storage technologies all are improving at such a pace that updating hardware alone enables consolidation. Also, advances in firmware and software allow system administrators to manage larger units of work in a more streamlined manner, resulting in potential systems management savings.
- Physical space, power, and cooling savings: High-density virtualized solutions decrease the number of physical servers, which increases available floor space, allowing companies to utilize physical space more efficiently and free up area for new investments. As the physical

footprint of servers decreases, opportunities for power and cooling efficiencies increase.

- Infrastructure savings: High-density consolidated solutions can reduce build-out costs, as less square footage and cabling are required for denser solutions that require fewer physical servers.
- Software license savings: Per-processor licensing models favor placing the same software on smaller numbers of physical servers. Doing this intelligently can have a large impact on software licensing costs in the datacenter.

Datacenter managers and virtualization engineers in a variety of situations can realize these benefits, and many find that consolidation through virtualization and high-density computing targets the problems they face.

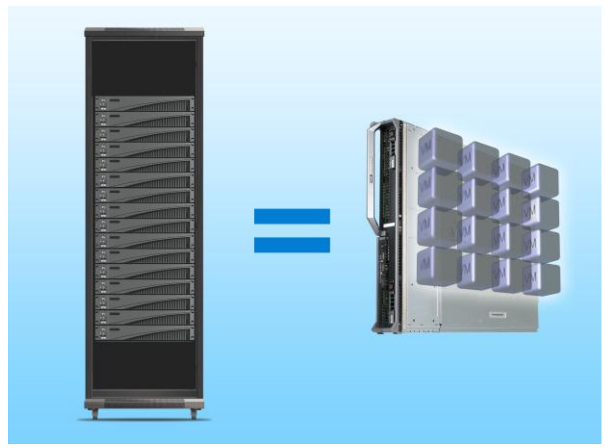
Datacenter managers, IT directors, and organizations as a whole face a common challenge without a simple solution. As server-based compute demands grow, there is finite physical space to grow out existing datacenters, and the cost to build new datacenter space is sometimes prohibitive. Recent studies show that datacenter costs range from $1,200[1] to $1,500 per square foot.[2] Properly employing consolidation and high-density practices allow you to avoid expanding your datacenter footprint as your server count or business demands increase.

All sizes of organizations can benefit from consolidating the workloads of legacy servers onto more powerful systems and climbing the density ladder as their requirements and resources allow. In this paper, we show that whether you are moving from a small, tower-based server environment to a single blade chassis or from a legacy rack-server farm to a high-density compute cluster, you can potentially reduce costs – in time, money, and power – for your organization by maximizing the density of your datacenter and applications.

WHAT DOES DENSITY MEAN?

For the purpose of this paper, we define density as the amount of work per rack unit a given environment can perform. Put differently, "The amount of work done per given amount of datacenter real estate is a function of the physical density of the servers as well as the logical density of the workloads within those servers."[3] Increasing density by this definition is possible by attacking the problem from two angles: increasing logical density through virtualization and increasing physical density by selecting servers with more processor cores that take up less physical space. When combined, these two approaches result in a powerful savings strategy for organizations.

Logical density – Consolidation via virtualization



Through virtualization, businesses have many different options for replacing older servers with new servers and virtualization software. Several approaches are possible to perform this transition, and the right approach will depend in part on many factors, including performance requirements, current application deployments, and budget, and may include more than one of the following:

- Physical-to-virtual migration (P2V) – in a P2V migration, IT staff migrate the operating system, applications, and data from legacy physical servers to virtual machines hosted on one or more servers running virtualization software.
- Virtual-to-virtual migration (V2V) – in a V2V migration, IT staff migrate the operating system, applications, and data from virtual machines on legacy physical servers to virtual machines hosted on one or more servers running virtualization software.
- Application migration – in a partial migration, IT staff migrate legacy applications, such as Microsoft® Exchange Server 2007 or Microsoft SQL Server® 2008, from older legacy servers to virtual machines on new servers. This type of migration does not include moving to new versions of those applications.

- Application migration with application upgrades – in a full migration, in addition to migrating from older legacy servers to new Dell PowerEdge servers, IT staff also upgrade the application stack. For example, IT staff may move application data from SQL Server 2008 R2 hosted on legacy servers to virtualized SQL Server 2012 instances on new servers. This type of migration allows businesses to take full advantage of new hardware and software and maximize the consolidation ratio.

Physical density - The density spectrum

To increase density, one option is to logically consolidate legacy physical servers' workloads on newer, more powerful servers - either as VMs or by collapsing multiple workloads onto a non-virtualized environment. Approaching the issue from a different perspective, datacenter managers and IT buyers can also choose to increase physical density by increasing processing power available in a certain amount of space, often described as processing power per U of rack space or processing power per square foot.

You've likely heard terms such as high density, low density, rack server, blade server, and converged solutions before, and you may know what they mean at a high level. But what do they mean, practically speaking, in a datacenter environment?

Datacenter density ranges from tower servers to highly dense compute nodes in hyperscale server farms. While not every organization requires the densest solution available, moving up the physical density spectrum has the potential to save businesses time related to managing infrastructure, power consumption, and other associated costs.

Low-density environments, such as small server closets or rooms common to small businesses, frequently use less expensive tower servers to meet their computing needs. Generally, these server infrastructures may not require additional equipment for power supplies or cooling, but these larger, less dense servers have a large physical footprint and may begin to take up a great deal of physical space as computing demand increases and the organization grows.

To avoid the cost of adding racks and any related switches and cables, an organization can instead choose to move up the density spectrum and replace their cumbersome servers with denser servers that pack similar processing power into just 2U of space. To realize even further savings, it's possible for businesses to invest in 1U rack servers.

When the compute density that rack servers provide is no longer enough, blade servers can increase density even further. Blade servers fit into blade chassis and offer greater flexibility for configuring a datacenter environment, allowing you to use integrated networking and storage or separate SAN storage with top-of-rack (ToR) switches. Like rack servers, blade servers come in different sizes: Dell offers blades that fill a whole chassis slot (8 per 10U), blades that fill half a chassis slot (16 per 10U), and blades that fill a quarter of a chassis slot (32 per 10U).

The most compute-heavy infrastructures tend to require the most compute-compact solutions available, such as ultra-dense PowerEdge M420 blade servers, which can run many workloads in a single chassis. This level of server density is frequently found in server farms and high-performance computing environments, where increasing density can reduce the number of buildings that house servers, for impressive savings.

Climbing the density spectrum and changing server types isn't the only way to maximize the density of your datacenter. Same-sized servers do not all utilize the same number of processors or cores, so upgrading and fitting more cores into the same amount of space will also provide you with more computing power per unit of space, for a more dense solution.

Clearly, increasing server density can deliver savings in a number of ways, from reducing the number of racks or chassis, switches, and cables to manage to maximizing and saving on datacenter space, both of which can affect an organization's bottom line.

THE DENSITY DECISION - TRENDS

As servers continue to make strides in both performance capacity and power efficiency, businesses turn to different technologies to increase server utilization and maximize return on investment for server capital expenditures. One such technology, virtualization, has facilitated server consolidation, which increases server density for businesses regardless of size or the number of servers in deployment. A 2012 survey, in fact, showed that x86 virtualization crossed a tipping point in 2012, with 51 percent of servers now virtualized.[4] That same study suggests the percentage of virtualized x86 servers will only increase, with more than two-thirds of those responding stating they have not yet virtualized their datacenter enough.

This industry trend in server computing can benefit both the emerging business concerned with datacenter expansion and build-out costs and the large enterprise with thousands of servers. Recent 2012 IDC data on server shipments show a growing trend in increased density in server deployments, and IDC expects blade servers and density-optimized solutions to continue to gain market share: "Together, blade and density optimized servers grew 15 percent in annual revenue and now represent 22 percent of the market. These modular form factors are expected to continue to gain adoption, with blades targeting virtualized environments in enterprises and density optimized servers targeting large-scale homogeneous environments in datacenters."[5]

Organizations are also increasing physical density by investing in more dense servers. Data from the Uptime Institute in 2012 shows this trend occurring year over year (See Figure 1).[6]

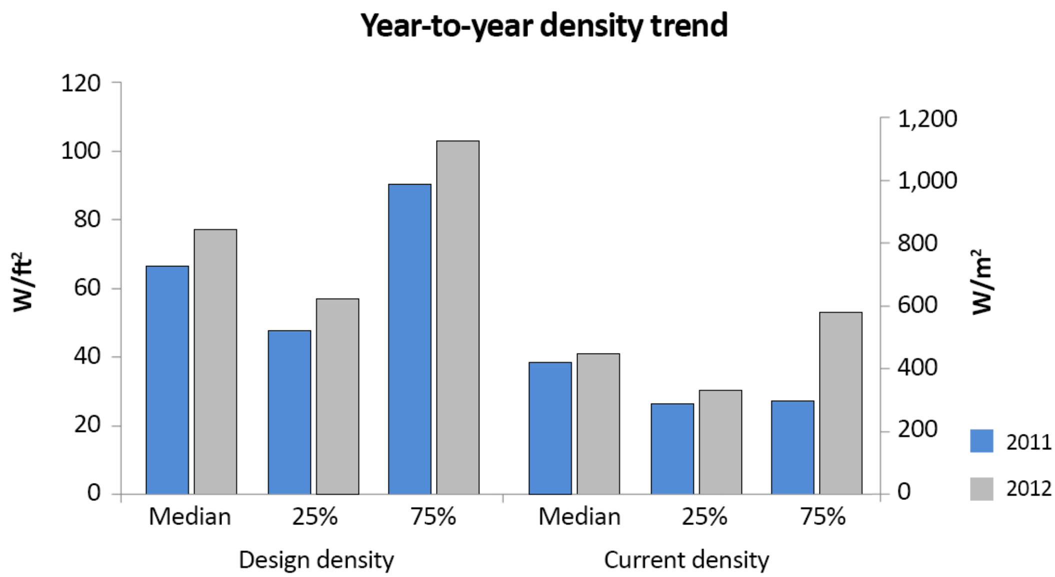


Figure1: Current and designed physical density trends.

DENSITY BENEFITS

Consolidation efficiencies and performance benefits

High-density server deployments provide businesses of all sizes with benefits through server consolidation. An emerging business replacing a larger quantity of tower or rack servers with just a single rack of servers or single chassis of blade servers, for example, can benefit immediately by reducing the number of physical servers that IT staff has to manage. Increasing IT management efficiency for the emerging business can reduce the ongoing operational expenses of growing IT demands.[7]

For the larger enterprise, consolidation to higher density servers can have a similar impact on a larger scale, potentially reducing not only the number of physical servers that IT staff has to manage, but possibly even facilitating consolidation of physical locations of servers that the larger enterprise and its IT staff have to support. For example, in a 5:1 server consolidation where one Dell PowerEdge R720 server replaces 5 legacy rack servers, annual administration costs could drop as much as 82 percent.[8]

For example, in a 5:1 server consolidation where one Dell PowerEdge R720 server replaces 5 legacy rack servers, annual administration costs could be reduced by as much as 82 percent.

For both emerging and established businesses, server consolidation can also lead to dramatic savings for application licensing costs. For example, the same study, looking at a sample 5:1 server consolidation, found that businesses could realize savings of up to 60 percent for SQL Server licensing. The savings in the first year alone from migrating to per-core licensing in SQL Server 2012 Enterprise Edition from per-processor licensing in SQL Server 2008 R2 Enterprise Edition would easily pay back the initial acquisition costs.

Businesses could realize savings of up to 60 percent for SQL Server licensing.

Recent studies proving the benefits of increased logical density

When you need additional application server capacity, simply adding more physical servers can create headaches rather than alleviating them. Where will the new servers go? What effect does adding physical servers have on power, cooling, infrastructure, and IT management costs? Instead of adding capacity through more physical servers, consolidation through virtualization increases application server capacity while also providing lower operational costs, as the specific examples below show.

Increasing Exchange Server capacity

First, we consider a business that needs to add additional capacity for Microsoft Exchange Server. Moving to a hosted Exchange environment or increasing the number of physical servers may be appealing options, but both can negatively affect the bottom line in both the short and long term. In a recent study in the Principled Technologies labs, we found that a Dell PowerEdge R720xd could handle four times the number of Microsoft Exchange workloads of an HP ProLiant DL380 G6, while also offering lower response times.[9] Consolidating four HP ProLiant DL380 G6 to just one Dell PowerEdge

R720xd offered not only lowered response times, but could reduce three-year TCO by as much as $19,028 and pay back the initial investment and migration in as little as 19 months. This includes saving as much as 77 percent annually in server administration costs and 67 percent annually in energy costs. While such a consolidation would improve the bottom line of any size business, the larger the scale of consolidation, the greater the savings.

Increasing SQL Server capacity with a full migration and application upgrade

Another recent PT study analyzed a sample business running out of capacity for a Microsoft® SQL Server® deployment. We found that adding servers would increase capacity, but would also increase operational expenses on top of the initial cost of the new servers, enough to be prohibitive. Server consolidation provides an opportunity to increase server capacity while lowering operational expenses. In the Principled Technologies labs, we found that Dell PowerEdge R720xd could support five times the SQL Server workload of a Dell PowerEdge 2950 III.[10] With a 5:1 consolidation ratio, a business moving from five Dell PowerEdge 2950 III servers to one Dell PowerEdge R720xd could lower three-year TCO by as much as $151,747.94 when also migrating to Microsoft SQL Server 2012 and its per-core licensing. In this scenario, where the operational savings due to lower Microsoft SQL Server licensing costs are significant, a business could achieve payback in as little as 5 months. Even when omitting Microsoft SQL Server migration and its related costs, a business could payback the initial investment in as little as 17 months. The Dell PowerEdge R720xd solution could save a business as much as 82 percent annually in server administration costs and 75 percent annually in energy costs.

Increasing SharePoint Server capacity by consolidating early

What about a business that only recently purchased new servers but is already running out of capacity for a SharePoint Server deployment? In the Principled Technologies labs, we compared a Dell PowerEdge R720 running SharePoint 2010 to an HP ProLiant DL380 G7 running SharePoint 2007.[11] We found the Dell PowerEdge R720 delivered 63.4 percent greater total performance, measured in requests per second. When replacing two HP ProLiant DL380 G7 servers with one Dell PowerEdge R720, a business in this scenario could achieve payback in just 36 months. While replacing servers relatively early in the lifecycle may not be ideal, a 2:1 server consolidation can still be a worthwhile investment. Moving to the Dell PowerEdge R720 could decrease total three-year operational costs by 50 percent, including a 55 percent reduction in server administration costs.

Replacing aging infrastructure to minimize unplanned downtime

For a business that needs to replace aging infrastructure, concern over the cost of new server hardware weighs against the cost of unplanned downtime from an increasingly likely server failure. In this scenario, the business also faces the task of consolidating a number of non-virtualized servers. In the Principled Technologies labs, we found that virtualizing eight 6-year-old HP ProLiant DL360 G4p servers onto a single Dell PowerEdge R720 could deliver 412.4 percent better performance for each database workload.[12] Even when also upgrading to Microsoft Windows Server 2012 and Microsoft SQL Server 2012 in the consolidation, a business could lower three-year TCO by as much as $64,035.[13] Moving from Windows Server 2003 and SQL Server 2005 may be seem like a costly and daunting task, but replacing legacy servers running outdated software with the Dell PowerEdge R720 can be a smart investment.

Other consolidation studies to consult

The benefits you can reap by maximizing virtual server density with consolidation via virtualization are many. At PT, we have performed a number of studies that show these performance and cost benefits with Dell PowerEdge servers such as the PowerEdge M420 and PowerEdge M620. For a list of studies supporting consolidation and density on Dell, see Appendix C.

Generational improvements that encourage density

Hardware advancements

In a year, or even months sometimes, hardware can improve in ways that vastly increases density potential. For example, in a Principled Technologies study, we found that a virtualized Dell PowerEdge R720xd with five virtual machines running Microsoft SQL Server 2012 delivered 461.7 percent more total performance than a legacy Dell PowerEdge 2950 III running SQL Server 2008.[14] The potential savings of increasing server density and replacing five Dell PowerEdge 2950 III servers with one Dell PowerEdge R720xd are enormous. We found that the potential savings in hardware, maintenance, power, and cooling costs in this scenario can lower total cost of ownership (TCO) over three years by as much as $151,747.94. The 5:1 server consolidation in this scenario can pay back the investment in hardware and the migration effort in as little as 5 months.[15]

Dell also provides the performance capacity needed for increasing density in blade server deployments. For example, in a previous study by Principled Technologies, we found that a Dell PowerEdge M620 was able to support up to 50 percent more virtual machines than the previous-generation HP ProLiant BL490.[16] Even while supporting more virtual machines, the Dell PowerEdge M620 and its new power-saving features offered 11.7 percent better performance per watt than the HP ProLiant BL490 did. According to that analysis, purchasing and running two new Dell PowerEdge M620 servers could give businesses a lower three-year TCO than running three HP ProLiant BL490 servers, with the Dell PowerEdge M620 solution providing payback within 25 months by consolidating the workload of the HP ProLiant BL490 solution.

Firmware and software advancements contribute to systems management advantages

Recent advances in systems management and power capping have changed how IT professionals work by simplifying the processes they need to follow in order to maintain their servers as well as unlocking more of the capabilities that are within the servers themselves. This has changed the impact of massively scaling out the number of compute nodes in a datacenter. While this previously required additional IT staff to take on the increased workload, adding compute nodes is now of very little consequence in the amount of daily work required by a company's IT department.

Traditionally, maintenance tasks such as configuring a server and updating the firmware took several hours for each system in the datacenter. BIOS settings, RAID controller settings, and several network adapters per unit needed to be configured by hand while directly connected to the server by an IT professional physically present in the datacenter. Dell servers use Integrated Dell Remote Access Controller 7 (iDRAC7) with Lifecycle Controller to speed up the management process.[17] IT administrators can connect to a system with no OS agent required; the connection to the iDRAC7 Enterprise is directly through the hardware, out of band. Such management tools allow IT staff to manage and patch hardware with ease. The iDRAC GUI allows administrators to connect to systems remotely and broadcast configuration settings to other systems with the push of a button. Administrators can quickly update firmware and drivers, as the Lifecycle Controller can pull them automatically from the Dell Repository Manager site.

A recent survey found that the number one concern of datacenter managers was the issue of running out of available power capacity in the near future.[18] Technology such as Intel® Node Manager provides a viable option to maximize existing power capacity through the power capping capabilities it provides in the latest release of Dell OpenManage™ Power Center.

The Dell OpenManage Power Center provides IT professionals the ability to manage their power budget from a system, rack, row, and room level all from one integrated interface using a predetermined rule-based approach. One would assume that if a system's power is capped significantly then performance would be negatively affected, but this is not the case. A recent evaluation of Dell OpenManage Power Center showed that power usage on a server can be capped to 80 percent of its original maximum, even at full CPU utilization, and experience just a 1 percent decrease in system performance.[19] This opens up a significant amount of power capacity that was previously unavailable in the datacenter. Equipped with these powerful new power management tools, datacenter managers can now confidently approach the idea of moving to a denser, virtualized consolidation solution without the fear of running out of available power capacity.

All Dell current generation servers come with the iDRAC7 with Lifecycle Controller and other management features that can speed up your move to a high-density solution

Physical space, power, and cooling savings

Datacenter space is extremely expensive, whether you rent space or have an in-house datacenter. This expense is not just a question of real estate square-footage, but the support infrastructure required to power, cool, and physically support the needs of thousands of rack-mount cabinets.

On a massive scale, a 2012 example of this concept in action is the Federal Government initiative to reduce their physical datacenter footprint: "As a result of the Federal Datacenter Consolidation Initiative (FDCCI), the number of government datacenters will shrink sharply from its current level of about 3,000 centers to about 1,800 by 2015 -- a reduction of 40 percent. Eventual savings could be in the range of US $5 billion."[20]

On a smaller scale, a coarse estimation method is to use synthetic benchmarking tools to estimate workload consumption of different form factor servers. Using the SPECint_rate2006 benchmark as a standard comparison point, the Dell PowerEdge M420, a high–density, two-socket quarter-height blade server, provides two times the performance of the Dell PowerEdge R900, a four-socket, 4U server.[21, 22] Considering that you can fit 128 PowerEdge M420 servers into one 42U server rack, this means that one rack of PowerEdge M420 blades could replace 26 racks of PowerEdge R900 servers (at 10 per rack) under conditions similar to the SPECint workload. Using SPECfp_rate2006 as the comparison point, the consolidation ratio jumps to a 39 to 1 advantage for the highly dense M420, which would allow you to reclaim an incredible amount of physical space.[23, 24]

Power and cooling savings

Reducing the number of physical servers through consolidation can also have significant benefits in power and cooling requirements for businesses of all sizes. As

Figure 2 shows, in our sample 5:1 server consolidation ratio, annual energy costs could drop by up to 76 percent.[25]

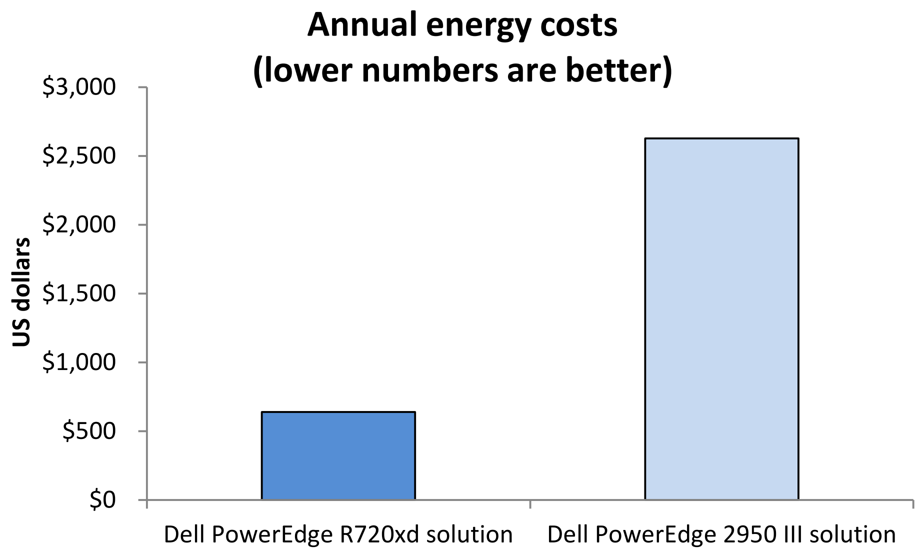


Figure 2: Sample annual energy cost comparison for a consolidated solution vs. running multiple physical legacy servers.

By virtualizing applications on a smaller number of servers, businesses can increase power and cooling efficiencies by increasing server utilization in the datacenter instead of powering a higher number of underutilized servers. For the large enterprise with servers on multiple sites, server consolidation could potentially reduce the number of physical locations to power and cool.

Using higher-density techniques, such as pressurized hot aisle/cold aisle cooling, sensors, dampers, fresh air cooling, and so on, air flow can be used much more efficiently than when using computer room air conditioners (CRACs). Other high-density cooling methods include water-cooled rack systems, which have the potential to reduce floor space usage significantly.

Infrastructure savings

Building Infrastructure savings

As organizations build new datacenters, they are choosing to move to physically dense solutions. Multiple studies have pointed to the lower cost to build and operate high-density datacenters compared to less dense datacenters.

A study from Emerson Network Power compares the cost for a 2,000 kW IT load at a low density of 400 racks averaging 5kW each versus a high density of 100 racks averaging 20kW each. They allowed 25 square-feet per rack and compared the costs for the resultant 10,000-square-foot low-density datacenter and the 2,500-square-foot high-density datacenter.[26] As Figure 3 shows, the study found that a high-density datacenter could provide well over $3 million in savings over 5 years compared to a low-density datacenter, using the example above.

The study found that a high-density datacenter could provide well over $3 million in savings over 5 years.

	Low density	High density	Difference (bolded = savings for high density)
Building capital costs at $250 per square foot	$2,500,000	$625,000	**$1,875,000**
Rack capital costs at $2,500 per rack	$1,000,000	$250,000	**$750,000**
Cooling capital costs	$830,000	$1,900,000	$1,070,000
Cooling operating costs (1 year)	$946,080	$525,600	**$420,480**
Total net savings of high density design			**$1,975,480**
5-year total net savings of high density			**$3,657,400**

Figure 3: Example savings of a high-density solution over 5 years, as reported from Emerson Network Power.

An earlier Intel study had similar findings – lower capital build costs and rack costs, higher cooling capital costs, and lower cooling operating costs created an overall large total net savings for the high density solution they analyzed.

A high-density solution could save well over $5 million dollars compared to a low-density solution.

The study compared costs for a low-density, 6.6kW-per-rack solution, and a high-density, 17kW-per-rack solution for 10,000 400W servers.[27] Figure 4 summarizes Intel's findings that a high-density solution could save well over $5 million dollars compared to a low-density solution.

	Low density	High density
Capital cost – building at $220 per square foot	$6,285,620	$2,393,600
Design cost for CFD	N/A	$54,440

	Low density	High density
Capital cost for raised floor	N/A	$250,240
Additional cost of lighting for bigger low density datacenter	$126,000	N/A
Racks	$1,875,000	$714,000
Operating costs - cooling	$1,091,000	$736,000
Total cost	$9,377,620	$4,148,280
Cost savings		**$5,229,340**

Figure 4: Example savings for a high-density solution, as reported by an Intel study.

Server infrastructure savings

Increasing density by maximizing processor count

One way to maximize density is to choose servers that have more processing power per U of rack space. Here, we show two examples of how you can move up the density spectrum with Dell rack and blade servers and the savings that are possible by choosing the denser solution. In the scenarios we analyzed, we found that the denser solutions could save on rack and chassis costs as well as power and cooling costs.

We compare datacenter costs for two rack server models deployed 20 to a rack: the 2U, two-socket Dell PowerEdge R720 and the 2U four-socket Dell PowerEdge R820. Then, we compare costs for two blade server models deployed in a fully populated chassis, with three chassis per rack: the two-socket, half-height Dell PowerEdge M620 blades and the two-socket, quarter-height Dell PowerEdge M420 blades.

For more details on assumptions and methodologies used in this analysis, see Appendix A.

We include the following costs in our analyses:

- Cooling equipment capital costs
- Building costs
- Rack capital costs
- Chassis capital costs (for blades only)
- Ongoing energy costs for power and cooling

Please note that we do not include server costs in this anaylsis, and only analyze datacenter costs.

Assumptions for our analyses

We made the following assumptions about the datacenter and its costs.

Assumptions	Value
Datacenter space per rack (in square feet)	27
Building cost $/sq foot	$250
Capital cost per rack for the rack and its installation	$3,000
Capital cost per M1000e chassis including redundant Dell Force10™ switches	$33,000
Number processors in solution	1,920
Cost per KWh of power and cooling	$0.11
Hours per year of datacenter operation	8,760
PUE (assume cost of cooling = .20 cost of power)	1.2

Figure 5: Assumptions for our 5-year TCO analysis.

Determining performance-equivalent configurations

In our analyses, we use processor count as a stand-in for performance equivalency. For each server, we estimate datacenter costs for configurations with 1,920 processors, which is the number of processors that fill 30 fully populated chassis of Dell PowerEdge M420 blades. At three chassis per rack, that is 10 racks of blades.

Figures 6 through 8 show the server counts for deployments of 1,920 processors for the two rack server models and two blade server models, along with a rack versus blade comparison. We also include rack counts for all four models and chassis counts for the blade servers.

Rack server configurations	Dell PowerEdge R720	Dell PowerEdge R820
Server socket count and rack units	2S,2U	4S,2U
Processors per server	2	4
Number of servers	960	480
Number of servers per rack	20	20
Number of racks	48	24

Figure 6: Equivalent deployments of 1,920 processors for the two rack servers.

Blade server configurations (in Dell PowerEdge M1000e chassis)	Dell PowerEdge M620	Dell PowerEdge M420
Server socket count and height	2S, half-height	2S, quarter-height
Number of servers	960	960
Number of servers per chassis	16	32
Number of servers per rack	48	96
Number of chassis	60	30
Number of racks	20	10

Figure 7: Equivalent deployments of 1,920 processors for the two blade servers.

	Dell PowerEdge R720	Dell PowerEdge M420
Server socket count and height or U	2S, 2U	2S, quarter-height
Number of servers	960	960
Number of servers per chassis	N/A	32
Number of servers per rack	20	96
Number of chassis	N/A	30
Number of racks	48	10

Figure 8: Equivalent deployments of 1,920 processors for one rack and one blade server.

Comparing the rack servers

Figure 9 compares cost estimates for the two- and four-socket 2U rack servers for configurations that include 1,920 processors filling 40U of datacenter racks. As Figure 9 shows, the higher-density four-socket, 2U Dell PowerEdge R820 servers in high-density 12kW racks can save up to $2,062,352.64 in datacenter costs over five years compared to the two-socket, 2U Dell PowerEdge R720 servers in medium-density 8kW racks. For details on this cost comparison, see Appendix A.

We calculate the 5-year cost subtotal for power and cooling at 1.2 PUE by multiplying the kWh for each solution by the cost per kWh (see Figure 5) by a PUE of 1.2 by five years.

Rack server comparison	Dell PowerEdge R720	Dell PowerEdge R820	Cost savings for the 4-socket R820
Server socket count and rack units	2S,2U	4S,2U	
Density (kW/Rack)	8	12	
Processors per server	2	4	
Number of servers	960	480	
Number of servers per rack	20	20	
Estimated power draw per rack (W)	6,480	9,360	
Number of racks	48	24	
kWh per solution	2,724,710	1,967,846	
Square feet (27 sq. ft. per rack)	1,296	648	
Cooling equipment capital costs (per rack)	$55,000.00	$75,900.00	
Building costs ($250/square foot) for feet used	$324,000.00	$162,000.00	$162,000.00
Rack capital costs ($3,000 per rack)	$144,000.00	$72,000.00	$72,000.00

Rack server comparison	Dell PowerEdge R720	Dell PowerEdge R820	Cost savings for the 4-socket R820
10GbEthernet switch and 10Gb and management cable costs	$1,020,844.80	$510,422.40	$510,422.40
Cooling equipment capital costs	$2,640,000.00	$1,821,600.00	$818,400.00
Capital cost subtotal	$4,128,844.80	$2,566,022.40	$1,562,822.40
5-year cost subtotal for power and cooling at 1.2 PUE	$1,798,308.86	$1,298,778.62	$499,530.24
5 year total	**$5,927,153.66**	**$3,864,801.02**	**$2,062,352.64**

Figure 9: Analysis of the savings possible over 5 years by choosing the denser PowerEdge R820 rack server.

Comparing the blade servers

Figure 10 compares cost estimates for the two-socket quarter-height and half-height servers for configurations that include 1,920 processors. We assume three full chassis per rack at the density we show in the earlier density calculation figure. As Figure 10 shows, the higher-density quarter-height PowerEdge M420 blades in high-density 20kW racks save can up to $2,601,606.73 in datacenter costs over five years compared to the half-height Dell PowerEdge M620 blades in lower-density 16kW racks. For this comparison, we include a cost of $33,000 per chassis to include the chassis and redundant Dell Force10 switches. For details on this cost comparison, see Appendix A.

We calculate the 5-year cost subtotal for power and cooling at 1.2 PUE by multiplying the kWh for each solution by the cost per kWh (see Figure 5) by a PUE of 1.2 by five years.

	16 x Dell PowerEdge M620 per Dell PowerEdge M1000e Blade Server Chassis	32 x Dell PowerEdge M420 per Dell PowerEdge M1000e Blade Server Chassis	Cost savings for the quarter-height M420
Server socket count and height	2-socket, half-height blades	2-socket, quarter- height blades	
Density (kW/Rack)	16	20	
Number of servers per chassis	16	32	
Number of servers	960	960	
Number of chassis	60	30	
Number of servers per rack	48	96	
Power capped power per rack (cap power at kW/rack)	16	20	
Number of racks	20	10	

	16 x Dell PowerEdge M620 per Dell PowerEdge M1000e Blade Server Chassis	32 x Dell PowerEdge M420 per Dell PowerEdge M1000e Blade Server Chassis	Cost savings for the quarter-height M420
kWh per solution	2,803,200	1,752,000	
Square feet (27 sq. ft. per rack)	540	270	
Cooling equipment capital costs (per rack) for this density	$94,133.00	$108,833.00	
Cooling equipment capital costs	$1,882,666.67	$1,088,333.33	$794,333.33
Building costs ($250/square foot)	$135,000.00	$67,500.00	$67,500.00
Rack capital costs ($3,000 per rack)	$60,000.00	$30,000.00	$30,000.00
Chassis capital costs ($33,000 per chassis)	$1,980,000.00	$990,000.00	$990,000.00
10Gb Ethernet switch and 10Gb and management cable costs	$63,802.80	$37,821.40	$25,981.40
Capital cost total	$4,121,469.47	$2,213,654.73	$1,907,814.73
5-year cost for power and cooling at 1.2 PUE	$1,850,112.00	$1,156,320.00	$693,792.00
5-year total	**$5,971,581.47**	**$3,369,974.73**	**$2,601,606.73**

Figure 10: Analysis of the savings possible over 5 years by choosing the denser PowerEdge M420 blade server.

Comparing two-socket, 2U rack servers and dense blade servers

Figure 11 compares cost estimates for 1,920-processor configurations of the two-socket quarter-height PowerEdge M420 blade servers and the two-socket, 2U rack servers. As Figure 11 shows, the higher-density quarter-height PowerEdge M420 blades in high-density 20kW racks save can up to $2,557,178.93 in datacenter costs over five years compared to the two-socket, 2U Dell PowerEdge R720 rack servers in lower-density 8kW racks. The M420 blade configuration includes 960 two-socket servers in M1000e chassis installed three chassis per rack. The rack server configuration includes 960 two-socket servers installed 20 to a rack. For this comparison, we include a cost of $33,000 per chassis to include the chassis and redundant Dell Force10 switches. For details on this cost comparison, see Appendix A.

We calculate the 5-year cost subtotal for power and cooling at 1.2 PUE by multiplying the kWh for each solution by the cost per kWh (see Figure 5) by a PUE of 1.2 by five years.

	Dell PowerEdge R720	Dell PowerEdge M420 blades in Dell PowerEdge M1000e Blade Server Chassis	Cost savings for the quarter-height M420
Server socket count and size	2S,2U rack server	2-socket,quarter-height blade	
Density (kW/Rack)	8	20	
Number of servers per chassis	N/A	32	
Number of servers	960	960	
Number of chassis	N/A	30	
Number of chassis per rack	N/A	3	
Number of servers per rack	20	96	
Estimated power draw per rack (W)	6,480	25,062	
Power capped power per rack (cap power at kW/rack)	N/A	20,000	
Number of racks	48	10	
kWh per solution	2,724,710	1,752,000	
Square feet (27 square feet per rack)	1,296	270	
Cooling equipment capital costs (per rack)	$55,000.00	$108,833.00	
Building costs ($250/square foot) for feet used	$324,000.00	$67,500.00	$256,500.00
Rack capital costs ($3,000 per rack)	$144,000.00	$30,000.00	$114,000.00
Chassis capital costs ($33,000 per chassis)	N/A	$990,000.00	-$990,000.00
10GB Ethernet switch and 10GB and management cable costs	$1,020,844.80	$37,821.40	$983,023.40
Cooling equipment capital costs	$2,640,000.00	$1,088,333.33	$1,551,666.67
Capital cost total	$4,128,844.80	$2,213,654.73	$1,915,190.07
5-year cost for power and cooling at 1.2 PUE	$1,798,308.86	$1,156,320.00	$641,988.86
5 year total	**$5,927,153.66**	**$3,369,974.73**	**$2,557,178.93**

Figure 11: Analysis of the savings possible over 5 years by choosing the denser PowerEdge M420 blade compared to a two-socket, 2U PowerEdge R720 rack server.

Software savings

Intelligently placing virtualized workloads on select physical hardware can enable targeted software license savings for organizations. Advanced management and consolidation analysis software can determine where costs advantages may exist in these scenarios.

One such example is CiRBA, a provider of consolidation analysis software, in early 2013 announced a Software License Control System that enables organizations to reduce the costs associated with processor-based software licensing by an average of 55 percent. The Software License Control module is an add-on to CiRBA's Capacity Control Console and optimizes VM placements in virtual and cloud infrastructure.

DELL OFFERINGS THAT CREATE VALUE FROM DENSITY

Dell offers server solutions across the spectrum to meet your density needs– from tower servers for the smallest businesses to highly dense server nodes for demanding HPC environments. With so many options to choose from, including different sizes and sockets of rack and blade servers, the Dell PowerEdge server portfolio can help you expand as your business does. By updating your infrastructure with new, more powerful servers, you can increase your workload density by virtualizing older legacy servers onto fewer new servers, and you maximize physical density to help save time, power, and money.

Dell offers enterprises "novel high-density blades," including the PowerEdge M420, which provides "some serious density." -Paul Venezia, Infoworld.com

In this section, we describe the options that Dell offers across the density spectrum, which Figure 12 summarizes. Dell current generation PowerEdge R series and PowerEdge M series servers incorporate systems management features such as the Dell Lifecycle Controller, implement leading industry power efficiency standards, and are designed to optimize performance while maintaining low power consumption.

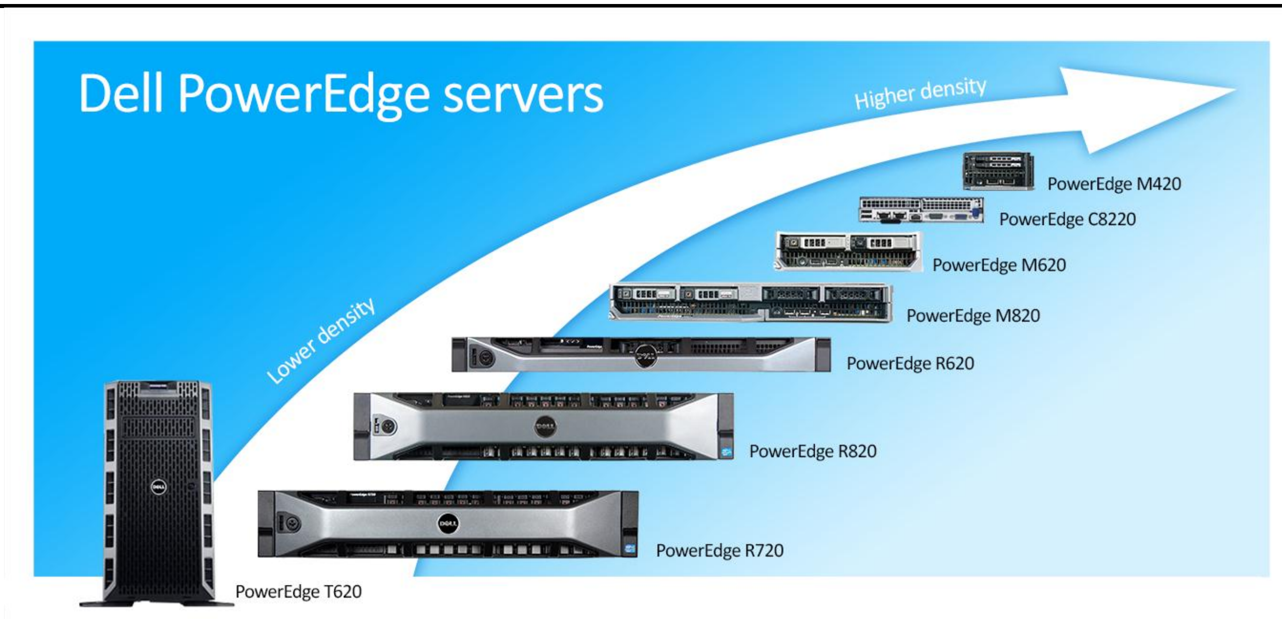


Figure 12: Dell PowerEdge servers along the density spectrum.

Quarter-height, two-socket blade: Dell PowerEdge M420 blade server

The quarter-height Dell PowerEdge M420 blade server sets a new standard for computing density in a blade environment, and uses the Dell PowerEdge M1000e blade enclosure. The M420 can double the core count per rack unit over half-height blade servers, as it features eight-core Intel Xeon® processor E5-2400-series units in a two-socket configuration to allow you to use your rack space to its maximum potential at 32 blades per 10U enclosure.

For more information about the quarter-height Dell PowerEdge M420, see http://www.dell.com/us/enterprise/p/poweredge-m420/pd.

Compute nodes for hyperscale datacenters: Dell PowerEdge C8220

For hyperscale environments, the Dell PowerEdge C8220 microserver with the PowerEdge C8000 chassis offers very high density. The platform combines compute, GPU, and storage nodes designed to run multiple applications in a single chassis.

Each compute node features two processors from the Intel Xeon processor E5-2600 family for up to eight cores, and the flexibility of the C8000 chassis' power supply options and the ability to meet your exact needs for computer, GPU, and storage requirements make the PowerEdge C8220 an ideal platform for large-scale highly dense environments.

For more information about the Dell PowerEdge C8220, visit http://www.dell.com/us/enterprise/p/poweredge-c8000/pd.

Half-height, two-socket blade: Dell PowerEdge M620 blade server

The Dell PowerEdge M620 is a half-height two-socket blade server powered by the Intel Xeon processor E5-2600 series that can hold up to 768 GB of RAM in 24 DIMM slots. The PowerEdge M620 comes standard with several management features, including iDRAC7 Express with Lifecycle Controller for Blades, which allow administrators to manage in physical or virtual environments locally or remotely. Along with other members of the M-series PowerEdge server line, the PowerEdge M620 fits right in with the power-efficient Dell PowerEdge M1000e Blade Enclosure.

For more information about the Dell PowerEdge M620, visit http://www.dell.com/us/enterprise/p/poweredge-m620/pd.

Full-height, four-socket blade: Dell PowerEdge M820 blade server

The Dell PowerEdge M820 is a scalable, full-height blade server powered by eight-core Intel Xeon processor E5-4600-series units in a four-socket configuration with the power needed to drive the most computation-intensive applications. The PowerEdge M820 supports up to 1.5TB of DDR3 RAM across 48 slots, providing both capacity and bandwidth to maximize throughput and reduce storage I/O. It has multiple hot-plug storage options including SAS, SSD, and Express Flash PCIe SSDs. Along with other blade servers in the PowerEdge line, the PowerEdge M820 fits right in with the power-efficient Dell PowerEdge M1000e Blade Enclosure.

For more information about the Dell PowerEdge M820, see http://www.dell.com/us/enterprise/p/poweredge-m820/pd.

Two-socket, 1U rack server: Dell PowerEdge R620

The Dell PowerEdge R620 is a two-socket server with eight-core processors that fits into just 1U of rack space. With up to 768 GB of RAM and holding up to 10 TB of internal storage, the R620 can run demanding workloads while maximizing the density of your rack server environment. The PowerEdge R620 offers a choice of network fabric technologies and optional hot-plug front-access PCIe SSDs for efficient management and performance.

In the past, server buyers were limited to 2U servers containing three PCIe expansion slots and having advanced networking options. This is no longer a restriction when selecting the Dell PowerEdge R620 – the Dell PowerEdge R620 has three PCIe slots and a bevy of advanced networking adapters to choose from. In contrast, the latest generation HP and IBM 1U competitors remain locked in at two PCIe slots.

For more information about the Dell PowerEdge R620, visit http://www.dell.com/us/enterprise/p/poweredge-r620/pd.

Four-socket, 2U rack server: Dell PowerEdge R820

Dell designed the four-socket Dell PowerEdge R820 to provide peak performance for compute-intensive tasks, making it a server capable of supporting expanding virtual environments.

The four-socket Dell PowerEdge R820, which takes up just 2U of datacenter rack space, features the Intel Xeon processor E5-4600 family and supports up to 1.5 TB of memory, making it a very memory-dense server. The R820 stores up to 16 TB of internal storage in a number of hot-plug hard drive options, including PCIe, SAS, and SATA SSDs, and SATA, SAS, and near-line SAS HDDs.

For more information about the Dell PowerEdge R820, visit http://www.dell.com/us/enterprise/p/poweredge-r820/pd.

Two-socket, 2U rack server: Dell PowerEdge R720

The Dell PowerEdge R720 is a 2U server that is powered by two processors from the Intel Xeon processor E5-2600 series. It was designed to handle complex workloads, with I/O and internal data management technologies (i.e., NSC, NPAR, CacheCade) to allow faster access to information and GPU accelerators for fast computational performance, making it a solid virtualization platform to consolidate legacy workloads.

The Dell PowerEdge R720 supports an impressive storage capacity for small business servers, and is available in both an 8-bay and 16-bay chassis. The Dell PowerEdge R720 holds up to 768 GB of RAM, many times the memory capacity of older comparable servers, and supports up to 32TB of internal storage.

For more about the Dell PowerEdge R720, see http://www.dell.com/us/enterprise/p/poweredge-r720/pd.

COMMON MYTHS ABOUT HIGH DENSITY

As technology evolves, certain barriers to technology adoption become less relevant. High-density computing is a prime example of technology that was once considered prohibitive but is now embraced by the technology industry. Advances in virtualization, power efficiency, and systems management have made several of the previously held negative views on high density computing less applicable. In this section, we outline some common myths about high-density computing, from both application and physical density perspectives. These myths have been disproved over the past few years, proving that what were once barriers to the adoption of high density computing may no longer apply.

Myth #1: Greater logical density increases risk of downtime

A common myth concerning workload consolidation is that moving distributed workloads onto a few servers increases the risk of downtime. The thought behind the myth is that if you reduce the number of servers in your datacenter, a hardware failure will impact a greater percentage of your business. Due to advances in virtualization and high-availability clusters that provide hardware redundancy, workload consolidation is considerably safer for your business and can actually provide greater uptime.

High-availability clusters provide protection for your data by having redundant servers, storage, and networking to eliminate any single points of failure within the cluster. A simple way to implement this type of cluster is through a 3-2-1 reference configuration that has been validated to work properly to provide the data and uptime protection required for your business.[28] With the hardware safeguards in place, this allows the virtualization software to manage the workloads and maintain their integrity.

Below are some of the data protection features offered in the latest releases of Microsoft Hyper-V™ and VMware® vSphere®, both leaders in the hypervisor market today.

- Allow for planned downtime by moving virtual machines and their storage to another physical server while keeping them fully functional during the move using Live Migration with Microsoft Hyper-V[29] or VMware vMotion™[30] and Storage vMotion[31] with VMware vSphere.
- Both Hyper-V Failover Clustering[32] and vSphere High Availability[33] (HA) protect your data during unplanned downtime by automatically detecting hardware failures, migrating the virtual machines to a backup server, and restarting them within minutes.

Myth #2: Greater logical density makes environments more difficult to manage

Many datacenter managers falsely believe that moving to a highly virtualized environment will makes systems management more complex. The progression of technology towards virtualization and consolidation has made this myth a thing of the past. Systems management has evolved to where many of its functions are integrated directly into the virtualization platform. The Dell management plug-in for VMware vCenter[34] is an excellent example of this integration.

The Dell vCenter plug-in allows systems administrators to manage both physical and virtual hardware all from one interface, andiDRAC7 with Lifecycle Controller allow admins to manage physical and virtual servers from one place. And with reduced cabling and port count, moving switches and machine connections from the physical to the virtual world further reduces the time needed to set up and administer servers.

Myth #3: Greater physical density significantly impedes compute efficiency

One of the most common myths about high-density solutions is that as compute density physically increases, processing efficiency decreases significantly. While this may have been true in the past, this is no longer the case. Advances in server power management, power delivery and consumption, as well as in microprocessor architecture have led to significant improvements in power versus performance efficiency. Studies and tests show the latest generation of servers can achieve great gains in density while also achieving the highest-ever scores in performance per watt.

SPECpower® is the industry-standard benchmark for measuring processing efficiency as related to power. The benchmark takes the ratio of processing capability (ssj_ops) divided by the amount of power used to perform these calculations (watts). The number of server-side java (ssj) operations (ops) performed at system load levels varying from 100 percent to 0 percent processor utilization are totaled and each is divided by the amount of power it took to run that workload level to give a total aggregate score. Figure 14 compares the processor density of a select group of Dell's latest generation servers. On this same axis is the published SPECpower score for each server. Figure 13 shows that as the processor density per U of the servers increases dramatically, there is just a small decrease in the power efficiency of the systems under test. [35,36,37,38,39] Organizations can now implement high-density solutions without the worry that they are trading power-efficiency for density.

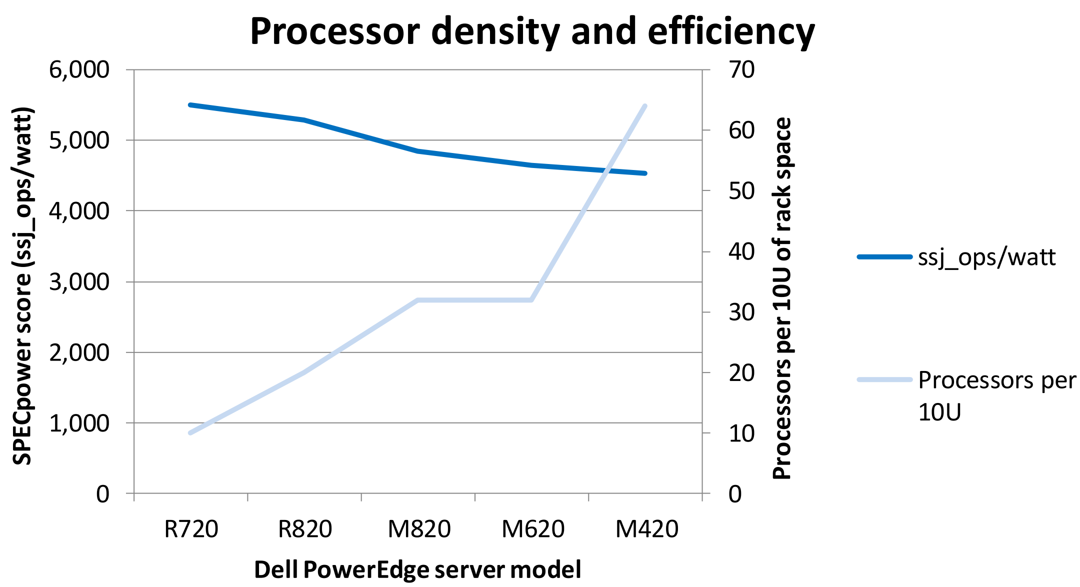


Figure 13: Dell PowerEdge servers and the relationship between processor density and power efficiency.

Myth #4: Greater physical density is expensive

Another common myth about high-density solutions is that they are costly to implement, not only up front but also on a recurring basis. To the contrary, recent studies by Emerson Power and Schneider Electric show that high-density datacenters are more power-efficient than low-density datacenters, and can provide a significant cost savings over the life of the datacenter.[40, 41] Replacing traditional forced air computer room air conditioning (CRAC) units with liquid-cooled top-of-rack chillers and containment aisles can provide a much more efficient use of power, lowering a datacenter's cooling costs. For example, consolidating the workload from 1,000 HP ProLiant DL380 G6 servers to 460 Dell PowerEdge M420 blades servers would use 59 percent less energy for power and cooling.

According to the Emerson study, changing the compute density of a datacenter from low to high can save new or retrofit datacenters an average of $3.65 million over the first five years of implementing the new solution. This means that investing in a high-density solution is not cost-prohibitive; it could actually save money for your business over time.

Changing the compute density of a datacenter from low to high can save new or retrofit datacenters an average of $3.65 million over the first five years of implementing the new solution.

Figure 14 compares the cost of cooling both high-and low-density solutions from the Emerson study, using traditional CRAC cooling versus specialized high-density cooling modules. It takes just half the electricity to cool the high-density solution, which can result in dramatic savings in operating costs.

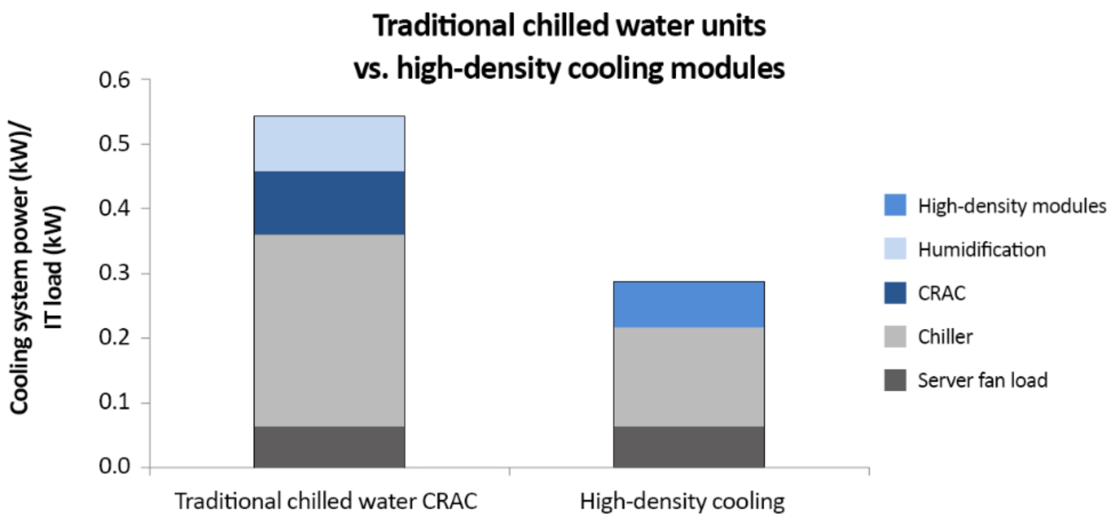


Figure 14: Traditional chilled cooling wattage versus high-density cooling module wattage.[42]

USE CASES – HIGH DENSITY IS VALUABLE

There are specific application density scenarios and datacenter scenarios with unique conditions that can make high density even more attractive. Not only can a high-density solution provide your organization with significant cost savings, but depending on which scenario applies, you can also find unique advantages to selecting high-density servers. Below we discuss specific use cases and stories of real customers and real density transitions and highlight savings and efficiencies these solutions can achieve.

Application density – The Enterprise server refresh

Virtacore Systems, Inc. a hosting solutions company that provides virtual servers in the cloud, had a significant need to upgrade its server and storage infrastructure. With more than 10,000 VMs in public and private clouds and a 99.999 percent availability guarantee made to its customers, management of the necessary hardware infrastructure to support Virtacore's business was becoming increasingly difficult for its IT staff.[43] Managing customer solutions in four datacenters across the country was becoming increasingly inefficient and negatively impacting the bottom line.

To address this problem, Virtacore standardized on Dell PowerEdge servers and Dell EqualLogic storage, allowing the company to take full advantage of management tools such as Dell OpenManage Server Administrator, Dell Remote Access Controller (iDRAC), Dell Lifecycle Controller, and Dell EqualLogic SAN HeadQuarters (SAN HQ). For example, with Dell Lifecycle Controller, Virtacore can now build a server image and easily deploy that image on multiple servers at a time, so that volume deployments now require significantly less time and less opportunity for human error. Lifecycle Controller also facilitates seamless server management, automating checks and installs for updates remotely over iDRAC.

Virtacore's entire business has benefited from moving to Dell hardware and management tools, from deployment to management to even the offerings it can sell to potential customers. Virtacore can now deploy new customer environments six times faster, and deploy individual VMs seven times faster. Virtacore estimates savings upwards of 1,000 hours a year that IT staff had previously allocated to server management and 400+ hours a year allocated to storage management.[44] These savings eliminated the need to hire additional IT staff to manage the growing data volume. New Dell EqualLogic storage paired with Dell PowerEdge servers also allowed Virtacore to expand its offerings with tiered storage performance options at different price levels.

Physical density - Co-location and hosted space

There is significant cost associated with each square foot of rack space that servers occupy in your datacenter. A recent study shows that for a Tier III-level datacenter building, real estate, power, and cooling costs can cost up to an estimated $900 per square foot when factored together.[45] As such, for many organizations, it is more cost advantageous to rent hosted or co-located space from a provider. Reducing your physical footprint in these hosted datacenters will maximize your return on investment by lowering recurring rental costs and providing flexibility by freeing up those funds for other strategic projects. Below, we offer two examples of this use case.

One common reason for renting rack space is disaster recovery; every business needs to have a disaster recovery plan in place to ensure the integrity of the company's data. A recent study shows that depending on the business, downtime can cost anywhere from $50K to over $6 million per hour.[46] According to industry standard best practices,[47] every disaster recovery plan should include off-site hosted servers at least 30 miles from the headquarters to reduce replication latency, as well as a second-tier site that is not in the same region in the event of a widespread disaster. According to the article "Using a colocation datacenter for disaster recovery," if a company chooses to use a service provider for their disaster recovery site, co-location can cost between $2,000 and $30,000 per month depending on the amount of rack space your servers use.[48] For example, according to Fogo Datacenters,[49] they offer entry-level co-location services starting at approximately $2,200 per server rack per month. This is $52 per U of rack space per month.

Faced with this wide range of cost, it is beneficial to minimize these monthly recurring costs by reducing the footprint of the servers your company needs at the disaster recovery site. Moving to a highly dense disaster recovery solution incurs hardware costs at the purchase stage, but could quickly pay for itself through the savings in monthly hosting service expenses.

A fine-grain example of a co-located servers is the high-frequency trading industry. High-frequency trading (HFT) is a class of stock trading that utilizes ultra-low latency connections between a stock exchange's execution engine and the firm's servers to take advantage of micro trends in the market price of stock to make huge gains in trading.

To take advantage of the lowest possible latency connections, global stock exchange firms have opened "liquidity centers."[50] These liquidity centers offer HFT firms the opportunity to rent co-location space right next to the stock exchange's execution engine servers, or in centers with dedicated and specially engineered communication to other trade exchanges. The cost to house servers in a liquidity center varies, but recent estimates put the price at $25,000 per month for each rack of servers you deploy within a liquidity center.[51] With that much capital to rent rack space alone, HFT firms can maximize their investment by deploying the densest compute solution available.

Physical density – Portability

In today's fast-paced world, having a capable IT environment is more important than ever, even in the most remote and harsh locations. In some economy sectors, the only way to have a datacenter in these environments is to bring the datacenter to the site. Self-contained, pre-configured portable datacenters such as the Dell Mobile

Datacenter solution[52] require only a generator to deploy and fit into sealed military-grade container. For these solutions, which are ideal for military field operations, remote scientific study, and disaster relief organizations, it is critical to pack as much compute power into this limited space as possible.

According to the Federal Emergency Management Agency (FEMA),[53] the first step in the disaster relief process is to have first responders set up a central field office to coordinate the recovery efforts. Connecting power to a portable datacenter and reestablishing communication can speed up this process dramatically.

High density is also extremely valuable for military, where mobile command centers are the communications hubs for units in the field, all while keeping the communications secure using the latest available encryption technology.

Physical density – HPC computing

High-performance computing is a tool that helps complete complex tasks, including automobile design and testing, cryptographic analysis, and even weather prediction. Organizations use HPC when they need to generate, process, and analyze large data amounts, and such infrastructures require many powerful servers. Organizations choosing the highly dense Dell PowerEdge M420 quarter-height blade servers for their CPU-intensive workloads on HPC clusters can benefit significantly, especially when compared to half-height blade and rack-mount servers.

For this analysis, CiRBA[54] analyzed the performance of a hypothetical set of 690 HPC workloads on a variety of blade and rack mount servers including the quarter-height Dell PowerEdge M420 blade, 1U Dell PowerEdge R610 rack server, and half-height HP ProLiant BL460c Gen8 blade server. For the simulation, the older Dell PowerEdge R610 was configured with two hex-core Intel Xeon processors X5690. The more current Dell PowerEdge M420 and HP ProLiant BL460c Gen8 servers were configured with two eight-core Intel Xeon E5-2670 and Xeon E5-2680 processors, respectively.

When modeling the HPC workloads on the target servers, CiRBA found that the workloads were primarily constrained by the compute capacity of the target servers. In the simulations, the Dell PowerEdge M420 quarter-height blade servers ran the workloads in a physical footprint that was 43 percent smaller than the HP ProLiant BL460c Gen8 and 77 percent smaller than the Dell PowerEdge R610 rack-mount servers.

ENGAGING WITH DELL

Dell Services, using analytics engines provided by CiRBA and others, offer a variety of assessment tools that can help you determine the best path forward on your density journey. Dell Services take an empirical approach to assessing where you are and defining the right strategies for driving increased virtualization, consideration of cloud strategies and increasing efficiency and density significantly and safely. These approaches drive maximum density while reducing risk. No matter what phase you are in on a path to consolidation and virtualization, Dell offers an appropriate and practical set of services to help you in your decision making.

SUMMING IT ALL UP

Businesses today want to get the most out of server infrastructure, and increasing density through new hardware investment, consolidation, and virtualization culminates in high-density datacenters that allow them to do just that. The greater number of workloads you are able to push into a smaller amount of physical space, the greater the potential for savings – time savings, money savings, and power savings. As we have shown, consolidating your low-density solution into a higher-density solution – moving up the density spectrum – has the potential to save you time, power, and money, regardless of the size of your organization. And no matter where you are on the density spectrum, Dell has a number of options through the rack and blade space, as well as highly dense compute nodes that can help move your design up the density ladder. From the small business running out of room to large service providers that need maximum processing power of an entire datacenter in the smallest possible space, moving up the density ladder matters and can help the bottom line immediately.

Increasing density has the potential to :

- Reduce management overhead with fewer physical servers to manage
- Lower the amount of power and cooling, saving on operating costs
- Save physical space and the costs related to renting space or building new locations to house servers
- Enable portability of dense computing solutions for remote locations
- Reduce infrastructure costs with fewer servers to house and cable
- Reduce datacenter software licensing costs

Whether you're looking to upgrade your current infrastructure, planning to build a new datacenter, seeking to simplify systems management, improve power and cooling efficiency, or seeking to reduce costs of operating expenses – businesses are consolidating and climbing the density ladder today, and you can too.

APPENDIX A – SERVER INFRASTRUCTURE SAVINGS DETAILS

In this appendix, we provide further detail on how we arrived at the costs in our rack and blade server cost comparisons in the Server Infrastructure savings section above.

Calculating chassis and rack count and costs for each solution

Our analysis included chassis and rack counts for supporting 1,920 processors. We calculated rack capital costs at $3,000 per rack for each server model and chassis capital costs at $33,000 per chassis for the blade server models. The chassis cost includes the cost of redundant Dell Force10 switches in each chassis.

Calculating power density requirements for each rack

We estimated the kW of power each rack requires. We used the Dell Energy Smart Advisor (ESSA) to estimate power for a configuration of each server. Within the tool, we configured a full rack of servers for each solution and requested results for the tool's computational load. For each configuration, we included the maximum number processors for each server, 64GB (8x8) GB memory per processor, two 128GB hard drives, and, where available, and an embedded RAID H310 controller. Because we wanted a reasonable power utilization estimate, we were not rigid in those selections – the M420 caps at six memory modules for two processors, so we configured it with 6x8 GB memory. We used the tool's estimate of total power consumption in watts to assign a rack density to each solution and to calculate the number of chassis per rack for the blade solutions. For these estimates we had four chassis in each rack. The middle column shows those results. Figure 15 estimates usage the energy usage of the four Dell server models.

Assigning appropriate datacenter power density

We assume that the enterprise can choose among four different datacenter power densities ranging from medium to high density: 8kW, 12kW, 16kW, or 20kW. Each datacenter could deliver on average the specified kW of power and cooling to each rack.

We estimated the power usage of a rack of each of the server models and determined the closest match of the four rack densities for that rack. Watts per rack estimates for four chassis of each blade solution exceeded our maximum density, so we used three chassis per rack for the estimates instead. The right-hand column in Figure 15 shows those assignments. For the two blade solutions, we assume datacenter IT uses power capping to keep rack power within the assigned limit.

Full rack solution (40u)	Estimated watts per rack using Dell ESSA tool	Density determination
20 x Dell PowerEdge R720 servers	6,480	Calculate costs for full rack at 8kW per rack density
20 x Dell PowerEdge R820 servers	9,360	Calculate costs for full rack at 12kW per rack density
64 x Dell PowerEdge M620 in 4 x Dell PowerEdge M1000e Blade Server Chassis	22,372	Calculate costs for 3 chassis at 16kW per rack and cap the power at 16kW
128 x Dell PowerEdge M420 in 4 x Dell PowerEdge M1000e Blade Server Chassis	33,416	Calculate power for 3 chassis at 20kW per rack and cap power at 20kW

Figure 15: Power density requirement calculations for each rack.

Estimating cooling equipment capital costs and building costs

We used the estimate from Figure 15 above and Schneider electric tool estimates on cooling equipment costs estimates for racks of this density and multiply that by the rack count for the solution. Those results are in Figure 10. We estimate cost per square foot for datacenter construction at $250 per square foot for 27 square feet of datacenter space per rack.

Calculating energy costs for power and cooling

We also estimate an annual cost for power and cooling that we multiply by the 5-year expected life of the solution. The power cost is calculated using a value of 11 cents per kWh. We assume an efficient datacenter operating at 1.2 PUE on average and estimate the energy cost to cool the servers at 20 percent of the energy cost to power the servers.

Switch and cable costs

For each configuration we compare the prices of 10Gb Ethernet switches, using Dell PowerConnect™ 8100 series switches and the cables to connect the rack servers or blade chassis to the switches. We assume each rack server is already configured with a dual-port 10Gb Ethernet card. We include redundant Dell Force10 switches in the prices of the chassis elsewhere in this model. We also include prices for a single management cable from the rack servers or blade chassis for managing the servers through Integrated Dell Remote Access Controller 7 (iDRAC7) with Lifecycle Controller technology.

10Gb Ethernet switches

We priced 64-port and 32-port models of the Dell PowerConnect 8100 series switch, and use whichever one best fits each server configuration. The Dell PowerConnect 8164 switch, with a list price of $25,752 includes 48x 10GBase-T + 2x

40GbE base ports, up to 64 ports max via a 40GbE Module, which we included. The starting price of the Dell PowerConnect 8132 32-port switch is $15,836 for a model that includes 24x 10GBase-T ports, up to 32 ports max via a 40GbE Module, which we included. For both models, the price includes 3-Year ProSupport and NBD On-site Service. We include redundant Dell Force10 switches in the prices of the chassis elsewhere in this model.

For the rack server configurations, we price 64-port switches, with redundant switches for each set of three racks, using 60 of the 64 ports on each switch. Each 42U rack in these configurations holds 20 servers and has 2U free; the 1U switches will fill that free top of the rack space on every third rack.

For blade server configurations with fewer than 32 chassis, we price redundant 32-port switches. For bigger configurations we use the 64-port switches. At three 10U chassis per rack, the racks have ample spare room for the 1U switches.

TwinAx cable

For each port we use, we also add in the $99.99 price of a PowerConnect SFP+ 7 meter TwinAx cable.

Management cables

For each rack server or each blade server chassis we include a single management cable. We assume the datacenter can acquire these for $5 each.

Higher-density Dell PowerEdge R820 rack servers save on switch and cable costs over Dell PowerEdge R720 rack servers

960 Dell PowerEdge R720 rack servers in 48 racks require 32x 10Gb Ethernet 64-port switches and 1,920x 10Gb cables and 960 management cables. The 4S Dell PowerEdge R820 servers fit the same number of processors in half the number of servers and use only half the switches and cables of a configuration of Dell PowerEdge R720 rack servers with the same processor count.

The higher-density Dell PowerEdge R820 rack servers save $510,422.40 on switch and cable costs over the 2S, 2U rack servers. This solution saves 16U in rack space for the switches. Dell lists the maximum wattage at 395W for the 64-port switch.[55] The fewer and smaller switches needed for the Dell PowerEdge R820 rack server configuration draw 6,320 fewer watts based on their maximum wattage ratings. Figure 16 compares switch and cable cost estimates for the rack servers.

Switch and cable costs	Dell PowerEdge R720 rack servers		Dell PowerEdge R820 rack servers	
	Quantity	Cost	Quantity	Cost
10Gb Ethernet 64-port switch	32	$824,064.00	16	$412,032.00
10Gb cables	1,920	$191,980.80	960	$95,990.40
Management cables	960	$4,800.00	480	$2,400.00
Total		**$1,020,844.80**		**$510,422.40**
Savings for Dell PowerEdge R820 rack servers				**$510,422.40**

Figure 16: R720 and R820 switch and cable costs.

Higher-density Dell PowerEdge M420 blade servers save on switch and cable costs over Dell PowerEdge M620 blade servers

960 Dell PowerEdge M620 blade servers in 60 chassis on 20 racks use two 10Gb Ethernet 64-port switches and 120 10Gb cables and 60 management cables. 960 quarter height Dell PowerEdge M420 blade servers in 30 chassis require two 10Gb Ethernet 32-port switches, 60x 10Gb cables, and 30 management cables at a savings of $25,981.40 over the Dell PowerEdge M620 blade server configuration with the same number of servers and processors. Both solutions use 2U in rack space for the switches. Dell lists maximum wattage at 240W for the 32-port switch and 395W for the 64-port switch. Using those estimates, the smaller switches needed for the Dell PowerEdge M420 blade server configuration draw 310 fewer watts. Figure 17 compares switch and cable cost estimates for the blade servers.

Switch and cable costs	Dell PowerEdge M620 blade servers		Dell PowerEdge M420 blade servers	
	Quantity	Cost	Quantity	Cost
10Gb Ethernet 64-port switch	2	$51,504.00	0	$0.00
10Gb Ethernet 32-port switch	0	$0.00	2	$31,672.00
10Gb cables	120	$11,998.80	60	$5,999.40
Management cables	60	$300.00	30	$150.00
Total		**$63,802.80**		**$37,821.40**
Savings for Dell PowerEdge M420 blade servers				**$25,981.40**

Figure 17: M620 and M420 switch and cable costs.

Higher-density Dell PowerEdge M420 blade servers saves on switch and cable costs over Dell PowerEdge R720 rack servers

960 Dell PowerEdge R720 rack servers in 48 racks require 32x 10Gb Ethernet 64-port switches and 1,920x 10Gb cables and 960 management cables. 960 Dell PowerEdge M420 blade servers in 30 chassis require two 10Gb Ethernet 32-port switches, 60x 10Gb cables, and 30 management cables at a savings of $983,023.40 over the Dell PowerEdge R720 rack server configuration with the same number of servers and processors. This solution saves 30U in rack space for the switches. Dell lists maximum wattage at 240W for the 32-port switch and 395W for the 64-port switch. The fewer and smaller switches needed for the Dell PowerEdge M420 blade server configuration draw 12,160 fewer watts based on these maximum wattage ratings. Figure 18 compares switch and cable cost estimates for the two servers.

Switch and cable costs	Dell PowerEdge R720 rack server		Dell PowerEdge M420 blade server	
	Quantity	Cost	Quantity	Cost
10Gb Ethernet 64-port switches in redundant configuration	32	$824,064.00	0	$0
10Gb Ethernet 32 -port switches in redundant configuration	0	$0.00	2	$31,672.00
10Gb cables	1920	$191,980.80	60	$5,999.40
Management cables	960	$4,800.00	30	$150.00
Total		**$1,020,844.80**		**$37,821.40**
Savings for Dell PowerEdge M420 blade servers				**$983,023.40**

Figure 18: R720 and M420 switch and cable costs.

APPENDIX B – ABOUT THE CIRBA STUDY

In this appendix, we provide details about the study CiRBA conducted, with information they provided. For this analysis, CIRBA provided access to their consolidation simulation tools, and tested a number of server models running compute-intensive workloads like those that HPC computing would run. Figure 19 shows the server models they used in their simulation, along with their configurations, CINT2006 scores, and the rack units that they occupy in a datacenter. As the data shows, the quarter-height Dell PowerEdge M420 scores slightly less than the HP ProLiant BL460c Gen8, but it packs that comparable performance in half the space, which can greatly increase the density of a datacenter.

Model name	Description	Processor	Memory	CINT2006 Rate CPU benchmark score	Rack units
Dell PowerEdge M420	Current-generation quarter-height blade	2 x Intel Xeon E5-2470 (2300 MHz, 8 cores)	96 GB	551	0.3125U (32 blades/10U)
Dell PowerEdge R610	Previous-generation 1U rack	2 x Intel Xeon X5690 (3460 MHz, 6 cores)	96 GB	415	1U
HP ProLiant BL460c Gen8	Current-generation half-height blade	2 x Intel Xeon E5-2680 (2700 MHz, 8 cores)	128 GB	637	0.625U (16 blades/10U)

Figure 19: Server models, benchmark results, and rack units for the servers in the CiRBA simulation.

CiRBA ran their simulation of a migration of 690 hypothetical compute-bound HPC workloads using the following assumptions:

- CPU and memory utilization on target server does not exceed 70 percent and 90 percent
- Primary constraint is CPU capacity of the target servers

Figure 20 compares the density of the server running the HPC workloads in the simulation.

Model name	Number of servers of required	Rack units per server	Percentage larger footprint than the M420
Dell PowerEdge M420	8	2.5U	
Dell PowerEdge R610	11	11U	440%
HP ProLiant BL460c Gen8	7	4.4U	176%

Figure 20: The density of the servers running HPC workloads in the simulation.

Figure 21 shows a screenshot of the HPC workload simulation results, provided by CiRBA.

Name	Systems Analyzed	Server Models Used	Consolidation Ratio (N:1)	Annotation
Dell M420 (Current gen 1/4 height blade)	690	**8**	86.3:1	2.5U (8/32 of 10U chassis)
Dell R610 (Previous gen 1U rack server)	690	**11**	62.8:1	11U
HP BL460c G8 (Current gen 1/2 height blade)	690	**7**	98.6:1	4.4U (7/16 of 10U chassis)

Figure 21: Screenshot from CiRBA's HPC workload simulation.

APPENDIX C – RECENT PT STUDIES SUPPORTING CONSOLIDATION AND DENSITY BENEFITS

At PT, we have performed a number of studies that show the performance and cost benefits of consolidation and density. Figure 22 lists the most recent studies.

Title	Link
Dell PowerEdge M420 blade server solution with Dell EqualLogic storage delivered database clustering performance	http://www.principledtechnologies.com/Dell/M420_database_0912.pdf
Server consolidation and TCO: Dell PowerEdge M620 vs. Dell PowerEdge M610	http://www.principledtechnologies.com/Dell/M620_vs_M610_0312.pdf
Server consolidation and TCO: Dell PowerEdge M620 vs. Dell PowerEdge M710HD	http://www.principledtechnologies.com/Dell/M620_vs_M710HD_0312.pdf
Server consolidation and TCO: Dell PowerEdge M620 vs. HP ProLiant BL490	http://www.principledtechnologies.com/Dell/M620_vs_HP_BL490_0312.pdf
Server consolidation and TCO: Dell PowerEdge R620 vs. Dell PowerEdge R610	http://www.principledtechnologies.com/Dell/R620_vs_R610_0312.pdf
Server consolidation and TCO: Dell PowerEdge R620 vs. HP ProLiant DL360 G7	http://www.principledtechnologies.com/Dell/R620_vs_HP_DL360G7_0312.pdf
Server consolidation with the Dell PowerEdge M620	http://www.principledtechnologies.com/Dell/M620_Exchange_consolidation_0512.pdf
Dell PowerEdge M820 blade server solution: Software cost advantages with Oracle Database 11g R2	http://www.principledtechnologies.com/Dell/M820_Oracle_0912.pdf
Dell PowerEdge M820 blade server solution: Software cost advantages with Microsoft SQL Server 2012	http://www.principledtechnologies.com/Dell/M820_SQLServer_0912.pdf
Microsoft Exchange consolidation and TCO: Dell PowerEdge R720xd vs. HP ProLiant DL380 G6	http://www.principledtechnologies.com/Dell/R720xd_Exchange_0312.pdf
Microsoft Exchange consolidation and TCO: Dell PowerEdge R720xd vs. HP ProLiant DL380 G7	http://www.principledtechnologies.com/Dell/R720xd_Exchange_G7_0312.pdf

Title	Link
Microsoft Lync Server consolidation and TCO: Dell PowerEdge R720 vs. HP ProLiant DL380 G7	http://www.principledtechnologies.com/Dell/R720_Lync_0312.pdf
Microsoft SharePoint consolidation and TCO: Dell PowerEdge R720 vs. HP ProLiant DL380 G7	http://www.principledtechnologies.com/Dell/R720_SharePoint_0312.pdf
Microsoft SQL Server consolidation and TCO: Dell PowerEdge R720xd and Dell PowerEdge 2950 III	http://www.principledtechnologies.com/Dell/R720_SQL_0312.pdf
Server Consolidation and TCO: Dell PowerEdge R720 vs. Dell PowerEdge R720	http://www.principledtechnologies.com/Dell/R720_vs%20_R710_0312.pdf
Server Consolidation and TCO: Dell PowerEdge R720 vs. HP ProLiant DL380 G7	http://www.principledtechnologies.com/Dell/R720_vs_HP_DL380G7_0312.pdf
TCO Analysis of Upgrading to Dell PowerEdge R720 Servers	http://www.principledtechnologies.com/Dell/R720_Consolidation_TCO_Server2012_SQL2012_1112.pdf

Figure 22: Recent studies on virtualization and consolidation in the PT labs.

REFERENCES

[1] http://www.missioncriticalmagazine.com/ext/resources/MC/Home/Files/PDFs/(TUI3011B)SimpleModelDetermingTrueTCO.pdf
[2] http://www.forbes.com/sites/investor/2012/08/28/digital-space-a-bold-new-frontier-for-investing-in-reits/
[3] "Increasing Density Requires Thinking "Inside The Box", September 2011; Andrew Hiller, CTO and co-founder of CiRBA
[4] http://www.serverwatch.com/server-trends/survey-51-of-x86-servers-now-virtualized.html
[5] http://www.idc.com/getdoc.jsp?containerId=prUS23665812#.UP2JDqVG5FI
[6] Data approximated from: http://symposium.uptimeinstitute.com/images/stories/Symposium_2012_PPTs/uptime-institute-data-center-density-report.pdf
[7] http://www.principledtechnologies.com/Dell/R720_SQL_0312.pdf
[8] *Ibid.*
[9] http://www.principledtechnologies.com/Dell/R720xd_Exchange_0312.pdf
[10] http://www.principledtechnologies.com/Dell/R720_SQL_0312.pdf
[11] http://www.principledtechnologies.com/Dell/R720_SharePoint_0312.pdf
[12] http://www.principledtechnologies.com/clients/reports/Dell/R720_Consolidation_Performance_Server2012_SQL2012_1112.pdf
[13] http://www.principledtechnologies.com/Dell/R720_Consolidation_TCO_Server2012_SQL2012_1112.pdf
[14] http://www.principledtechnologies.com/Dell/R720_SQL_0312.pdf
[15] If migrating from SQL Server 2008 R2 Enterprise licensed per processor to SQL Server Enterprise 2012 licensed per core.
[16] http://www.principledtechnologies.com/Dell/M620_vs_HP_BL490_0312.pdf
[17] http://i.dell.com/sites/content/business/solutions/engineering-docs/en/Documents/idrac7-overview-features.pdf
[18] http://www.emersonnetworkpower.com/en-US/Brands/Liebert/Pages/LiebertGatingForm.aspx?gateID=886
[19] http://www.principledtechnologies.com/Dell/R720_power_0312.pdf
[20] http://www.ecommercetimes.com/story/76887.html
[21] http://www.spec.org/cpu2006/results/res2012q2/cpu2006-20120522-22161.html
[22] http://www.spec.org/cpu2006/results/res2008q4/cpu2006-20080914-05301.html
[23] http://www.spec.org/cpu2006/results/res2012q2/cpu2006-20120522-22225.html
[24] http://www.spec.org/cpu2006/results/res2008q4/cpu2006-20081105-05843.html
[25] *Ibid.*
[26] http://www.emersonnetworkpower.com/en-US/Brands/Liebert/Documents/White%20Papers/Emerson%20Network%20Power%20Higher%20Density%20Equals%20Lower%20Cost.pdf
[27] http://www.intel.com/technology/eep/datacenter.pdf
[28] http://www.principledtechnologies.com/Dell/R720_321_configuration.pdf
[29] http://en.community.dell.com/techcenter/virtualization/w/wiki/3020.aspx
[30] http://www.vmware.com/products/datacenter-virtualization/vsphere/vmotion.html
[31] http://www.vmware.com/products/datacenter-virtualixation/vsphere/storare-vmotion.html
[32] http://technet.microsoft.com/en-us/magazine/hh127064.aspx
[33] http://www.vmware.com/products/datacenter-virtualization/vsphere/high-availability.html
[34] http://content.dell.com/us/en/enterprise/d/virtualization/management-plug-in-for-vmware-vcenter
[35] R720: http://www.spec.org/power_ssj2008/results/res2012q4/power_ssj2008-20121113-00578.html
[36] R820: http://www.spec.org/power_ssj2008/results/res2012q4/power_ssj2008-20121113-00586.html
[37] M820: http://www.spec.org/power_ssj2008/results/res2012q3/power_ssj2008-20120807-00525.html
[38] M620: http://www.spec.org/power_ssj2008/results/res2012q2/power_ssj2008-20120320-00447.html
[39] M420: http://www.spec.org/power_ssj2008/results/res2012q3/power_ssj2008-20120626-00504.html

[40] http://www.emersonnetworkpower.com/en-US/Brands/Liebert/Documents/White%20Papers/Emerson%20Network%20Power%20Higher%20Density%20Equals%20Lower%20Cost.pdf
[41] http://www.apcmedia.com/salestools/VAVR-6J5VYJ_R2_EN.pdf
[42] Data approximated from: http://www.emersonnetworkpower.com/en-US/Brands/Liebert/Documents/White%20Papers/Emerson%20Network%20Power%20Higher%20Density%20Equals%20Lower%20Cost.pdf
[43] http://i.dell.com/sites/doccontent/corporate/case-studies/en/Documents/2011-virtacore-10009304.pdf
[44] *Ibid.*
[45] http://www.datacenterjournal.com/design/the-price-of-data-center-availability/
[46] *Ibid.*
[47] http://searchdisasterrecovery.techtarget.com/feature/Using-a-colocation-data-center-for-disaster-recovery
[48] *Ibid.*
[49] http://www.fogodatacenters.com/how-much-does-colocation-cost/
[50] http://www.nytimes.com/2011/01/02/business/02speed.html?pagewanted=all&_r=1&
[51] http://content.dell.com/us/en/fedgov/d/fed/mobile-data-center
[52] http://content.dell.com/us/en/fedgov/d/fed/mobile-data-center
[53] http://www.fema.gov/disaster-process-disaster-aid-programs
[54] For details, see Appendix B.
[55] http://www.dell.com/us/business/p/powerconnect-8100/pd

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1007 Slater Road, Suite 300
Durham, NC, 27703
www.principledtechnologies.com

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