



# Cost Effective Workload Consolidation using the DataON Windows Server HCI Platform

Migrate SQL Server 2008 workloads to a modern,  
on-premises hyper-converged environment

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**Western Digital**<sup>®</sup>



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# Executive Summary

Companies running SQL Server 2008 and SQL Server 2008 R2 face a critical milestone in July 2019, when Microsoft's End of Support (EOS)<sup>1</sup> for those databases. With EOS, Microsoft will stop releasing security updates for those SQL Server releases on-premises, and those databases will face great risk of being hacked and will no longer conform to many regulatory requirements.

A cost-effective solution is needed for migrating and consolidating those SQL Server 2008<sup>2</sup> workloads that need to remain on-premises for regulatory reasons, or by customer preference.

This whitepaper demonstrates that SQL Server 2008 workloads can cost effectively be migrated to a modern hardware and software solution, the DataON Windows Server HCI platform for Microsoft SQL 2017 OLTP, with the current SQL Server 2017 and Windows Server 2016 releases.

As described in more detail in the section "The Solution", DataON hyper-converged infrastructure (HCI) is built to optimize the full-stack of Windows Server software-defined data center (SDDC). It is designed with integrated compute, network and storage infrastructure with near-linear scalability to simplify and maximize the deployment of Microsoft SQL Server 2017 application. By fully leveraging the features and capabilities of Microsoft Storage Spaces Direct architecture, the DataON Windows Server based-HCI combines many new hardware capabilities including high performance Intel® Xeon® Scalable Processors, solid state drives (SSDs) using the NVMe interface, and 40GbE SMB3 RDMA Ethernet fabric to fully deliver high bandwidth and low latency storage access. DataON integrates these into a highly scalable, highly available hyper-converged architecture to deliver enterprise grade resiliency, easy deployment, and cost savings through reduced operational overhead.

The software environment includes the current SQL Server 2017<sup>3</sup> release which provides industry-leading performance and availability for mission-critical, intelligent applications and data warehouses, while protecting data at rest and in motion with the least National Vulnerability Database (NVD) over the last seven years in the NVD of National Institute of standards and Technology (NIST)<sup>4</sup>.

The current Windows Server 2016<sup>5</sup> release delivers security, efficiency, and innovation that supports current workloads like Hyper-V virtualization, which Microsoft uses to run hyperscale data centers around the globe, while introducing new technologies like Storage Spaces Direct to build highly

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<sup>1</sup> ["SQL Server 2008 and SQL Server 2008 R2 End of Support"](#)

<sup>2</sup> For brevity, "SQL Server 2008" refers to both the SQL Server 2008 and SQL Server 2008 R2 releases.

<sup>3</sup> ["SQL Server 2017 on Windows and Linux"](#)

<sup>4</sup> NVD data retrieved from [JSON feed](#) on June 28, 2018

<sup>5</sup> ["Windows Server"](#)

available, scalable software-defined storage solutions at a fraction of the price of SAN or NAS using industry-standard servers with local storage

Bringing all of this together, this whitepaper demonstrates that DataON SQL Server 2017 Solution can host OLTP workloads:

- Up to 52 migrated SQL Server 2008 workloads on a 4-server cluster using four NVMe SSDs in each server, at a cost per workload of \$12,270. Assuming straight line depreciation over five years with no salvage value, the price per workload would be \$204 per month.
- Up to 80 migrated SQL Server 2008 workloads on a 4-server cluster using six NVMe SSDs in each server, at a cost per workload of \$10,797. Assuming straight line depreciation over five years with no salvage value, the price per workload would be \$180 per month.

Additional workloads can be supported by adding more servers to the cluster, although this project did not test that.

## The Problem: SQL Server 2008 End of Support

SQL Server 2008 R2 is one of the most-deployed SQL Server database releases, which makes Microsoft's End of Support (EOS) for SQL Server 2008 and SQL Server 2008 R2 in July 2019 a critical milestone for many customers.

For database workloads that will remain on-premises due to regulatory requirements or customer preference, a cost-effective solution is needed, that includes migration to supported releases of SQL Server and Windows Server<sup>6</sup>. Microsoft has changed to a per-core licensing model for both SQL Server and Windows Server, making licensing decisions more complicated, and poor licensing decisions more expensive.

Most customers will finally retire the 2008-era hardware the SQL Server 2008 workload currently run on and must decide what new hardware to run their migrated workloads on. There are many choices: physical servers, servers to host virtualized workloads, private clouds; hyper-converged or disaggregated architectures; traditional SAN or DAS storage, or new software-defined storage solutions.

Changes to Microsoft's software licensing model in recent years has made licensing choices more

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<sup>6</sup> End of Support for Windows Server 2008 and Windows Server 2008 R2 is coming as well, in January 2020. See "[Windows Server 2008 and 2008 R2 End of Support](#)"

complex, and increased the cost of software licenses to the point that software cost can dominate the total cost of a system. With that comes increased risk of making an expensive mistake if you make a poor licensing decision. Well-informed choices can minimize software license cost, as we'll demonstrate.

This white paper presents two solutions, different configurations of the same DataON 4-node cluster, to consolidate and virtualize the migrated SQL Server 2008 workloads.

The first configuration we tested uses a four-node cluster of the new DataON Windows Server HCI platform for Microsoft SQL Server 2017, with four Western Digital Ultrastar SN200 1.92TB NVMe drives in each cluster node, for a total of 16 NVMe drives in the 4-node cluster.

The second configuration is identical except it uses adds two more NVMe drives to each node, for a total of six NVMe drives per node, and 24 NVMe drives in the 4-node cluster.

This whitepaper and benchmarking project document and quantify the benefits of harnessing recent advancements in hardware system architecture and software, to achieve a cost-effective solution to the challenges facing customers who must deal with the SQL Server 2008 End of Support.

## The Solution: DataON Windows Server HCI Platform for Microsoft SQL Server 2017

The DataON SQL Server 2017 Solutions for Microsoft SQL Server 2017, based on the DataON S2D family of hyper-converged infrastructure, are designed, validated and tested for breakthrough performance, reduced disk latency, near-linear scalability, system resiliency with HA while delivering significant cost savings with a Windows-based HCI cluster platform.

Leveraging the latest Intel® Xeon® Scalable Processors, chipsets and NVMe SSDs, the DataON solution for Microsoft SQL Server gives businesses powerful OLTP performance to support their mission-critical workloads. DataON's SQL Server 2017 solutions with four-node HCI clusters are optimized for Microsoft SQL Server 2017 with automatic failover to keep the business operating.

The HCI clusters are configured as a hyper-converged infrastructure running Storage Spaces Direct in Windows Server 2016 and tuned for SQL Server 2017 to maximize business performance and high availability. The DataON system brings together many innovations in hardware and software, to a powerful, flexible and cost-effective system that is especially well suited to consolidating migrated SQL Server 2008 workloads.

DataON SQL Server 2017 solutions are workload-optimized solutions are designed to simplify and accelerate the deployment of hardware and software needed for SQL Server 2017 workloads. DataON SQL Server 2017 HCI solutions:

- Simplify evaluation and eliminate guesswork via tightly specified hardware and software components
- Have pre-defined settings and system-wide tuning, enabling smooth deployment
- Are designed and benchmarked to perform optimally for SQL Server 2017 workloads

Based on Intel® Xeon® Scalable processors, DataON SQL Server 2017 Solutions enable enterprises to make confident choices in deploying database infrastructure. DataON SQL Server 2017 Solutions are rigorously tested and benchmarked at a system-wide level. Well-known third party and industry benchmarking tools that simulate real-world loads.

### **DataON S2D family of hyper-converged infrastructure**

The DataON S2D family of hyper-converged infrastructure is built to optimize the full stack of Windows Server Storage Spaces Direct in a hyper-converged platform. It is built with integrated compute, network and storage infrastructure with near-linear scalability to simplify and maximize the deployment of Microsoft applications, virtualization, data protection and hybrid cloud services. Each pre-configured cluster can support 40 Hyper-V VMs per node, for expanded capacity and operational flexibility. The DataON platform features Intel® Xeon® Scalable Processors with Intel® C620 Chipsets and industry leading NVMe SSDs with SMB3 RDMA networking to maximize performance and capacity. DataON's HCI platform has achieved Windows Server Software-Defined (WSSD) HCI premium certification to ensure that customers have a seamless deployment and steady-state operations experience on validated hardware. It provides a comprehensive software-defined "data center in a box" for the highest level of performance, manageability, and security offered, delivered as a fully-deployed experience.

- Breakthrough performance and dramatically reduced disk latency with greater IOPS performance (over the previous generation) for write-intensive workloads by leveraging NVMe SSDs for the fast cache tier in Windows Server 2016
- Greater VM density per cluster with Intel® Xeon® Scalable Processors, delivering up to 28 cores per socket, 18 DIMMS per CPU memory density, and 224 physical cores for a 4-node Storage Spaces Direct HCI deployment
- Highest networking efficiency and throughput with SMB3 RDMA fabric delivering 2x throughput compared to TCP/IP, less than 1µsec latency from VM-to-VM communication, and fewer CPU cycles per I/O with better core utilization
- Quicker, more responsive data access to slower SATA-based storage devices (HDD, SSHD or SATA SSD) with Storage Class Memory, system acceleration solution for new 7th Gen Intel® Core™ processor platforms

## Intel Xeon Scalable Processors

Intel® Xeon® Scalable Processors with Intel® C620 Series Chipsets, formerly Purley (Skylake-SP and Lewisburg), deliver new levels of consistent and breakthrough performance. The platform is based on cutting-edge technology and provides compelling benefits across a broad variety of usage models including big data, artificial intelligence, high-performance computing, enterprise-class IT, cloud, storage, communication, and Internet of Things (IoT). Top enhancements include performance for a wide range of workloads with 1.5x memory bandwidth, integrated network/fabric, and optional integrated accelerators.

## Microsoft SQL Server 2017

SQL Server 2017 delivers the reliability, security, and simplified management for your mission-critical workloads need, all on a data platform that leads in in-memory performance to online transaction processing (OLTP) databases.

Since SQL Server 2008 R2, the SQL Server team has delivered over 100 significant new features with the 2017 release.

WHAT'S NEW IN SQL SERVER 2017 SINCE 2008 R2			
OLTP Performance	Security	Business Intelligence	Hybrid Cloud
<ul style="list-style-type: none"> <li>Real-time operational analytics with in-memory OLTP or on disk</li> <li>In-memory for more applications</li> <li>Unparalleled scalability with Windows Server 2016, with 128 memory and Windows Server 2016 max cores</li> <li>Enhanced AlwaysOn with 8 secondaries and Replica Wizard</li> <li>Multiple node failover clustering (3 synchronous, up to 8 replicas)</li> <li>In memory OLTP</li> <li>Buffer Pool Extension to SSDs</li> <li>Enhanced query processing</li> <li>Resource Governor adds IO governance</li> <li>SysPrep as cluster level</li> <li>Predictable performance with tuning of compute, network and story with Windows Server 2012 R2</li> <li>Delayed Durability</li> <li>Clustered Shared Volume support, VHDX support (Windows Server 2012 R2)</li> <li>Manage on-premises and cloud apps (System Center 2012 R2)</li> <li>Query optimization enhancements</li> <li>Recovery Advisor</li> <li>Windows Server Core</li> <li>Live Migration</li> <li>Online operations enhancements</li> <li>Query Store</li> <li>Temporal support</li> </ul>	<ul style="list-style-type: none"> <li>SQL Server Data Tools</li> <li>Local DB runtime (Express)</li> <li>Data-tier application component project template</li> <li>Data Tier Application Framework (DAC Fx)</li> <li>Interoperability support (ADO.NET, ODBC, JDBC, FDO, ADO APIs and .NET C/C++, Java, Linux and PHP platforms)</li> <li>Enhanced support for ANSI SQL standards</li> <li>Transact-SQL Static Code Analysis tools</li> <li>Transact-SQL code snippets</li> <li>Intelligence</li> <li>FileTable build on FILESTREAM</li> <li>Remote Blob Storage with SharePoint 2010</li> <li>Statistical Semantic Search</li> <li>Spatial features, Full Globe and arcs</li> <li>Large user-defined data types</li> <li>Distributed Replay</li> <li>Container Database Authentication for SQL Server 2012</li> <li>Windows PowerShell 2.0 support</li> <li>Multi-server Management with SQL Server Utility Control Point</li> <li>Data Tier Application Component</li> <li>Automatic Plan Correction</li> </ul>	<ul style="list-style-type: none"> <li>Transparent Data Encryption</li> <li>Always Encrypted</li> <li>Enhanced separation of duty</li> <li>Row-level security</li> <li>Dynamic data masking</li> <li>Enhanced separation of duties</li> <li>Default schema for groups</li> <li>SQL Server Audit</li> <li>SQL Server fine-grained auditing</li> </ul>	<ul style="list-style-type: none"> <li>Enhanced connectors, new transformations, object-level security, ragged hierarchies**</li> <li>Graph data support</li> <li>Mobile BI</li> <li>Enhanced SSIS</li> <li>Enterprise-grade Analysis Services</li> <li>Advanced tabular models</li> <li>In-memory analytics</li> <li>Enhanced multidimensional models</li> <li>JSON support</li> <li>Enhanced DQS</li> <li>Enhanced MDS</li> <li>Modern Reporting Services</li> <li>Temporal tables</li> <li>Advanced data mining</li> <li>Create mobile reports using the SQL Server Mobile Report Publisher</li> <li>Consume with Power BI mobile apps</li> <li>Azure HDInsight Service</li> <li>Power BI</li> <li>Power Maps for Excel</li> <li>Match up data from different sources, such as Oracle &amp; Hadoop</li> <li>HA for StreamInsight, complex event processing</li> <li>SQL Server Data Tools support for BI</li> <li>Change Data Capture for Oracle</li> <li>Import PowerPivot models into Analysis Services</li> </ul>
	<h3>Data Warehousing</h3> <ul style="list-style-type: none"> <li>Adaptive Query Processing</li> <li>Operational analytics</li> <li>In-memory ColumnStore</li> <li>Deployment rights for APS</li> <li>Enhanced In-memory ColumnStore for DW</li> <li>PolyBase for simple T-SQL to query structured and unstructured data</li> <li>Enhanced database caching</li> <li>Up to 15,000 partitions</li> <li>Analytics Platform System</li> </ul>	<h3>Advanced Analytics</h3> <ul style="list-style-type: none"> <li>Enhanced productivity and performance</li> <li>Power View</li> <li>Configurable reporting alerts</li> <li>Reporting as SharePoint Shared Service</li> <li>Build organization knowledge base</li> <li>Connect to 3rd party data cleansing providers</li> <li>Master Data Hub</li> <li>Master Data Services Add-in for Excel</li> <li>Graphical tools in SSIS</li> <li>Extensible object model</li> <li>SSIS as a Server</li> <li>Broader data integration with more sources: DB vendors, cloud, Hadoop</li> <li>Pipeline improvements</li> </ul>	<ul style="list-style-type: none"> <li>Stretch database</li> <li>Partitioning for efficient data loading</li> <li>Hybrid scenarios with SSIS</li> <li>Enhanced backup to Azure</li> <li>Easy migration to the cloud</li> <li>Simplified cloud DR with AlwaysOn replicas</li> <li>Simplified backup to Azure</li> <li>Support for backup of previous versions of SQL Server to Azure</li> <li>Cloud back-up encryption support</li> <li>Simplified cloud Disaster Recovery with AlwaysOn replicas in Azure VMs</li> <li>New Azure Deployment UI for SQL Server</li> <li>Larger SQL Server VMs and memory sizes available in Azure</li> <li>SQL Server Data Tools</li> <li>Snapshot backups to Azure via SQL Server Management Studio</li> </ul>
			<h3>Platform</h3> <ul style="list-style-type: none"> <li>Linux support</li> <li>Container support</li> </ul>

Figure 1 - New features added to SQL Server since SQL Server 2008 R2

Key on-line transaction processing (OLTP) processing features available in SQL Server 2017 include:

- **Performance** – SQL Server’s integrated in-memory toolset goes far beyond isolated features and provides support for improving performance dramatically in a wide range of scenarios.
- **Security and compliance** – As SQL Server progresses, we’re adding new capabilities to protect data both at rest and in motion, with new features like Always Encrypted and Row-Level Security.

- **Availability** – Already known for rock-solid, reliable performance, SQL Server is adding significant new enhancements to AlwaysOn, better load balancing, and new features for flexible and efficient backups.
- **Scalability** – New advancements in compute, storage and networking will provide a direct impact on mission-critical SQL Server workloads.
- **Cloud services** – New tools in SQL Server and Microsoft Azure make it even easier to scale to the cloud; to build patching, backup and disaster recovery solutions; and to access resources wherever they are — on-premises, private cloud or public cloud.

This testing is focused on using default disk-based tables instead of taking advantage of in-memory OLTP capabilities because our goal was to show how the DataON SQL Server 2017 Solutions can be used to consolidate SQL Server 2008 R2 workloads by running on modern hardware without making any changes to the database other than a simple upgrade.

### Windows Server 2016 Datacenter Edition

Windows Server 2016 is a cloud-ready operating system that delivers new layers of security and Microsoft Azure-inspired innovation for the applications and infrastructure that power your business. From a storage perspective, Windows Server 2016 includes new features and enhancements for software-defined storage, as well as for traditional file servers.

[Storage Spaces Direct](#) is a new feature in Windows Server 2016. It uses servers with locally-attached drives (such as the DataON SQL 2017 Server Solutions) to create highly available, highly scalable software-defined storage at a fraction of the cost of traditional SAN or NAS arrays.

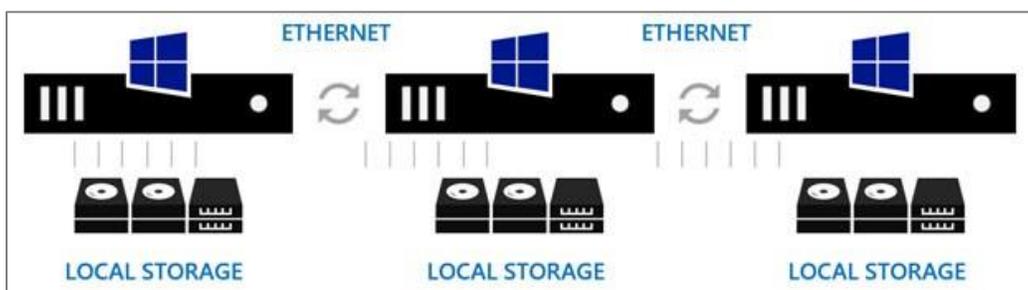


Figure 2 - Using Windows Server Storage Spaces Direct to create a HCI storage and compute solution

- Storage Spaces Direct utilizes NVMe storage devices for better performance and efficiency. These devices greatly reduce the I/O latency for storage, and you can also use SATA storage devices to lower the cost of storage.

- In a DataON hyper-converged system, storage uses RDMA over Converged Ethernet (RoCE) as the storage fabric instead of having a shared physical storage fabric behind the servers which reduce the CPU utilization to server storage.
- Storage Spaces Direct is included in Windows Server 2016 Datacenter Edition.

## Western Digital NVMe SSDs

Western Digital NVMe SSDs drives provide the next wave of application acceleration with simplified PCIe SSD system integration. The standardized NVMe protocol for PCIe SSDs enables broad system interoperability and ease of deployment, resulting in lower cost of ownership. Western Digital 3D NAND technology provides blazing speed, top-tier performance, lower latency, and higher power efficiency.

## Hardware

The DataON S2D-5224w is an Intel-based server system that provides scale-out and scale-up infrastructure and management services for deploying Microsoft Windows Server 2016. It features Intel® Xeon® Scalable Processors with Intel® C620 Chipsets and and NVMe SSDs. It is optimized for performance and density for the delivery of core Microsoft services and enterprise applications. The S2D-5224w is designed on three core principles:

- Scale-out hyper-converged cluster
- Integrated software-defined services
- Complete visibility and management of the storage infrastructure via DataON's exclusive MUST infrastructure and management software tool



Figure 3 - DataON S2D-5224w 2U 24-bay 2.5" all-NVMe hyper-converged infrastructure

Mellanox 40GbE ESF solutions for Windows Server 2016 data centers delivers end-to-end RDMA over Converged Ethernet (RoCE) support. These end-to-end solutions provide consistently high bandwidth and low latency to I/O intensive applications and fast flash storage, enabling data centers to operate with high performance and efficiency. By supporting speeds from 10GbE to 100GbE, Mellanox Spectrum® switches and ConnectX-4® network adapter cards give IT managers flexibility in how they

deploy higher bandwidth to the servers, providing simple upgrade paths from 10GbE to 40GbE, or to 25/100GbE.

With Mellanox ESF solutions, data access using file-based protocols such as Microsoft SMB Direct (SMB over RDMA) enables:

**Increased throughput** – Leverages the full throughput of high-speed networks in which the network adapters coordinate the transfer of large amounts of data at line speed.

**Constantly low latency** – Provides extremely fast responses to network requests, and eliminates network bottleneck. As a result, makes remote file storage appear as if it were directly attached block storage. Besides supporting latency sensitive applications such as in-memory databases, close-to-local storage performance truly makes it truly possible to disaggregate control plane and data plane for software defined storage.

**Low CPU utilization** – Uses fewer CPU cycles when transferring data over the network, which leaves more power available to server applications, thus improving the overall server utilization.

The SN2100 Spectrum Switch provides a high density, side-by-side 40GbE switching solution which scales up to 128 ports in 1U (10/25G, two SN2100s) for the growing demands of today's database, storage, data centers environments.

**High performance** – Powered by the Mellanox Spectrum™ ASIC, the SN2100 carries a whopping throughput of 3.2Tb/s with a landmark 4.76Bpps processing capacity. The port-to-port latency is around 300ns, and no packet loss regardless of speed and frame size. By dynamically shared buffer and faster ECN, the SN2100 provides the best congestion management, thus optimized for RoCE traffic such as NVMe-oF.



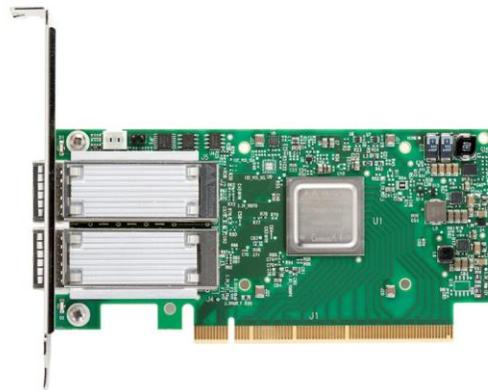
Figure 4 - Mellanox Spectrum SN2100 10/25/40/50/56/100GbE Switch

## 40 Gigabit Ethernet Adapter Cards

Mellanox ConnectX-4 40 Gigabit Ethernet adapters provide exceptional high performance for the most demanding data applications, from public and private clouds, Web2.0, Big Data applications, to storage systems, enabling today's corporations to meet the demands of the data explosion.

**Best RoCE Performance** – ConnectX-4 adapters support RoCE specifications delivering low-latency and high-performance over Ethernet networks. Leveraging data center bridging (DCB) capabilities as well as advanced congestion control hardware mechanisms, ConnectX-4 RoCE provides efficient low-latency RDMA services over Layer 2 and Layer 3 networks.

With RDMA/RoCE offload in the ConnectX-4 adapters, and predictable high performance by the Spectrum switches, the Mellanox ESF solution accelerates Microsoft Server 2016 Storage Spaces Direct, unleashes the power of faster storage devices such as NVMe SSDs, and greatly improves server CPU and application efficiency.



*Figure 5 - Mellanox ConnectX-4 40/56 GbE Adapters*

Microsoft SQL Server 2017 S2D HCI  
4x S2D-5224w Network Connection Diagram

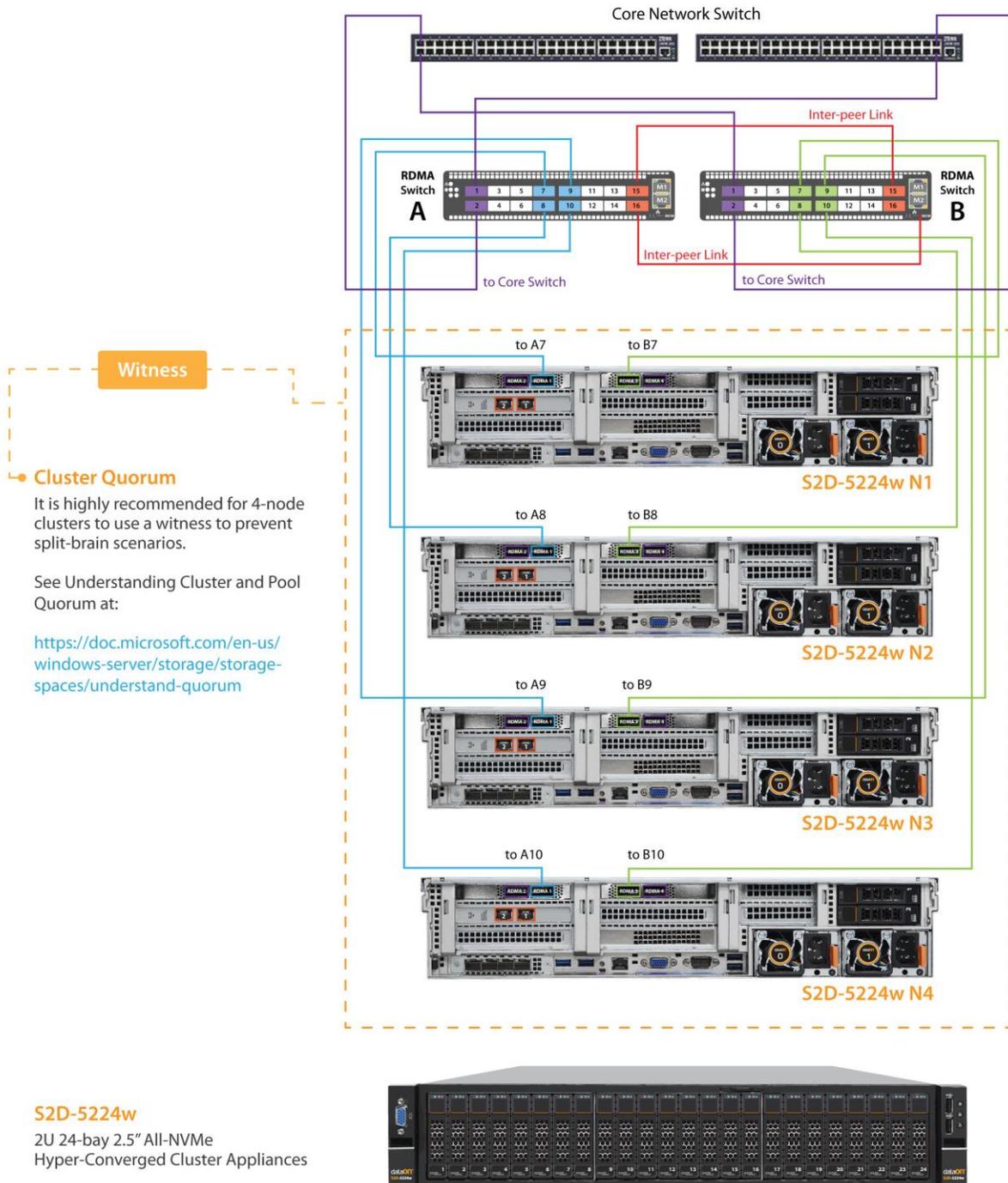


Figure 6 – Four-node DataON S2D-5224w network connection diagram

Each server used two Intel Xeon Gold 6148 CPUs: 2.4GHz, 20-core, 27.5MB cache. Each of the 4 servers has 40 cores, so the 4-node cluster has 160 cores. Each server used eight Samsung 32GB DDR4 2666MHz ECC-Register DIMMs for a total of 256GB per node.

The four servers were interconnected using a Mellanox Spectrum based 40GbE Ethernet switch and RDMA cards.

The NVMe drives were added to a single Storage Spaces Direct pool with multiple volumes based on the number of DataON S2D server nodes.

## Software

Each server ran Windows Server 2016 Datacenter Edition (required for Storage Spaces Direct) and participated in a Windows Failover Cluster (also required for Storage Spaces Direct).

Volumes were configured for operating system (OS), data and log drives as 3-way mirrored volumes, resulting in one local copy of data, and two remote copies on other nodes.

SQL Server workloads ran in Hyper-V virtual machines, with Windows Server 2016 as the guest OS, running SQL Server 2017 Standard Edition. Each VM was configured with 4 virtual cores (mapped to 2 physical cores) and 10GB of RAM.

The disk layout included the following:

Drive	Size (GB)	Purpose	Notes
C:	40	OS	SQL Server was installed in each VM using sysprep
H:	70	Data	Format at 64k
I:	5	Log	Format at 8k

Figure 7 - Disk layout for SQL Server VMs running TPC-C with a 60GB database

### Load Generation and HammerDB Setup

The HammerDB tool was used to generate a TPC-C like transactional workload. [HammerDB](#) which is commonly used for server benchmarking, and it is somewhat of an industry standard controlled by the community. The benchmark itself ran using the open-source [AutoHammer extension](#) designed to automate the execution of the test runs.

For the test run, we used a 60GB database that represents the typical size OLTP database based on data collected from DB Best customers. We chose 100 threads (also known as users) for the TPC-C runs as we found that this configuration on a single VM ran the CPU at 100% with no measurable disk latency.

## SQL Server Setup

SQL Server 2017 Standard Edition in the virtual machines was configured as shown in the table below.

Parameter name	Minimum	Maximum	Config value	Run value
Max degree of parallelism	0	32767	1	1
Max server memory (MB)	128	2147483647	2147483647	2147483647
Min server memory (MB)	0	2147483647	0	16
Network packet size (B)	512	32767	4096	4096

Figure 8 - SQL Server configuration optimized for OLTP workloads

## Hyper-V Virtual Machine Setup

We created a base VM that was used to create a VHDX files on the cluster storage for cloning the VMs used for the load testing using the following steps:

- Created the base VM with Windows Server 2016 with the C: drive
- Created and formatted the K: (Data) and L: (Log) drives as per **Figure 7**.
- Installed SQL Server on the C: drive and set the default database drive to the K: drive and the default Log drive to the L: drive. This includes setting up mixed authentication and enabling the SA account for running the benchmark without having to rely on a domain controller.
- Created the 60 GB TPC-C database using Hammer DB and made a backup of the database to a shared cluster location.
- Configured SQL Server as per **Error! Reference source not found**. Note, we use a value of 1 for max degree of parallelism as a best practice for running the TPC-C benchmark with HammerDB in a virtualized environment with a relatively small number of cores.
- Install the AutoHammer files to C:\AutoHammer.
- Stop the and delete the Virtual Machine.
- Copied the three VHDX files to a shared folder for the TPC-C benchmark.

At this point, we have three VDHX files that we used to clone the VMs for the test runs for the given configuration.

## Cloning the Base VM for the Benchmarks

To clone the virtual machines, we would do the following steps:

- Created directories for the named VM on the clustered storage for the OS, Data, and Log VHDX files.
- Ran a PowerShell script that performed the following tasks:
  - Create the VM
  - Start the VM
  - Rename the VM from the original source VM to the unique VM for the runs and restarts the VM
  - Rename the SQL Server instance on the VM to match the VM
  - Stop the VM

We did this for each of the 52 VMs across the four nodes. VMs 1-13 were on node 1, 14-26 on node 2, 27-39 on node 3, and 40-52 on node 4. We did a similar process later on for our 6 drives per node run with 80 VMs.

## Using a Centralized Collection Server

We used a separate server on the same virtual private network to run the benchmarks that used a combination of PowerShell scripts and SQL Server agent jobs. The high-level process ran as follows for each VM until all were running:

- Start the VM and restore the TPC-C database if needed
- Generate the AutoHammer template definition for the VM
- Execute the AutoHammer scheduled process
- Once all the VMs are running, continue the test run for 40 mins while capturing the performance metrics
- After 40 mins, a scheduled task terminates the AutoHammer process and the benchmark is marked as completed.
- Databases on the VMs are restored after the run.

The test results were written to the SQL Server database on the central server. We then ran a query that outputted the results to CSV file and then used Power BI to analyze the results.

# Benchmarking Testing Scenarios

## Understanding the performance profile for SQL Server 2008

The benchmark configuration was optimized to see how the overall system would perform by consolidating SQL Server 2008 workloads using hardware that was available around 2010. In 2016, SanDisk® (now Western Digital) and DB Best performed a similar benchmark using a base configuration as follows:

- Two Dell R730XD servers running Windows Server 2012 R2 in the Hyper-V role, each server had:
  - 250GB DRAM, 10GB Network cards, and 28 physical cores (56 logical cores with Hyper-Threading enabled)
  - Hard disk drive storage using 24x 300GB 15k RPM SAS drives
- One server was used for the benchmark and the other server ran AutoHammer as the load injector.
- Each VM configured used two logical cores with 4GB of memory.
- HammerDB was configured to run against a 100GB TPC-C database using 22 threads (users).
- The disk drives were formatted with the same block sizes as used for this paper.
- SQL Server 2014 was used with settings were the same as the ones used for this paper.

This test aims to find the limitations of the underlying physical storage system where the hard disk drives can no longer keep up with CPU and transaction burden.

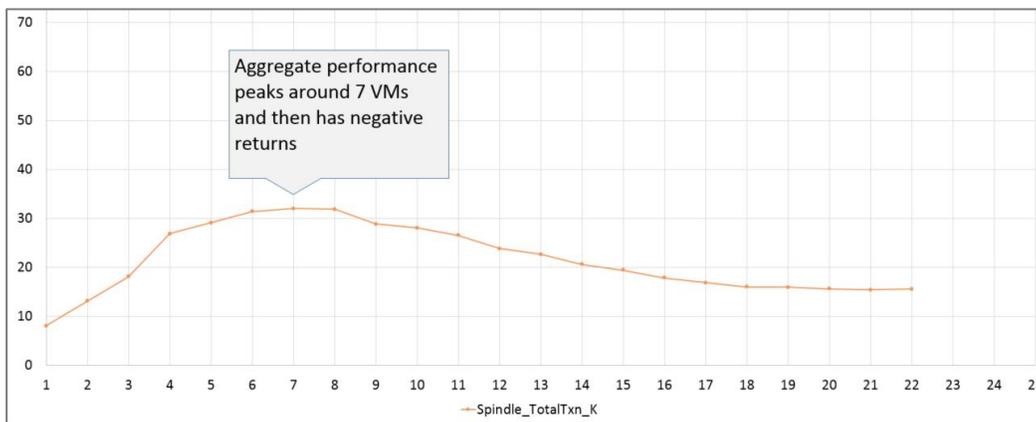


Figure 8 - SQL Server 2014 performance with HDD based storage with multiple VMs

Although performance peaked at 7 VMs for the system, 10 VMs were capable of processing a total of 28,100 transactions per second (TXN/sec). This comes out to 2,800 TXN/sec per VM.

Since SQL Server 2017 includes performance enhancements<sup>7</sup> made since the SQL Server 2014, we set a minimum goal of 3000 TXN/sec when setting up the HammerDB TCP-C test scenarios.

## Benchmark Rational

Because we wanted to test the consolidation of both the application and database for this benchmark, we ran AutoHammer on the same VM as SQL Server running the TPC-C database. The AutoHammer execution used one of the four virtual cores of the VM, giving SQL Server the other three virtual cores for processing the benchmark.

It's important to note, if we were attempting to get the maximum number of transactions per second out of the overall system, we would have used a separate driver system so that the entire system was processing transactions. Again, our goal to demonstrate how consolidating SQL Server workloads using modern hardware and NVMe storage provides a cost-effective solution for organizations needing to upgrade their SQL Server 2008 databases.

We first tested a single VM with 100 threads, where each thread represents an application user, and removed the wait times between transactions so that we could saturate the VM CPU and have no disk latency for the 60 GB TPC-C database.

# Test Results

## Results: Four NVMe SSDs per node, Up To 52 VMs

This test established how many VMs running transactional workloads the 4 drives/node configuration could support, and with what performance level.

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<sup>7</sup> MSDN Blog for SQL Server PSS – [SQL Server \(It Just Runs Faster\)](#)

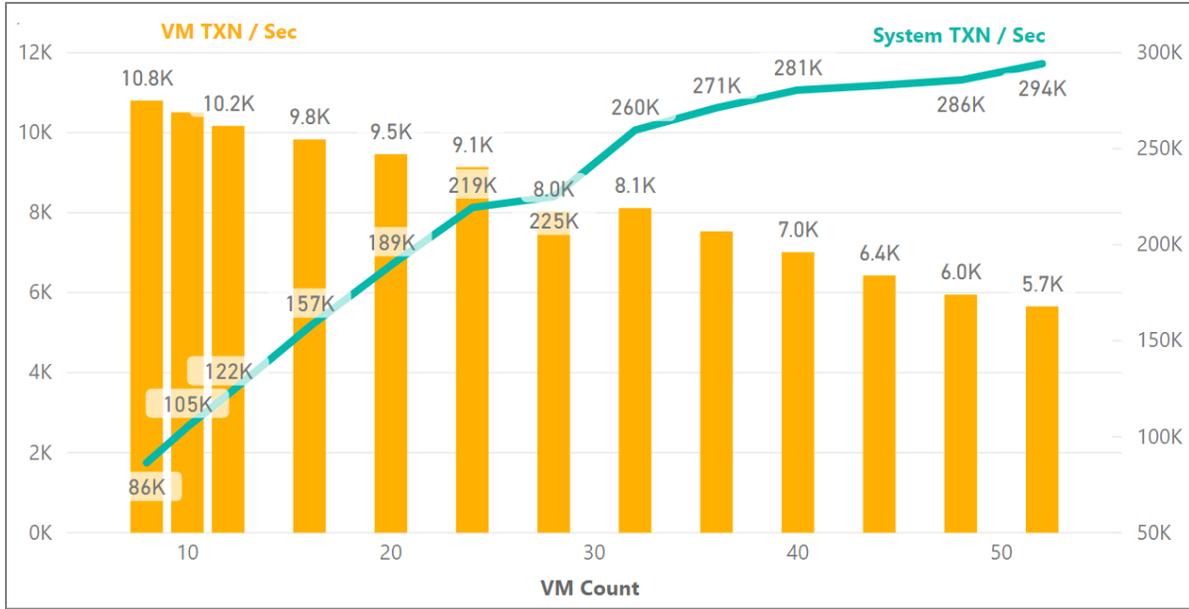


Figure 9 - Transactions (TXN) per second results for four NVMe drives per node

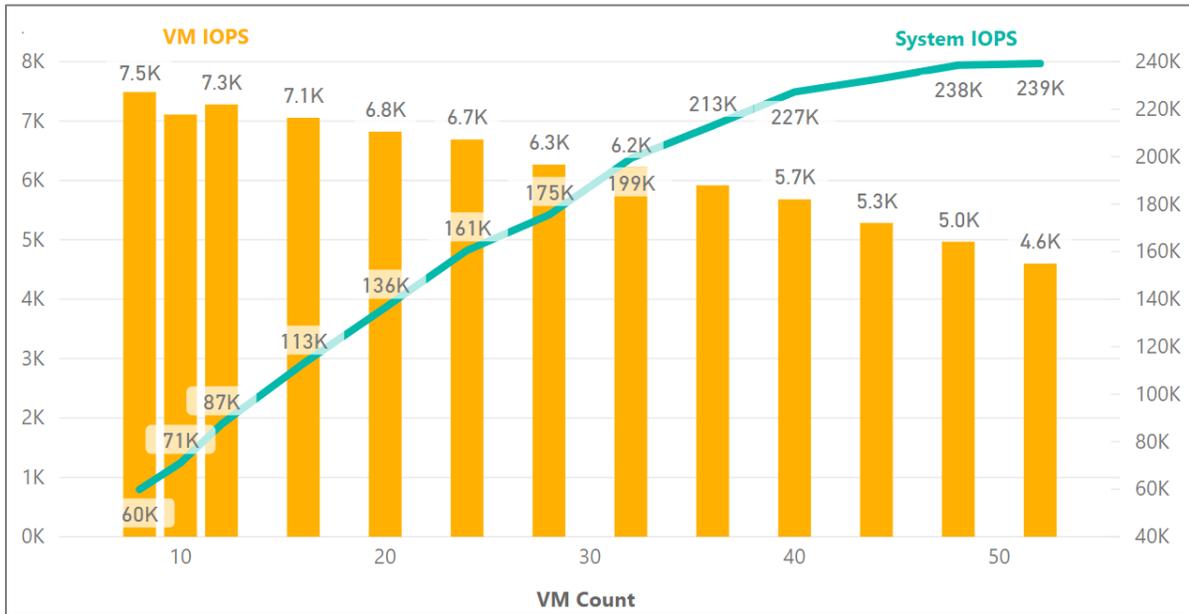


Figure 10 - IOPS results for four NVMe drives per node

During the testing, CPU utilization varied in a limited range, from 98% to 100%, from 8 VMs through 52VMs.

At the maximum number of VMs – determined by the capacity of the 4 NVMe SSDs - each VM was processing approximately 5,700 transactions/second and 4600 IOPS.

## Results: Six NVMe SSDs per node, Up To 80 VMs

This test established how many VMs running transactional workloads the six drives/node configuration could support, and with what performance levels.

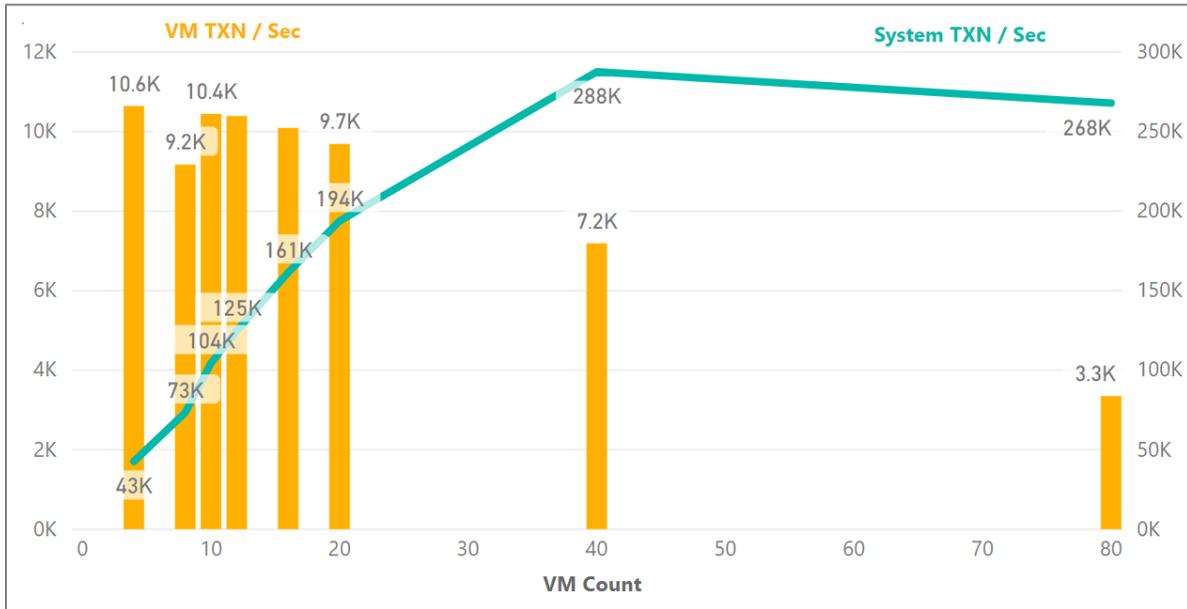


Figure 11 - Transactions (TXN) per second results for six NVMe drives per node

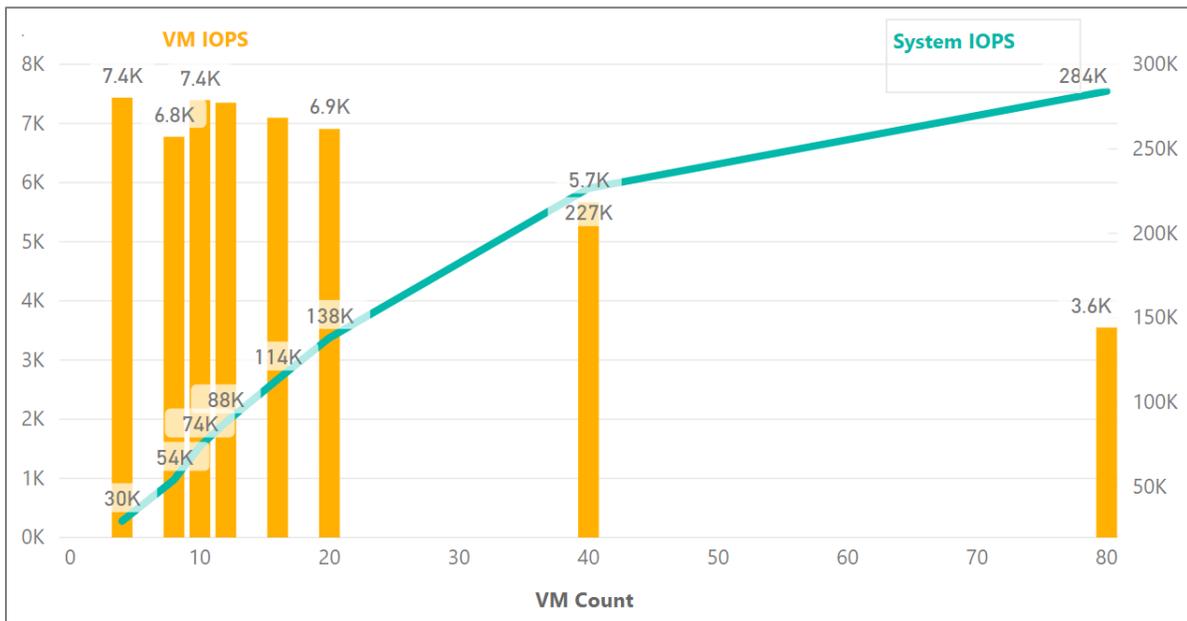


Figure 12 - IOPS results for six NVMe drives per node

CPU utilization again varied in a limited range, from 98% to 100%, up to 80VMs.

At the maximum 80 VMs, each VM was processing approximately 3,300 transactions/second and 3,600 IOPs.

## Results: Comparing the 4-drive and 6-drive configurations

One interesting thing from these results was that the performance characteristics are very similar, regardless of the number of drives used.

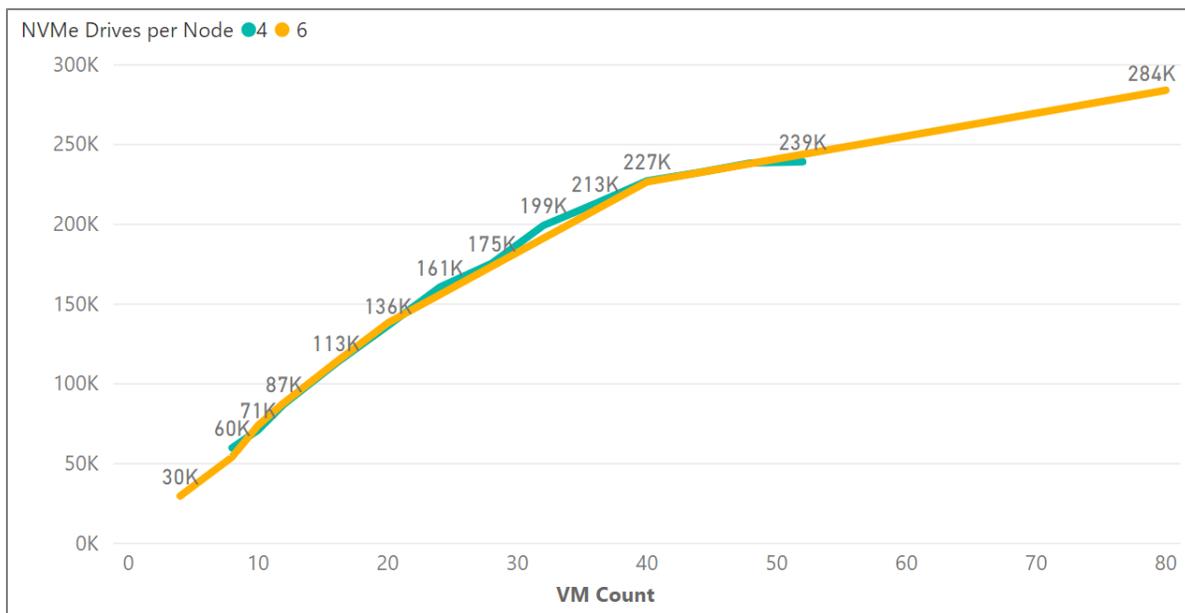


Figure 13 - IOPS performance curves for 4 and 6 drives per node looking at overall system performance

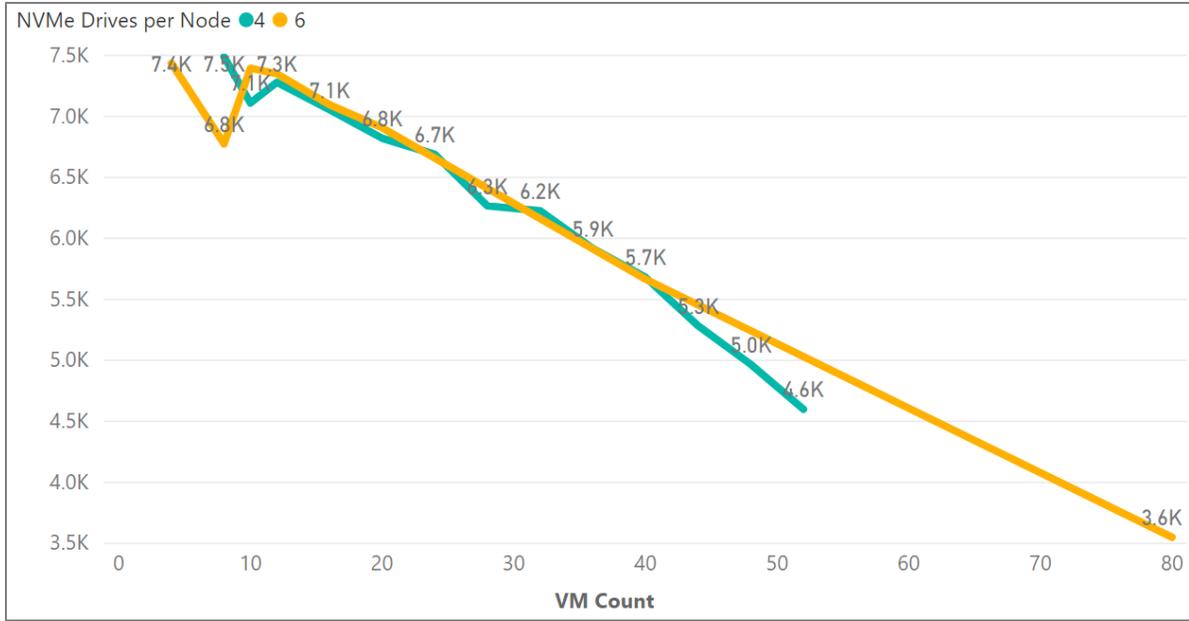


Figure 14 - IOPS per VM curves for 4 and 6 drives per node

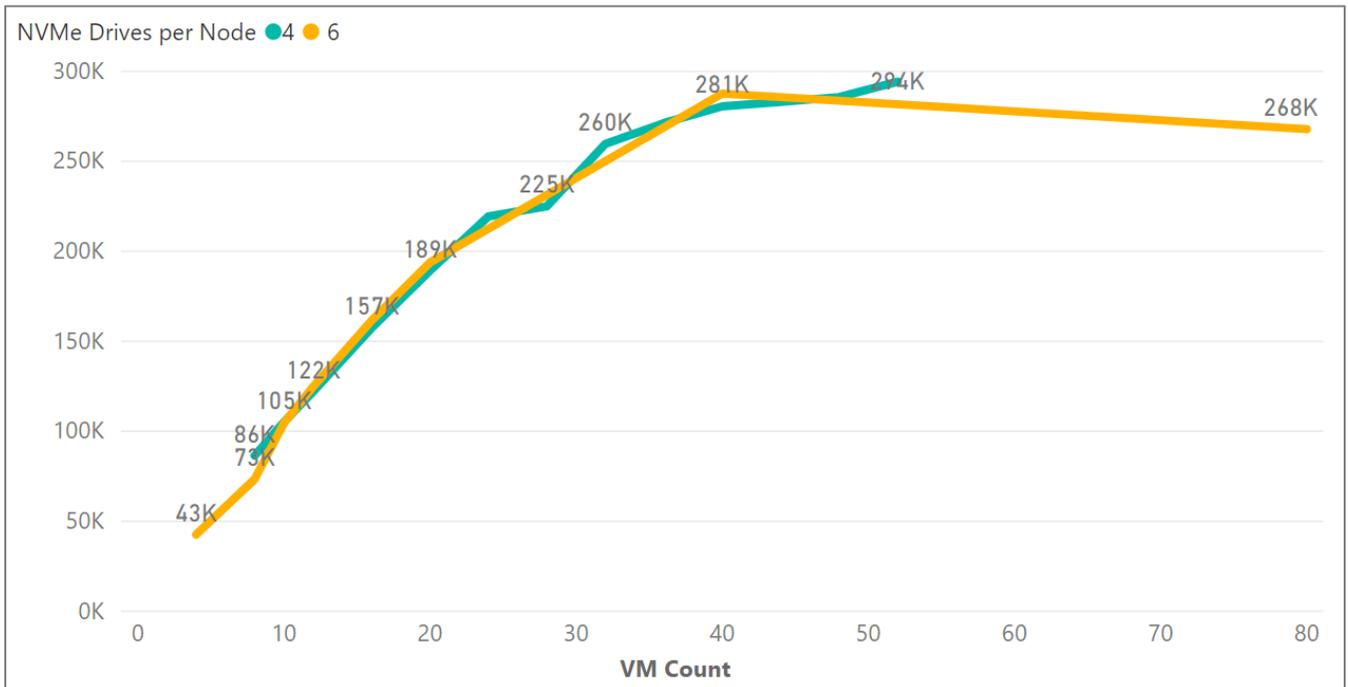


Figure 15 - TXN per second performance curves for 4 and 6 drives per node looking at overall system performance

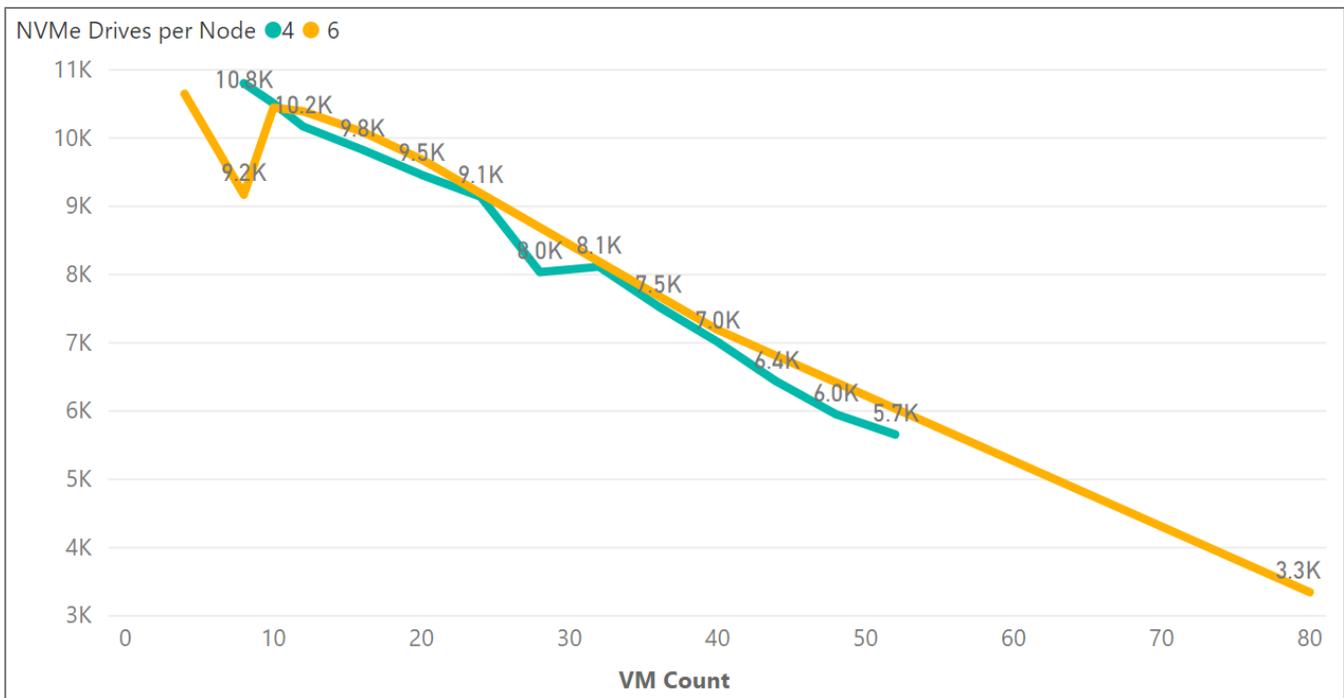


Figure 16 - TXN per second per VM curves for 4 and 6 drives per node

## Conclusions

Workload consolidation increases the efficiency of IT organizations as well as cloud and hosting providers, by harnessing the increasing power of modern host servers to support an increasing number of workloads. Increasing the workload density – the number of workloads running on a host server – drives the economics of consolidation, by reducing the number of host servers required to run a given number of workloads.

Reduce the number of host servers needed, and you reduce both hardware and software license costs. Software license costs are critical to consider when evaluating potential savings, as shown in [Appendix B – Bill of Materials for Test System](#), which provides the retail cost of the host server configurations used during this testing.

The software license cost dominates the total system cost, primarily the cost of SQL Server Standard Edition per-core licenses, accounting for over 60% of the total system cost. Greater workload consolidation, using fewer cores, means you'll need fewer per-core licenses – and you can realize significant savings.

In prior testing by SanDisk and DB Best using SQL Server 2014, a performance baseline was established using a single physical server with local HDD drives, and that system was able to achieve 28.1K transactions per second (TPS) with 10 VMs, or 2.8K TPS per VM. That testing used VMs configured for 2 physical cores and 16GB of RAM.

With the four node DataON SQL Server 2017 Solution using four NVMe drives per server as per [Appendix B – Bill of Materials for Test System](#), we were able to run a total of 52 VMs, each with 4 virtual cores (vCores) and 10GB of RAM, and deliver 5.6K TPS per VM.

The performance and low latency of the NVMe storage allowed us to reduce the system memory allocation from 16GB to 10GB per VM. SQL Server typically uses in-memory page buffering (caching) to keep recently used pages quickly available, originally intended to reduce how often the database engine stalled waiting for data from lower-performance HDDs. In this configuration, that buffering is not needed, and that system memory is better used to support additional workloads.

The high CPU utilization with near-zero I/O latency indicates the NVMe storage performance is high enough to keep the CPUs busy - even for the maximum VM count, and even with unusually small system memory allocation.

Keep in mind that in this test, that one virtual core in each VM was busy generating the load (running HammerDB) while the other three virtual cores in that VM processed the transactions. This configuration over-subscribed virtual cores to physical cores by 2:1, allocating 80 virtual cores against the underlying 40 physical cores on each host server. Thus both the load generation and the database workload were running on 2 physical cores, the same number of cores used in our prior testing using SQL Server 2014 and HDDs.

This implies that with the DataON SQL Server 2017 Solution, you can cost effectively consolidate your SQL Server 2008 and 2008 R2 workloads by upgrading to SQL Server 2017, virtualizing, and running them with fewer virtual cores and system memory per workload, by leveraging the performance of NVMe storage.

In the case of the four NVMe drives per node scenario, the number of VMs was constrained by the capacity of the storage configuration, i.e., dividing the available storage by the storage required by each VM, then accounting for the requirements of 3-way mirroring by Storage Spaces Direct.

By adding two more NVMe drives per node for a total of six, we were able to support up to 80 VMs. In this scenario, we were limited by the total of 160 physical cores across the four nodes. We were able to achieve 3.6K TPS per VM across the 80 VMs. What this means is that by increasing the overall system price by 26% (\$17.6K for 8 additional drives and \$208.2K for software licenses for 28 additional VMs), we were able to improve workload density by 35%. The performance of the 80 workloads likely exceeds their current performance running SQL Server 2008 or 2008 R2 on older hardware.

Our testing did not establish the maximum number of SQL Server 2008-like workloads that these configurations could support, rather it established that limited storage capacity stopped our testing before we could overwhelm the system.

## Next Steps

### Contact DataON to Migrate your Microsoft SQL Server 2008 workloads to SQL Server 2017 based on DataON™ Windows Server HCI Platform

Visit - [www.dataonstorage.com/Solutions](http://www.dataonstorage.com/Solutions) to learn more about DataON SQL 2017 Solutions

Email: [DataON\\_Sales@dataonstorage.com](mailto:DataON_Sales@dataonstorage.com) to schedule a meeting with our SQL specialists

DataON is the industry-leading provider of hyper-converged infrastructure and storage systems optimized for Microsoft Windows Server environments. It has been named to CIO Review's '20 Most Promising Microsoft Solution Providers 2018.' Our enterprise-SQL solutions, delivered as a complete, turnkey experience, are designed to provide the highest level of performance and density. For more information, go to [www.dataonstorage.com](http://www.dataonstorage.com) or call +1 (714) 441-8820.

### Get an assessment of your environment by DB Best

We expect no customer's host server configuration and workloads will be identical to our test environment, and the differences will affect the impact of these solutions. While we believe the assumptions and choices reflected in our test environment are reasonable and representative, and the results we observed reflect rigorous testing, we encourage any customer evaluating the applicability of these solutions to arrange for an assessment of their unique environment by contacting DB Best:

Reach us on the web at <https://www.dbbest.com/company/contact-us/>

Or contact Dmitry Balin, [Dmitry@dbbest.com](mailto:Dmitry@dbbest.com), or any of the paper's authors.

### Project Participants

DataON is the leader in Microsoft Windows Server software-defined solutions. Our company is focused on customers who have made the "Microsoft choice" to deploy Microsoft applications, virtualization, data protection, and hybrid cloud services. Our enterprise-level solutions are designed to provide the highest level of performance, manageability, and security offered, delivered as a complete, turnkey experience.

DB Best Technologies, Microsoft's dominant database modernization, migration, and optimization partner, collaborated with DataON and Western Digital on this project, and knows these solutions well. DB Best's DBMSYS modeling is purpose-built to assess customer environments and recommend the optimal modernization and migration outcomes.

Western Digital creates environments for data to thrive. The company is driving the innovation needed to help customers capture, preserve, access and transform an ever-increasing diversity of data.

Everywhere data lives, from advanced data centers to mobile sensors to personal devices, our industry-leading solutions deliver the possibilities of data. Western Digital® data-centric solutions are marketed under the G-Technology™, HGST, SanDisk®, Tegile™, Upthere™, and WD® brands.

# Appendix A – Key Metrics from Testing

## Recorded Data – 4 NVMe drives per node - TPC-C – 100 users

VM Count	Txn/Sec per VM	CPU %	Latency (Data) ms	Latency (Log) ms	Total System Txn/Sec	Total System IOPS	IOPS per VM
8	10,804	99	0	1	86,439	59,907	7,488
10	10,510	98	0	1	105,105	71,103	7,110
12	10,171	99	0	1	122,053	87,349	7,279
16	9,831	98	0	1	157,308	112,891	7,055
20	9,463	98	0	1	189,271	136,439	6,821
24	9,140	99	1	1	219,362	160,546	6,689
28	8,036	99	1	2	225,025	175,460	6,266
30	7,808	99	1	2	234,244	182,145	6,071
32	8,115	99	1	2	259,685	199,283	6,227
36	7,534	99	1	2	271,243	213,032	5,917
40	7,013	99	1	3	280,533	227,253	5,681
44	6,431	99	1	3	282,979	232,531	5,284
48	5,953	99	1	3	285,747	238,497	4,968
50	4,854	99	1	3	242,745	210,646	4,212
52	5,658	99	1	3	294,226	239,231	4,600

## Recorded Data – 6 NVMe drives per node - TPC-C – 100 users

VM Count	Txn/Sec per VM	CPU%	Latency (Data) ms	Latency (Log) ms	Total System Txn/Sec	Total System IOPS	IOPS per VM
4	10,647	99	1	1	42,591	23	29,746
8	9,171	99	1	1	73,371	18	54,203
10	10,446	98	1	0	104,463	23	73,949
12	10,393	99	1	0	124,726	23	88,208
16	10,092	98	1	0	161,473	21	113,550
20	9,689	99	1	0	193,781	19	138,143
40	7,190	98	3	1	287,623	19	226,649
80	3,348	98	15	9	267,912	17	284,078

# Appendix B – Bill of Materials for Test System

## DataON

DataON makes it easy to buy their solution under one all-inclusive price that include support. Here is a breakdown for the system components that made up the test solution for with four [Ultrastar SN200 1.92 TB NVMe U.2 2.5" SSD](#) drives per server node.

DataON S2D-5224w SQL Server 2017 Solution		
Qty	Part#	Description
4	S2D-5224W	DataON® S2D-5224W 2U 24-Bay All-NVMe Server
8	CPU-XEON-6148	Intel® Xeon® Gold 6148 2.4 GHz, 20-Core, 27.5MB Cache (160 total cores)
32	MMD-32G-2666CC	Samsung® 32GB DDR4 2666MHz ECC-Register DIMM
8	SD8SN8U-256G	SanDisk® X400 256GB SATAIII M.2 2280 SSD
24	0TS1355	Ultrastar® DC SN200 1.92TB NVMe U.2 2.5" SSD
4	NC-MCX414A-BCAT	Mellanox® ConnectX-4 EN Dual Port QSFP28 40/56 GbE RDMA Card
8	CB-MC2210128003	Mellanox® LinkX™ Passive Copper cable, ETH 40GbE, 40Gb/s, QSFP, 3M
2	NC-MSN2100-BB2F	Mellanox® Spectrum™ based 40GbE, 16 QSFP28 ports, 1U Open Ethernet Switch
2	CB-MC2210130001	Mellanox® LinkX™ Passive Copper cable, ETH 40GbE, 40Gb/s, QSFP, 1M
1	MTEF-KIT-D	Rack installation kit for SN2100 series short depth 1U switches
	<b>MSRP:</b>	<b>\$189,900</b>

Figure 17 - DataON S2D-5224w SQL Server Platform for a four-node cluster with **four** NVMe drives per node

DataON S2D-5224w SQL Server 2017 Solution		
Qty	Part#	Description
4	S2D-5224W	DataON® S2D-5224W 2U 24-Bay All-NVMe Server
8	CPU-XEON-6148	Intel® Xeon® Gold 6148 2.4 GHz, 20-Core, 27.5MB Cache (160 total cores)
32	MMD-32G-2666CC	Samsung® 32GB DDR4 2666MHz ECC-Register DIMM
8	SD8SN8U-256G	SanDisk® X400 256GB SATAIII M.2 2280 SSD
32	0TS1355	Ultrastar® DC SN200 1.92TB NVMe U.2 2.5" SSD
4	NC-MCX414A-BCAT	Mellanox® ConnectX-4 EN Dual Port QSFP28 40/56 GbE RDMA Card
8	CB-MC2210128003	Mellanox® LinkX™ Passive Copper cable, ETH 40GbE, 40Gb/s, QSFP, 3M
2	NC-MSN2100-BB2F	Mellanox® Spectrum™ based 40GbE, 16 QSFP28 ports, 1U Open Ethernet Switch

2	CB-MC2210130001	Mellanox® LinkX™ Passive Copper cable, ETH 40GbE, 40Gb/s, QSFP, 1M
1	MTEF-KIT-D	Rack installation kit for SN2100 series short depth 1U switches
	<b>MSRP:</b>	<b>\$207,500</b>

Figure 18 - DataON S2D-5224w SQL Server Platform for a four-node cluster with **six** NVMe drives per node

## Software Platforms

The system tested used Windows Server 2016 Data Center Edition and SQL Server 2017 Standard Edition.

Microsoft Software Licensing - 52 VMs				
		Price	Description	Total License Cost
52 VMs	4 vCores per VM	\$7,424 per four cores	SQL Server 2017 Standard Edition	\$386,568
160 cores	10 16-core packs	\$6,155 per 16 core pack	Windows Server 2016 Datecenter Edition	\$61,550.00
			<b>Software MSRP Total (USD)</b>	<b>\$448,118.00</b>

Figure 19 - Software license costs for 52 VMs using 4 virtual cores per VM on a 160-core host

Microsoft Software Licensing - 80 VMs				
		Price	Description	Total License Cost
80 VMs	4 vCores per VM	\$7,424 per four cores	SQL Server 2017 Standard Edition - sold in 2-core pack - Each VM used 4 vCores	\$594,720.00
160 cores	10 16-core packs	\$6,155 per 16 core pack	Windows Server 2016 Datecenter Edition - sold in 16-core pack	\$61,550.00
			<b>Software MSRP Total (USD)</b>	<b>\$656,270.00</b>

Figure 20 - Software license costs for 80 VMs using 4 virtual cores per VM on a 160-core host

## About SQL Server Licensing

The SQL Server 2008 workloads envisioned in this solution used SQL Server 2008 Standard Edition and will continue to use the Standard Edition of SQL Server 2017.<sup>8</sup>

When running several virtualized instances of SQL Server, there are several licensing strategies to consider.<sup>9</sup>

- Each VM is licensed separately - each VM is licensed for Standard Edition, with a minimum of 4 core licenses per VM (even for VMs using fewer than 4 virtual cores).
- Each core is licensed for Enterprise Edition - each physical core is licensed for Enterprise Edition, and the maximum number of allowed SQL Server VMs is the same as the number of licensed cores.
- Each core is license for Enterprise Edition with Software Assurance - each physical core is licensed for Enterprise Edition, to run an unlimited number SQL Server VMs.

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<sup>8</sup> If your SQL Server 2008 workloads already use features that require Enterprise Edition, or you want to take advantage of features of SQL Server 2017 that require Enterprise Edition, your licensing cost will be different than shown.

<sup>9</sup> Microsoft's software licensing is complex, and additional considerations may influence your decision. The three strategies shown are most applicable to the scenario described in this solution.

Calculating the SQL Server license cost<sup>10</sup> for each scenario, we get:

Standard Edition				
SQL Server VMs	vCores/VM	4-core pack	Total License Cost	Notes
52	4	\$7,424	\$386,568	52*7424
Enterprise Edition				
SQL Server VMs	Physical Cores	2-core pack	Total License Cost	Notes
N/A	160	\$14,256	\$1,140,480	(160/2)*14256
Enterprise Edition w/ SA				
SQL Server VMs	Physical Cores	2-core pack w/SA	Total License Cost	Notes
N/A	160	\$17,820	\$1,425,600	(160/2)*17820

There's a clear cost advantage in this scenario to use SQL Server 2017 Standard Edition.

### About Windows Server Licensing

This system uses Storage Spaces Direct, which is available only in Windows Server 2016 Datacenter Edition; which also grants unlimited Hyper-V VMs per licensed server.

Calculating the Windows Server license cost<sup>11</sup> we get:

Datacenter Edition				
VMs	Physical Cores	16-core pack	Total License Cost	Notes
N/A	160	\$6,155	\$61,550	(160/16)*6155

<sup>10</sup> ["SQL Server - Pricing and Licensing"](#), showing Open No Level retail prices. Retrieved 29-August-2018.

<sup>11</sup> ["Windows Server 2016 Licensing & Pricing"](#), showing Open No Level retail prices. Retrieved 29-August-2018.

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## Additional Resources

### Hardware

[DataON S2D-5224 & Windows Server 2016 Storage Spaces Direct Solution with Mellanox Spectrum Switches](#)

[Intel® Xeon® Scalable Processors with Intel® C620 Series Chipsets \(Purley\)](#)

[Ultrastar DC SN200 Series](#)

[Mellanox Spectrum™ Ethernet Switch](#)

[Mellanox ConnectX®-4 EN Single/Dual-Port 100 Gigabit Ethernet Adapter](#)

## Software

[Microsoft Windows Server 2016 Storage Spaces Direct](#)

[Microsoft SQL Server 2017 Technical White Paper](#)

[HammerDB for OLTP Testing \(TPC-C\)](#)

[AutoHammer extensión](#)

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