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Enterprise Computing Solutions – North America

Intel Solid State Drives
What Sellers Need to Know

Five Years Out

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Intel and the Solid-State Drive Market

Intel is dynamically changing the focus of the company beyond what the IT community views as its traditional role. Intel's has an overall mission of being the "preeminent computing solutions company that powers the worldwide digital economy."

"As a result, we are transforming our primary focus from the design and manufacture of semiconductor chips for personal computing (PC) and servers to the delivery of solutions consisting of hardware and software platforms, and supporting services across a wide range of computing devices."

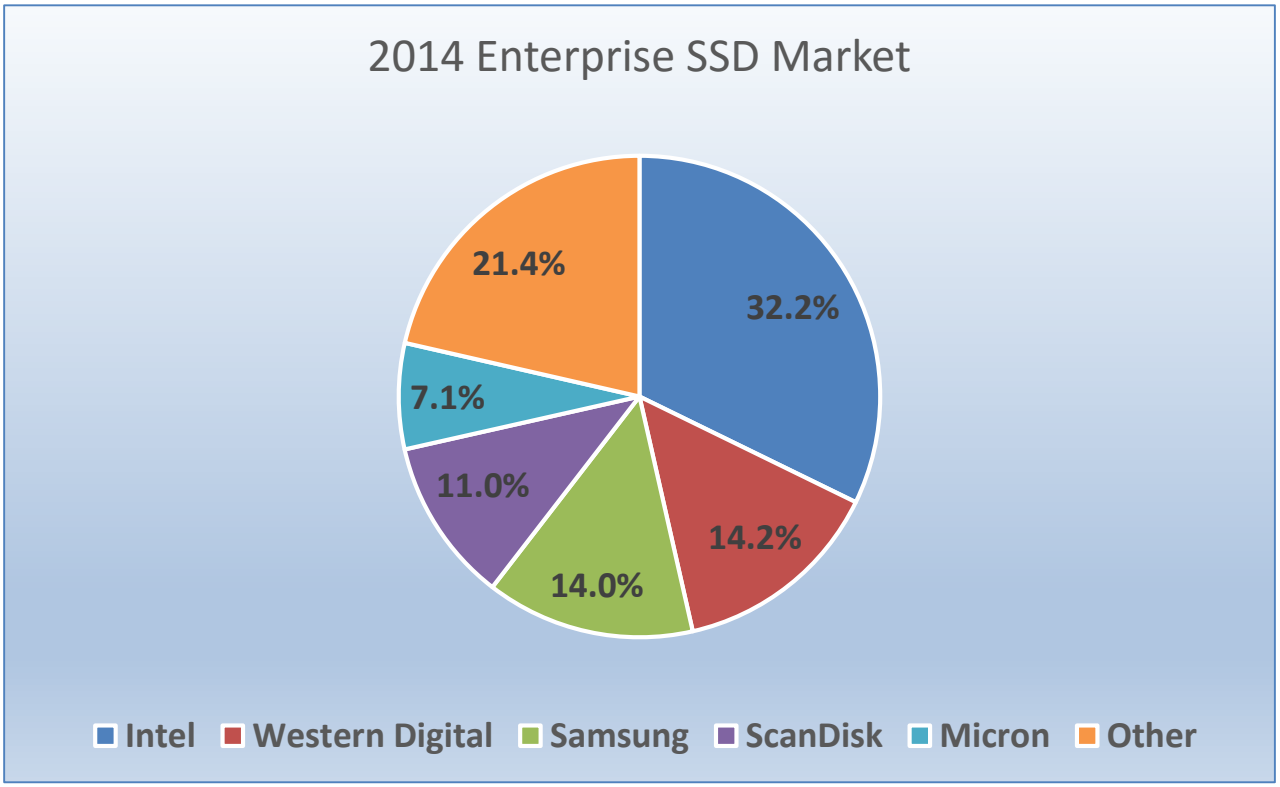
As part of this strategy, Intel has devolved multiple lines of Solid-State drives (SSDs).

- The Intel SSD Consumer Family is targeted to the home consumer market.
- The Intel SSD Professional Family addresses the demanding business environment and includes manageable, robust security features.

The Intel SSD Data Center Family maximizes performance delivery, reduces the probability of silent data corruption to effectively zero percent, provides performance consistency, reduces power use, and lowers operation costs. This family includes both SATA and PCIe SSDs. This paper only addresses the Intel Data Center family SSD products. The SSD industry is exploding. According to IDC, the overall market for SSDs globally was $15 billion in 2015, up 21% from 2014. The driving factors in this growth include lower costs for SSDs, better performing drives, and ease of use, such as the adoption of the NVMe standard for PCIe form factor drives.

The Enterprise market segment for total HDDs and SSDs in the data center is estimated to be about 180,000 PB (Petabytes) in 2015. Of this amount, SSDs comprise less than 4% of the total disk in the data center. This leaves a very large market opportunity for technology refreshes for customers to move them from HDD-based servers to new servers with SSDs, but also replacing existing HDDs with SSDs as an upgrade to give old servers new life and performance (Arrow ECS sells Intel SSDs stand-alone).

The 2014 enterprise vendor market was reported by IDC to be $4.2B and is broken down in the following chart:



The market share of Intel (32.2%) and Western Digital (14.2%) who remarkets Intel SSD drives provides Intel SSDs with a commanding effective 46.4% market share for Intel SSD in the enterprise market. Additional providers with 21.4% market share in the “Other” category include, but are not limited to: Fujitsu, HGST, Kingston, PMC, Seagate, SK-Hynix, Smart-Modular, and Toshiba.

Solid-State Drives (SSDs) – Different Technology, New Dynamics

Sold-State Drive technology is fundamentally different than the technology used with traditional hard disk drives. The removal of the mechanical process used by HDDs for reading a spinning disk and replacing it with the Solid-State technology of SDDs provides extreme performance, increased throughput, and advanced reliability to the disk drives in the data center.

Firmware (software) controls the important characteristics of each manufacturer’s SSDs. Each accomplishes the same task – to store data – but they all contain different performance and reliability features. Much like Chrome, Firefox, and Explorer, they all access the Web with different speed and features.

Evaluating a Data Center SSD

Selecting a disk drive for the data center used to be much easier when spinning hard disk drives (HDDs) were the only choice. Capacity and disk performance (measured in RPM) were matched to budget. Drive interface (SAS vs SATA vs PCIe) factored in based upon application performance needs.

This is a simplification, but overall the choices were limited. Once the price of enterprise SSDs became competitive, SSDs moved from use in niche applications to the main data center floor – and added complexity to the disk drive selection process. The following are a few of the considerations you need to factor in when selecting the SSD that meets the customer's performance, reliablity and consistacy needs, along with their Total Cost of Ownership (TCO) crieteria. $/GB of disk should not be the customer's only consideration if they are evaluating HDDs against SSDs. For the forseeable future, HDDs will continue to have a $/GB advantage over SSDs, but have a considerable disadvantage in performance and reliablity.

Performance

SSDs have much faster access time and throughput than HDDs for random or transactonal performance. Some SSDs are so fast that they move the "bottleneck" of performance to another server component or possibly to the application itself.

Input/Output Operations per Second (IOPS) is a key metric for disks. A large proportion of the server storage activity is made up of 4K random reads and writes, making this a key benchmark when selecting disks for the data center.

Sequential throughput, the speed of a sequential data transfer, is an important metric for applications that work with large files and require a large number of sequential I/O operations, such as video-on-demand, medical imaging, and web applications.

The following chart compares approximate IOPS and throughput for a few select disk types and interfaces to provide reference points:

Drive Type	Interface	Approximate Read IOPS	Approximate Write IOPS	Sequential Read/Write (Up to MB/s)
10,000 RPM HDD	SATA	75-100	75-100	Est 40 – 100
10,000 RPM HDD	SAS	140	140	Est 60 – 110
15,000 RPM HDD	SAS	175-210	175-210	Est 95 – 130
Intel DC S3500 SSD	SATA	75,000	15,500	500/460
Intel DC P3700 SSD	PCIe	460,000	175,000	2,800/2,000

Reliability

Each Intel SSD also features a robust Mean Time Between Failures (MTBF) of 2 million hours. In addition, Intel SSDs provide some of the lowest return and failure rates in the industry. This is due in part to the industry-leading rigorous testing and validation procedures that Intel uses, including performing more than 1M power cycles per product within platform and system validation.

Intel SSD drives provide the following reliability features:

- Up to 10 drive writes per day or 36.5 PB data written
- AES 256-bit Advanced Encryption Standard (AES) data protection
- Industry's best five-year warranty – competitors only offer three-year warranties
- End-to-end data protection for data reliability
- Have power-loss protection features with built-in self-test
- Virtually zero percent chance of Silent Data Corruption (SDC) – ***no competitor offers this reliability or even tests for SDC***

Consistency

Performance consistency is key in an enterprise RAID environment, because the performance of a RAID set is limited by the lowest performing drive. As a RAID set increases the number of drives, the probability of any given drive performing poorly increases, as well as it limits the overall performance. Therefore, if an SSD or HDD drive is inconsistent with its performance, the inconsistency decreases the performance of the entire RAID set. SSDs feature a wide performance variation when compared to HDDs. Wide performance variations are also seen among competing enterprise SSDs, making the selection of a consistently preforming SSD an important selection criteria. SSD drives that stress consistency, like Intel, sacrifice a small amount of top-end "speed" to provide a more valuable consistent product.

Tom's IT Pro article, How We Test Enterprise SSDs, discusses testing methods for enterprise SSDs and contains a detailed explanation of testing drives for consistency.

Why Choose a Data Center Class SSD?

Today's focus on lowering data center costs and budget constraints make it very tempting to select the SSD with the lowest cost. This method may work for consumer desktops, but could lead to problems and extra costs for the data center.

The Intel brief, Why Choose a Data Center Class SSD? provides a detailed explanation of the difference between consumer grade SSDs and Data Center SSDs. Among the issues it presents is the SSD endurance needed for data center workloads, data protection enhancements, power loss

protection, and performance consistency advantages that the data center-class SSDs provide. In addition, consumer SSDs are tested with a client workload, as compared to a data center workload. This is a key difference since endurance specifications for Drive Writes Per Day (DWPD) appear to show comparable endurance. The data center SSD, however, is tested with a more strenuous data center workload, while the consumer SSD is tested using a less strenuous client workload. The analogy used in the brief compares two marathon runners – one completing a flat course, and the other completing a course with mountains and valleys. Both run the same distance, but one is much more strenuous than the other. Data Center class SSDs are designed for the more strenuous workloads found in the data center.

Silent Data Corruption

Silent errors that occur during the write process that are not reported or corrected (silent) by the server and its subsystems are known as Silent Data Corruption (SDC). These errors can be caused by a number of factors, such as cosmic radiation, errors in disk firmware, and other software and hardware problems. Since they are not detected or reported, they are "silent" until the data or file is read and the corruption detected.

These types of errors are very troubling, since there is no indication the data is incorrect. The ZDNet article, Data Corruption Is Worse Than You Know, discusses experiments at CERN, the world's largest particle physics lab. They analyzed a 8.7TB database and found one data corruption error in every 1,500 files – none of which were reported or corrected when the data was written. The Enterprise Storage article, Keeping Silent About Silent Data Corruption, discusses a few incidents, along with the challenges of tracking SDC in the data center.

Why is this important? SDC is also a problem for HDDs, but experts believe SSDs are more prone to SDC than HDDs mainly because of the density of the storage material. Intel takes steps that other competitive SSD manufacturers do not to ensure the error rate for SDC is 0%. The Intel article, Data Integrity in Solid-State Drives: What Supernovas Mean to You, provides a detailed explanation of the extensive testing and verification of all Intel series SSDs to eliminate Silent Data Corruption in their SSDs.

Intel's SSD firmware is written to reduce the probability of SDC to virtually zero, provide fast, consistence performance, and uniform endurance with low overhead.

Not only does Intel provide protection from SDC, but they also are the only vendor to do radiation testing of their SSD drives at the Indiana University Cyclotron Facility and Los Alamos Nuclear Science Center. This extra testing is an important competitive advantage for Intel.

Intel describes in detail how they tested both Intel and competitor SSDs using a particle accelerator in the techreport.com article, Behind the Scenes With Intel SSD Division.

Cost Per IOPS vs. Cost Per GB

Enterprise disk drives have been traditionally evaluated by cost/GB. While still an important metric, the dramatically better performance of SSDs has made the cost/IOPS a more useful measurement in evaluating disk selection for the data center.

Short-stroking is the practice of purposely restricting the total capacity so that the actuator of an HDD only has to move the heads across a smaller number of total tracks, reducing the average seek time of an HDD. It is a common practice in enterprise servers that increases the number of IOPS for a HDD.

Any data center using short-stroking to increase performance is a great prospect for upgrading their disks to SSDs. They have already invested to gain performance and already see the value. Replacing their current structure with SSDs with the amount of disk they actually use will provide greater performance and a better TCO.

SSD Endurance/Life Expectancy

An SSD has a huge but finite number of program/erase (P/E) cycles. This affects how long a drive can perform write operations and, therefore, its life expectancy. This makes matching the read/write profiles of the SSDs workload to the expected drive endurance important. If the endurance specification of an SSD drive is exceeded, an SSD will switch to "read only" mode – ***NO DRIVE WRITES WILL BE ALLOWED.*** This will continue until the drive is replaced or fails completely. Each server manufacturer provides tools to monitor endurance and provides reporting to the server administrator.

Because of this, planning must be done to ensure the application read/write profile matches the SSD drives' read/write endurance. This will ensure the SSD does not exceed its required life expectancy for drive writes.

SSD Endurance Measurement

There are two primary specifications used to measure SSD drive endurance: Total Bytes Written (TBW) and Drive Writes Per Day (DWPD). (**Note:** Sometimes TBW is referred to as "Terabytes Written.") The TBW value assigned to a Solid-State device is the total bytes of written data that a drive can be guaranteed to complete. Reaching the TBW limit does not cause the SSD to fail, but at some point after surpassing the TBW value – based upon manufacturing variance margin – the drive reaches the end-of-life point, at which time the drive goes into read-only mode.

DWPD measures how many times you can overwrite the entire capacity of the SSD every day of its usable life without failure during the warranty period. Both TBW and DWPD are guaranteed specifications by the vendor.

The following conversion is useful when comparing the two measurements:

- TBW = DWPD * warranty years * 365 * (capacity/1,024)
- DWPD = TBW * (1024/(capacity * warranty years * 365)

SSDs are generally classified by vendors using several different terms. “Read centric” or “Value” SSDs have very good read performance, but limited write performance and endurance. “Write centric” or “Enterprise” SSDs have very good read/write performance and very good endurance. “Mixed Use” SSDs fall in between the performance and endurance of “Read” and “Write” centric drives.

SSDs and Workloads

Matching data center workloads to the correct type of SSD drive is important to ensure these drives meet the performance and endurance the data center user is expecting.

The following chart provides a reference of workloads and appropriate SSD type

Application Type	Application Characteristic	Application Compatible “Write” Centric Enterprise SSD Drives?	Application Compatible “Read” Centric Enterprise SSD Drives?
OLTP Database	Read & Write Intensive	Yes	
Data Warehouse	Read Intensive		Yes
Email Server	Read & Write Intensive	Yes	
Medical Imaging	Read Intensive		Yes
Video on Demand	Read Intensive		Yes
Web, Internet	Read Intensive		Yes
Web 2.0	Read & Write Intensive	Yes	

From a drive endurance standpoint, both “Write” centric and “Read” centric drives can handle huge numbers of write cycles as illustrated in the following chart.

Drive	Drive Type	Total TBW	TBW Per Day for 5 Years	TBW Per Day for 3 Years	IOPS Writes	IOPS Reads
Lenovo 400 GB Intel DC S3500	Read Centric	225 TB	123 GB	205 GB	11,000	75,000
Lenovo 400 GB Intel DC S3700	Write Centric	7.3 PB	4 TB	6.6 TB	36,000	75,000

In a RAID 5 array where each drive is written to equally, these numbers would be multiplied by the number of drives in the array (less any parity only drives). In a system with four drives plus a parity drive using the Lenovo Intel DC S3500 400GB SSDs, 492 (4X123GB) GB of data could be written per day over 5 years and 820 (4X205) GB of data could be written per day over 3 years. Likewise the Lenovo Intel DC S3700 400 GB SSD would handle a total of 16 TB of data written per day over 5 years and 26.4 TB of data written per day over 3 years.

Keep in mind that even if an SSD can handle the endurance needed in the data center, drive write performance is different as listed in the chart for the two drive types. This metric provides a compelling reason to select a “write” centric drive for a heavy write-centric application workload, i.e. OLTP databases, Web 2.0, and e-mail servers.

Solid-State Drive Data Center Total Cost of Ownership (TCO) Calculator

Matching the performance and capacity of a data center's HDD configuration with SSDs can be a complex task, mostly due to the different technology each uses. HDDs have a $/GB advantage. SDDs have an edge over HDDs in:

- Performance
- Reliability
- Power costs
- Maintenance costs

The $/GB HDD advantage is minimized and very possibly eliminated in many instances when the TCO of both HDD and SDD solutions are analyzed in data centers with:

- Relatively low HDD capacity used
- Ones needing more performance
- Those valuing a savings on power a cooling costs

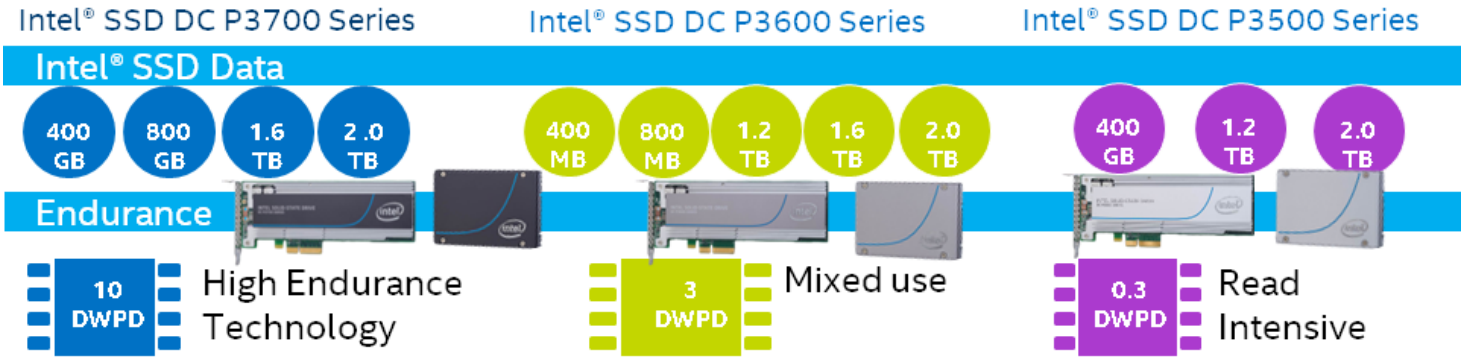
Use the Intel Solid-State Drive Data Center TCO Calculator to discover the potential savings of deploying Intel SSDs vs. HDDs in these data center environments.

Intel Data Center Solid-State Disk Drives

Intel's lines of enterprise data center Solid-State Drives provide a compelling combination of performance, predictability, and endurance to meet the challenges of the data center. Each has unique characteristics that allow a data center to select the product series that matches their needs.

The following chart describes Intel's data center SSD product lines:

Intel® SSD Data Center PCIe/NVMe™ Family



Performance		Sequential latency of 20µs	
Random 4k Read	450k IOPS	450k IOPS	450k IOPS
Random 4k Write	175k IOPS	56k IOPS	35k IOPS
Random 4k 70/30 R/W	265k IOPS	160k IOPS	85k IOPS
Sequential Read	2800 MB/s	2600 MB/s	2500 MB/s
Sequential Write	2000 MB/s	1700 MB/s	1700 MB/s

Tests document performance of components on a particular test, in specific systems. Differences in hardware, software, or configuration will affect actual performance. Configurations: Intel Core i7-3770K CPU @ 3.50GHz, 8GB of system memory, Windows* Server 2012, IOMeter. Random performance is collected with 4 workers each with 32 QD

Intel® SSD Data Center SATA Family

	Intel® SSD DC S3710 Series	Intel® SSD DC S3610 Series	Intel® SSD DC S3510 Series
Capacity	200, 400, 800GB & 1.2TB	100*, 200, 400, 480*, 800GB, 1.2* & 1.6*TB	80, 120, 240, 480, 800GB, 1.2 & 1.6TB
Interface	SATA 6Gb/s	SATA 6Gb/s	SATA 6Gb/s
Form Factor	2.5"	2.5" (*2.5 only), 1.8"	2.5"
64KB Sequential R/W Performance	Up to 550/460 MBps	Up to 500/450 MBps	Up to 500/450 MBps
4K Random R/W Performance	Up to 85/45K IOPS	Up to 84/28K IOPS	Up to 68/20K IOPS
Endurance (PB data written)	Up to 24.3 PBW, 10 DWPD	Up to 10.95 PBW, 3 DWPD	Up to 1 PBW, 0.3 DWPD
Average Latency (Read/Write)	55/66µs	55/66µs	55/66µs
Data Integrity	End-to-end data protection	End-to-end data protection	End-to-end data protection
Power Loss Protection Features & Self Test	Yes	Yes	Yes
Limited Warranty	5 years	5 years	5 years

The Intel DC P3500, DC P3600, and DC P3700 series provide PCIe and NVMe solutions with outstanding performance and up to six times faster data transfer speeds when compared to 6 Gbps SAS/SATA SSDs. The DC P3700 series has the highest endurance measured by its DWPD of 17, while the DC P3600 series provides 3 DWPD, followed by the DC P3500 series with 0.3 DWPD.

The Intel DC S3710, DC S3610, and DC S3510 series provide:

- Exceptional performance
- Strong data protection with 256-bit encryption Advanced Encryption Standard (AES) technology
- Full end-to-end data protection
- Enhanced power-loss protection

The Intel DCS3710 offers 10 DWPD, while the DC S3610 series offers 3 DWPD, and the DC S3510 provides 0.3 DWPD.

Older Intel SSD Drives

Intel's Data Center Family of SSDs have recently been refreshed. Many of the studies referenced in this paper refer to them and would still apply since the new drives improved on their base technology. The drives available prior to November 2015 include the following:

Intel Data Center Product	Interface	Capacity (GB)	Sequential Read/Write (max MB/s)	Random 4KB Read/Write (max IOPS)	Form Factor	AES 256-bit Encryption
DC S3500 Series	SATA 6 Gb/s	80 / 120 / 160 / 240 / 300 /340 /400 /480 / 600 / 800 / 1.2TB / 1.6TB	500 / 460	75,000 / 15,500	2.5 and 1.8 inch M.2	
DC S3700 Series	SATA 6 Gb/s	100 /200 /400 /800	500 / 460	75,000 / 36,000	2.5 and 1.8 inch	Yes

The Intel DC S3500 series provides fast, consistent read performance, full end-to-end data protection, and enhanced power-loss protection at an economical price.

The Intel DC S3700 series combines consistent performance, the high endurance of up to 10 DWPD, and strong data protection with 256-bit encryption AES technology.

Intel SSD Consistency

SSDs in RAID arrays must wait for the last drive to write before moving to the next instruction. Uneven drive performance can slow an entire RAID system far below a SSDs maximum performance advertised by Intel competitors.

Intel SSDs deliver consistency and quality of service by providing maximum latencies of less than 500 µs, 99.9% of the time. These specifications are among the highest in the industry, allowing Intel SSDs to deliver the QoS (Quality of Service) and the consistency that data centers require to maximize performance. Competing drives do not make consistency a priority, instead focusing on maximizing IOPS performance – while not delivering what most customers need – consistent performance.

The technical brief, Intel Solid-State Drive DC S3700 Series Quality of Service, introduces the metrics on which QoS and performance consistency are measured and characterized and focuses on the importance of QoS in multiple data center applications. In addition, the white paper, Intel SSD DC S3500 Series Workload Characterization in RAID Configurations, looks at performance characteristics in RAID configurations across multiple workloads.

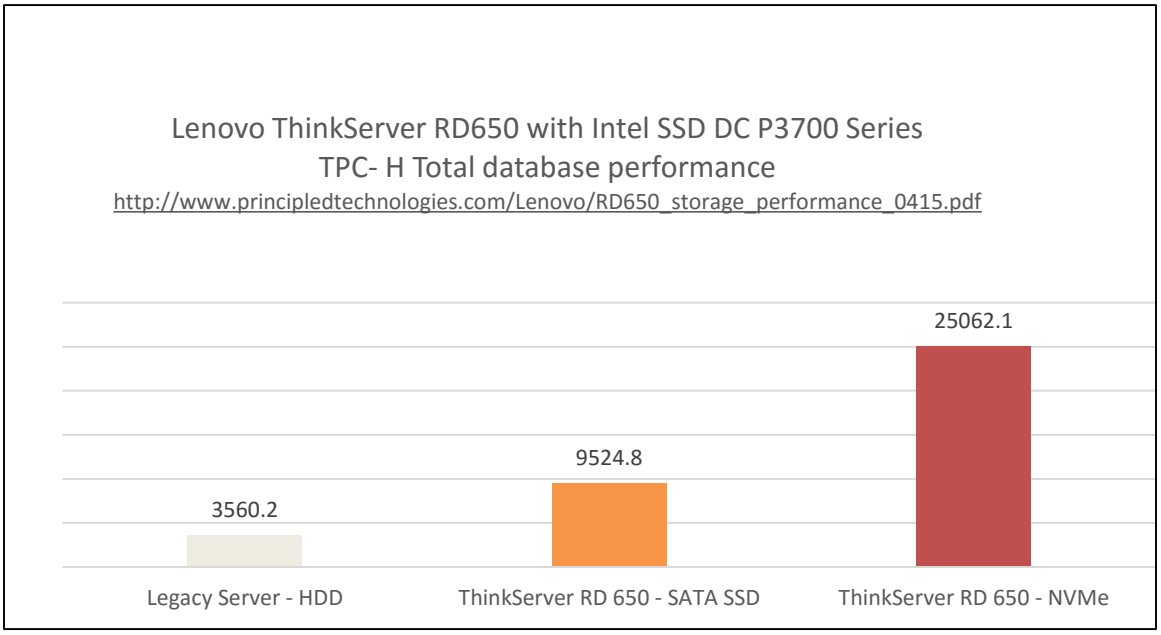
Intel SSD Reliability

Intel's SSD firmware is written to reduce the probability of Silent Data Corruption to virtually zero, provide fast consistence performance, and offer uniform endurance with low overhead.

Not only does Intel provide protection from SDC, but they also are the only vendor to do radiation testing of their SSD drives at the Indiana University Cyclotron Facility and Los Alamos Nuclear Science Center. This extra testing is an important competitive advantage for Intel.

Four Legacy Servers into One Lenovo Intel SSD Server

Lenovo Servers combined with the Intel PCIe NVMe Solid-State drives provide the outstanding performance needed to replace multiple legacy servers. The total database performance for a Lenovo ThinkServer RD650 using an Intel DC P3700 Series SSD demonstrated a 7x performance increase over legacy server HDDs, allowing this combination to replace four legacy servers based upon testing done by Principled Technologies.



As this study proves, server consolidation using SSD SATA or PCIe disks rather than new servers is a powerful play for data centers with database and other transactional workloads.

Intel's Lenovo Solid-State Drives

Lenovo classifies their Solid-State drives as either Enterprise or Enterprise Value and primarily uses the TBW (Total Bytes Written) endurance measurement. Both types of drives typically have similar read IOPS characteristics. The major difference is their write IOPS performance and endurance.

For instance, the "Enterprise" Intel DC S3710 series SSDs have a maximum endurance of 24.3 PB TBW, while the "Enterprise Value" Intel DC S3510 series SSDs have a maximum endurance of 1 PB TBW. Enterprise Value SSDs are priced lower than their Enterprise counterparts, allowing data centers to more affordably service read-intensive workloads while maintaining a very similar, if not the same, read IOPS.

The key difference between Lenovo's Enterprise and Enterprise Value SSDs are their write IOPS performance, their endurance/life expectancy, and price.

Intel's Lenovo Enterprise SSDs are:

- Lenovo Enterprise Value – Intel DC S3510 series (SATA) and Intel DC P3500 series (PCIe)
- Lenovo Enterprise – Intel DC S3610 series (SATA), Intel DC S3710 series (SATA), Intel DC P3600 series (PCIe), and Intel DC P3700 series (PCIe)

Intel's HP Solid-State Drives

HP Enterprise SSDs are broken up into three classifications and primarily use the Drive Writes Per Day (DWPD) measurement:

- Read Intensive (RI) – Drives with a typical endurance of less than or equal to 1 DWPD
- Mixed Use (MU) – Drives with a typical endurance greater than 1 and less than 10 DWPD
- Write Intensive (WI) – Drives with a typical endurance of greater than or equal to 10 DWPD

The "Write Intensive" Intel DC S3710 series SSDs have a maximum endurance of 10 DWPD, while the "Read Intensive" Intel DC S3510 series SSDs have a maximum endurance of .3 DWPD. The "Mixed Use" Intel DC S3610 series have a maximum endurance of 3 DWPD.

Read Intensive SSDs are priced lower than their "Write Intensive" counterparts, allowing data centers to more affordably service read-intensive workloads while maintaining a very similar, if not the same, read IOPS. Mixed-Use SSDs feature a middle combination of endurance and price.

Intel's HP Enterprise SSDs are:

- HP Read Intensive – Intel DC S3510 series (SATA) and Intel DC P3500 series (PCIe)
- HP Mixed Use – Intel DC 3610 series (SATA) and Intel DC P3600 series (PCIe)
- HP Write Intensive – Intel DC S3710 series (SATA) and Intel DC P3700 series (PCIe)

More Intel Inside

In addition to the processors and SSDs, Intel provides high-bandwidth I/O adapters. These adapters use the latest technology to provide enterprise-class communications for the data center. The Intel Ethernet Converged Network Adapters and 10 Gigabit Server Adapters portal provides product information and additional details.

Resources

Web Portal

- SSD – Intel Solid-State Drives
- Lenovo Intel SSD Resource portal

Product Information

PCI Express Gen3 Interface

- Intel SSD DC P3700 Series
- Intel SSD DC P3608 Series
- Intel SSD DC P3600 Series
- Intel SSD DC P3500 Series

SATA 6 GB/s Interface

- Intel SSD DC S3710 Series
- Intel SSD DC S3700 Series
- Intel SSD DC S3610 Series
- Intel SSD DC S3510 Series
- Intel SSD DC S3500 Series

Other Resources

- Intel Product Information and Comparison Tool – This online tool provides detailed product information on Intel processors, chipsets, boards and kits, servers, Solid-State drives, networking and I/O; a reference of products by code names is also provided.

White Papers

Intel SSDs in Server Storage Applications – This white paper discusses tips and suggestions on how to obtain the best performance from your server with Solid-State drives.

Exceptional Data Center Performance with Intel PCIe and NVMe Enterprise Solid-State Drives – This paper provides benchmark performance results for Intel's PCIe and NVMe SSDs, and details the performance benchmarking methodology and considerations to allow effective evaluation.

Are You Five Years Out?

Most people live in the present. The world of now. But a handful of us work in a unique world that doesn't quite exist yet—the world of Five Years Out.

Five Years Out is the tangible future. And the people who live and work there know that new technologies, new materials, new ideas and new electronics will make life not only different, but better. Not just cheaper, but smarter. Not just easier, but more inspired.

Five Years Out is an exciting place to be. So exciting that, once you've been there, it's hard to get excited about the present. Because we know what's coming is going to be so much better.

Five Years Out is a community of builders, designers, engineers and imaginers who navigate the path between possibility and practicality. Creating the future of everything from cars to coffeemakers.

Are you one of them? Then you're probably working with us.

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