



## Handle more online transactions with non-volatile memory module-based storage

A Dell EMC PowerEdge R740xd solution powered by Intel Xeon Scalable processors fulfilled more customer orders using NVDIMM technology than with SATA SSDs

If your company relies on high-performing databases, you've likely already made the jump from traditional hard drives to faster, flash-based storage. But for companies that need to handle even more challenging database work, Non-Volatile Dual In-line Memory Modules (NVDIMMs) may be the solution you need to give your business a competitive edge.

At Principled Technologies, we compared the online transaction processing performance of the Dell EMC™ PowerEdge™ R740xd in two configurations. The first configuration used SATA SSD-only storage, while the other included NVDIMMs in DirectAccess mode along with the SATA SSDs. NVDIMM technology enabled this configuration to process more customer orders each minute, which could mean better customer satisfaction for a real-world business.

With non-volatile memory, your database transactions could occur on the scale of mere nanoseconds<sup>1</sup>, making NVDIMMs an excellent choice for companies who rely on intense speed.

Serve more Microsoft SQL customers



Faster database transactions with NVDIMMs in DirectAccess mode



38% more transactions per minute

## NVDIMMs

A non-volatile dual in-line memory module (NVDIMM) is a type of persistent memory that combines NAND flash, DRAM, and a dedicated backup power source into a single subsystem. You can use NVDIMMs to extend system RAM—or as we did in this study—to supply high-performance storage and accelerate workloads on next-generation platforms.<sup>3</sup>

## How we tested

In another Principled Technologies report from October 2017<sup>2</sup>, we discussed how upgrading to the PowerEdge R740xd could help organizations make business decisions faster by improving database query times. But after making analysis-based improvements to your services, would you be able to serve a sudden influx of online users? NVDIMM technology could help.

We compared online transaction processing (OLTP) workload performance on two configurations of a PowerEdge R740xd server. The first configuration used only SATA SSDs for storage, while the second used SATA SSDs in conjunction with NVDIMM technology. Both configurations ran four databases with Microsoft® SQL Server® 2016, and used the same CPUs from the Intel® Xeon® Processor Scalable Family.

Our OLTP workload came from a benchmark in the HammerDB suite. We measured the average number of transactions per minute (TPM) and new orders per minute (NOPM) each server configuration could handle.

## How NVDIMMs in DirectAccess mode speed up database transactions

On operations that insert, update, or delete data, Microsoft SQL Server typically modifies the data page in the data buffer, marks the page as “dirty,” and creates a new log record in the log buffer. (The log buffer is a small area of memory that stores the operations before writing the log record to disk).

To maintain consistency, SQL Server flushes the log buffer at a commit point. SQL Server must write the log buffer to persistent storage before the database flushes the dirty pages from its data buffer cache.

The log buffer flush process may seem brief, but under intense load the wait time can increase. NVDIMM-N storage in DirectAccess (DAX) mode can help speed up this process.

As the name implies, DAX mode allows an application to directly access the NVDIMM-N at byte-level instead of having to go through a traditional I/O stack. This allows SQL Server to access it like traditional RAM. However, SQL Server doesn't need to wait for the log buffer to flush, as the data is already durable on the battery-backed NVDIMM. Other transactions can begin immediately instead of waiting on the log buffer flush. The application then can move transaction log records to disk storage as a background process that does not pause main database functions.

For more information on Microsoft SQL Server, NVDIMM-Ns in DAX mode, and how these components work together to improve online transaction processing workloads, see the September 2017 report “Accelerating Microsoft SQL Server Performance with NVDIMM-N on Dell EMC PowerEdge R740” by Dell EMC Engineering.<sup>4</sup> Keep in mind that the configuration featured in the Dell EMC report differs from our own.

## HammerDB

We tested each server with an OLTP workload from the HammerDB suite of benchmarks. Their TPC-C-like benchmark gives results in two metrics: transactions processed per minute (TPM) and new orders per minute (NOPM).

To learn more about TPM, NOPM, and other information specific to our benchmark workload, visit the HammerDB website at [www.hammerdb.com](http://www.hammerdb.com).

## Microsoft solutions for native NVDIMM-N access

Starting with its Service Pack 1 release, Microsoft SQL Server 2016 includes native support for NVDIMM-Ns in DirectAccess mode. Modify your databases to use NVDIMMs with familiar commands in SQL Server Manager instead of having to use APIs to create your own customizations for NVDIMM support.

Windows Server 2016 also offers native support for NVDIMM technology. Ready-made drivers and command line support for NVDIMM modules allow for hassle-free implementation of your NVDIMMs.

## Harness the power of NVDIMM technology to support more online transactions

If your current-generation hardware uses SATA SSD-driven storage, your ability to process online users' orders might resemble that of our baseline configuration. The new Dell EMC PowerEdge R740xd combined with fast SATA SSDs managed to process 1.2 million transactions per minute, or 274K new orders per minute. But you could get more out of your database servers by incorporating NVDIMM technology into your hardware stack.

The NVDIMM-enabled server processed 1.7 million transactions per minute (380K new orders per minute), which is 38 percent more than the SSD-only configuration. With the extra boost, your business could handle more transactions without opting to replace SSDs with a large number of NVMe SSDs. Furthermore, we used only four NVDIMMs in our solution; your business could use as many as 12 per server for the possibility of even greater performance gains.

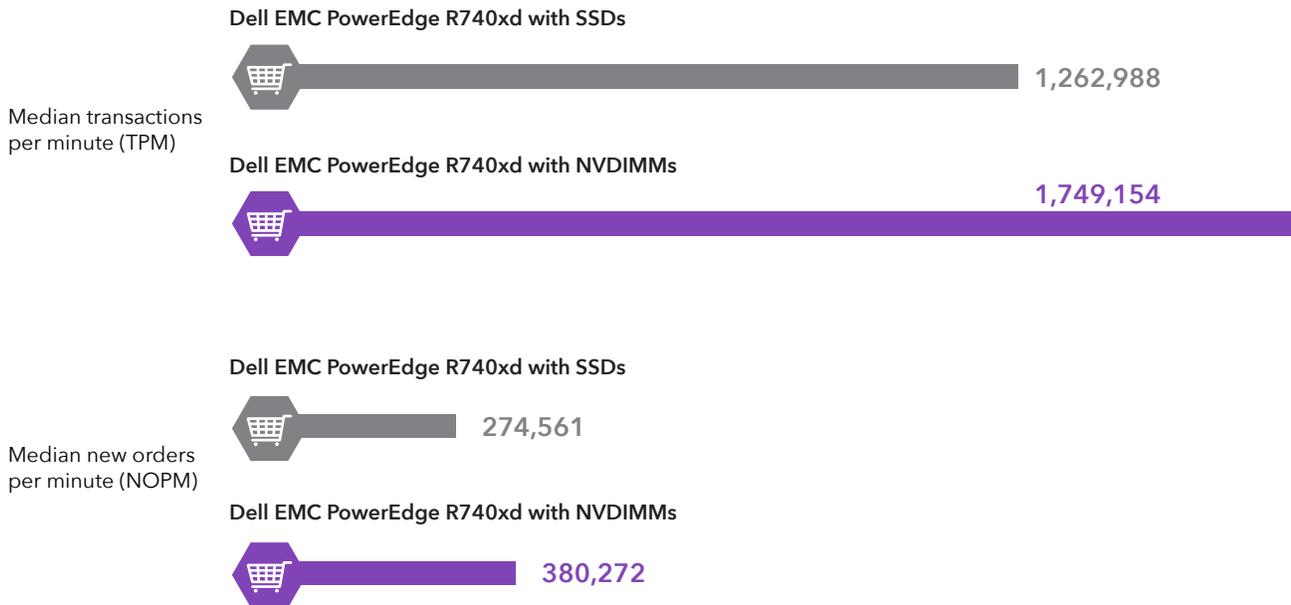


Figure 1: An NVDIMM combines NAND Flash, DRAM, and a dedicated backup power source into a single subsystem.



## Conclusion

After using data analysis to improve your business, your company may find itself struggling to keep up with a ton of requests from new online users. To meet that extra demand, consider how NVDIMM technology could improve your Microsoft SQL Server performance. In our tests, an NVDIMM-equipped server processed 1.7 million customer transactions per minute—38 percent more than a server without NVDIMMs.



Figure 2: The Dell EMC PowerEdge R740xd

- 1 "How It Works (It Just Runs Faster): Non-Volatile Memory SQL Server Tail Of Log Caching on NVDIMM", accessed August 24, 2017, <https://blogs.msdn.microsoft.com/bobsq/2016/11/08/how-it-works-it-just-runs-faster-non-volatile-memory-sql-server-tail-of-log-caching-on-nvdim/>
- 2 "Consolidate your data analytics servers with the Dell EMC PowerEdge R740xd", accessed October 18, 2017, <http://facts.pt/rszSR7>
- 3 "NVDIMM (Non-Volatile Dual In-line Memory Module)", accessed October 16, 2017, <http://searchsolidstatestorage.techtarget.com/definition/NVDIMM-Non-Volatile-Dual-In-line-Memory-Module>
- 4 "Accelerating Microsoft SQL Server Performance With NVDIMM-N on Dell EMC PowerEdge R740", accessed November 9, 2017, [http://en.community.dell.com/techcenter/enterprise-solutions/m/sql\\_db\\_gallery/20444570](http://en.community.dell.com/techcenter/enterprise-solutions/m/sql_db_gallery/20444570)

On September 12, 2017, we finalized the hardware and software configurations we tested. Updates for current and recently released hardware and software appear often, so unavoidably these configurations may not represent the latest versions available when this report appears. For older systems, we chose configurations representative of typical purchases of those systems. We concluded hands-on testing on October 6, 2017.

## Appendix A: Our results

HammerDB transactions per minute			
SQL instance database	Without NVDIMMs	With NVDIMMs	Percent increase
Database 1	313,910	426,659	36%
Database 2	318,542	441,066	38%
Database 3	314,737	433,022	38%
Database 4	315,799	448,407	42%
<b>Total</b>	<b>1,262,988</b>	<b>1,749,154</b>	<b>38%</b>



## Appendix B: System configuration information

Server configuration information	Dell EMC PowerEdge R740xd	Dell EMC PowerEdge R740xd + NVDIMMs
BIOS name and version	Dell 1.0.2	Dell 1.0.2
Non-default BIOS settings	N/A	N/A
Operating system name and version/build number	Microsoft Windows Server® 2016 Datacenter	Microsoft Windows Server 2016 Datacenter
Date of last OS updates/patches applied	9/12/2017	9/12/2017
Power management policy	Performance	Performance
<b>Processor</b>		
Number of processors	2	2
Vendor and model	Intel Xeon Gold 6152	Intel Xeon Gold 6152
Core count (per processor)	22	22
Core frequency (GHz)	2.10	2.10
Stepping	4	4
<b>Memory module(s) type A: RDIMMs</b>		
Total memory in system (GB)	320	320
Number of memory modules	20	20
Vendor and model	Hynix HMA82GR7AFR8N-VK	Hynix HMA82GR7AFR8N-VK
Size (GB)	16	16
Type	PC4-2666	PC4-2666
Speed (MHz)	2,666	2,666
Speed running in the server (MHz)	2,666	2,666
<b>Memory module(s) type B: NVDIMMs</b>		
Total memory in system (GB)	N/A	64
Number of memory modules	N/A	4
Vendor and model	N/A	Micron MTA18ASF2G72XF1Z-2G6
Size (GB)	N/A	16
Speed (MHz)	N/A	2,666
Speed running in the server (MHz)	N/A	2,666
<b>Storage controller</b>		
Vendor and model	Dell PERC H730P	Dell PERC H730P
Cache size (MB)	2048	2048
Firmware version	25.5.0.0018	25.5.0.0018
Driver version	6.603.7.0	6.603.7.0



Server configuration information	Dell EMC PowerEdge R740xd	Dell EMC PowerEdge R740xd + NVDIMMs
Local storage A: Boot drives		
Number of drives	2	2
Drive vendor and model	Seagate	Seagate
Drive size (GB)	300	300
Drive information (speed, interface, type)	12 Gb/s, SAS, HDD	12 Gb/s, SAS, HDD
Local storage B: Testing drives		
Number of drives	6	6
Drive vendor and model	Intel SSD DC S3520	Intel SSD DC S3520
Drive size (GB)	800	800
Drive information (speed, interface, type)	6 Gb/s, SAS, SSD	6 Gb/s, SAS, SSD
Network adapter		
Vendor and model	QLogic BRCM 10G/GbE 2+2P 57800-t	QLogic BRCM 10G/GbE 2+2P 57800-t
Number and type of ports	2 x 1Gb, 2 x 10Gb	2 x 1Gb, 2 x 10Gb
Driver version	8.7.26	8.7.26
Cooling fans		
Number of cooling fans	6	6
Power supplies		
Vendor and model	Dell PWR SPLY 1100W	Dell PWR SPLY 1100W
Number of power supplies	2	2
Wattage of each (W)	1100	1100



## Appendix C: How we tested

In our labs, we measured the database performance of a PowerEdge R740xd server with and without the tail of the log placed on NVDIMM-N storage class memory (SCM) using the HammerDB benchmark and running a TPC-C-like workload.

We began by creating a RAID1 volume with two 15K HDDs for our OS. We then securely erased the SATA SSDs in our testing environment with the PartedMagic software, and seasoned the drives individually with Iometer. After securely erasing and seasoning the drives, we put four Intel S3520 SSDs into a RAID10 for our Data and Log volume, and we created a separate RAID1 volume with two Intel S3520 SSDs for the TempDB and TempLog files. We used two SSDs we had in-house, and put them in a RAID0 to store the backup files.

Next, we installed four Microsoft SQL Server 2016 Enterprise instances on our SUT. We used HammerDB to create a 251GB TPC-C-like database on SQL Server, and then created a .bak file of the database.

Using that backup file and SQL Server's built-in restore options, we were able to create the database on each SQL server instance. We pointed HammerDB clients (hosted on the client system) to the database on each SQL server instance, and simultaneously ran the TPC-C-like test. We ran this test three times, and reported the results from the median run.

We captured various performance metrics on the SUT during the run, such as transactions per second and batch requests per second. We started all clients simultaneously, and gathered the results when the run finished.

After completing the procedure above, we installed four Micron NVDIMM-N modules into our system and created a DirectAccess (DAX) volume on each SCM module. Next, we created a secondary log file to hold the tail of the log for each database, and spread them evenly across the four DAX volumes. Finally, we followed the same steps as in our initial testing without SCM modules and separate tail of the log files, running the test three times and taking the results from the median run.

Follow these steps to recreate our test.

### Installing Windows Server 2016 Datacenter Edition

1. Insert the installation media into the CD/DVD drive, and restart the server.
2. When the option appears, press F11 to enter the Boot Manager.
3. Select UEFI Boot Menu.
4. Select the boot media, and press Enter.
5. When prompted to boot from DVD, press any key.
6. When the installation screen appears, leave language, time/currency format, and input method as default, and click Next.
7. Click Install now.
8. When the installation prompts you, enter the product key.
9. Select Windows Server 2016 Datacenter Edition (Server with a GUI), and click Next.
10. Check I accept the license terms, and click Next.
11. Click Custom: Install Windows only (advanced).
12. Select Drive 0 Unallocated Space, and click Next. This starts Windows automatically, and Windows will restart automatically after completing.
13. When the Settings page appears, fill in the Password and Reenter Password fields with the same password.
14. Log in with the password you set up previously.

### Securely Erasing and Seasoning the SATA SSDs and NVMe SSDs

1. Ensure that the disks are set to Non-RAID mode in the BIOS or through the RAID controller.
2. Create a bootable USB drive with the PartedMagic ISO.
3. Insert the bootable USB into the server.
4. Press F11 to select a boot device.
5. Select the bootable USB.
6. Select the time zone and click OK.
7. From the desktop, double-click the Secure Erase icon.
8. In the Internal tab, select SATA SSD Secure Erase.
9. Check each disk you wish to secure erase and click Next.
10. Click the checkbox to confirm you'd like to securely erase the SSDs and click OK.
11. When the process is over, confirm that each SSD completed successfully, and click OK.
12. Double-click the quit icon, and select Reboot.
13. After Windows reboots, open Iometer.
14. In the Disk Target tab, assign 1 worker to each raw disk.



15. Set the number of outstanding I/O to 256 and the Write IO data pattern to Psuedo random.
16. Click the Access Specification tab.
17. Create a new Access Specification with the following parameters:
  - a. Transfer Request Size – 128K
  - b. Percent of Access Specification – 100
  - c. Percent Read/Write Distribution – 100% Write
  - d. Percent Random/Sequential Distribution – 100% Sequential
18. Assign the newly created Access Specification to each worker.
19. Click the Test Setup tab.
20. Set the Ramp Up time to 60 seconds.
21. Set the Run Time to the appropriate amount of time it takes to fill up twice the capacity of the drives.
22. Click the green flag icon to begin the seasoning process.

## Formatting a Windows NTFS volume for SQL Server 2016

1. Right-click the Start Icon, and click Disk Management.
2. Right-click the disk, and click Online.
3. Right-click the disk again, and click Initialize.
4. Right-click an unallocated area, and select New Simple Volume.
5. Click Next.
6. Click Next.
7. Assign a letter path, and click Next.
8. Set the Allocation Unit Size to 64K, and name the Volume Label.
9. Click Next.
10. Click Finish.

## Installing Microsoft SQL Server 2016

1. Attach the SQL Server 2016 installation media ISO to the VM.
2. Click Run SETUP.EXE. If Autoplay does not begin the installation, navigate to the SQL Server 2016 DVD, and double-click it.
3. In the left pane, click Installation.
4. Click New SQL Server stand-alone installation or add features to an existing installation.
5. Click the checkbox to accept the license terms, and click Next.
6. Click Use Microsoft Update to check for updates, and click Next.
7. To install the setup support files, click Install.
8. If there no failures display, click Next.
9. At the Setup Role screen, choose SQL Server Feature Installation, and click Next.
10. At the Feature Selection screen, select Database Engine Services, Full-Text and Semantic Extractions for Search, Client Tools Connectivity, Client Tools Backwards Compatibility.
11. Click Next.
12. At the Instance configuration screen, leave the default selection of default instance, and click Next.
13. At the Database Engine Configuration screen, select the authentication method you prefer. We used Mixed Mode.
14. Enter a password for the system administrator account, and confirm it.
15. Click Add Current user. This may take several seconds.
16. Click the TempDB tab.
17. Change the number of TempDB files to 8, set the file size to 1024 MB, and change its location to the TempDB volume.
18. Set the file size to 1024 MB, and change the location of the TempLog file to the TempDB volume.
19. Click Next.
20. At the Error and usage reporting screen, click Next.
21. At the Installation Configuration Rules screen, check that there are no failures or relevant warnings, and click
22. At the Ready to Install screen, click Install.
23. Close the installation window.
24. Repeat steps 1–23 for each of the remaining SQL Server 2016 instances.
25. Download and Install SQL Server Management Studio.



## Enabling Lock Pages in memory

1. Click Start, and type `gpedit.msc`. Hit the return key.
2. In the Local Group Policy Editor, expand Computer Configuration→Windows Settings→Security Settings→Local Policies
3. Select User Rights Assignment, and scroll down to Lock pages in memory in the right pane.
4. Right-click Lock pages in memory, and click Properties.
5. Click Add User or Group, and add your SQL user accounts (NT SERVICE\MSSQLSERVER1; NT SERVICE\MSSQLSERVER2; NT SERVICE\MSSQLSERVER3; NT SERVICE\MSSQLSERVER4).
6. Click OK.

## Creating DAX volumes on SCM modules

1. In Disk Management, create a RAW volume on the SCM disk.
2. Open Powershell.
3. Format the Volume as DAX by typing the following command:  
`C:\> format <Volume> /dax /q`
4. Check to make sure the volume is correctly formatted with the following command:  
`C:\> fsutil fsinfo volumeinfo <Volume>`
5. Close Powershell.

## Adding the tail-of-log file

1. Open SQL Management Studio.
2. Highlight the correct instance.
3. Run the following query:  

```
ALTER DATABASE tpcc ADD LOG FILE (NAME = taillog, FILENAME = '<Path to file>', SIZE = 179200 KB, FILEGROWTH = 0)
```
4. Repeat steps 1–3 three for each remaining database.

## Configuring the HammerDB clients

1. Install Windows Server 2012 R2 Datacenter.
2. Install updates.
3. Download the most recent HammerDB release from <http://hammerora.sourceforge.net/download.html>.
4. Run the HammerDB installation file, select your language, and click OK.
5. When prompted, click Yes to install HammerDB.
6. At the Welcome window, click Next.
7. Accept the default install location, and click Next.
8. Accept the default setup type, and click Next to start the installation.
9. Click Finish to complete the installation.
10. Download Microsoft ODBC Driver 11 for SQL Server from <http://www.microsoft.com/en-us/download/details.aspx?id=36434>.
11. Run the installer you downloaded.
12. In the Welcome window, click Next.
13. Accept the terms of the license agreement, and click Next.
14. Accept the default installation options, and click Next.
15. Click Install to begin the installation.
16. When the installation completes, click Finish to close the installer.



## Running the test

1. Open HammerDB.
2. Select Options→Benchmark.
3. In the Benchmark Options window, select MSSQL Server, and click OK.
4. In the left pane, expand TPC-C→Driver Script, and double-click Options.
5. Use the following options for the TPC-C Driver Script:

SQL Server	[servername]MSSQLSERVERxx (or your first SQL server hostname)
SQL Server Port:	1433 (default)
SQL Server ODBC Driver	ODBC Driver 11 for SQL Server
Authentication	SQL Server Authentication
SQL Server User ID	sa (default)
SQL Server User Password	Your password
SQL Server Database	tpcc
TPC-C Driver Script	Timed Test Driver Script
Total Transactions per User	100,000,000
Exit on SQL Server Error	unchecked (default)
Keying and Thinking Time	unchecked (default)
Checkpoint when complete	unchecked (default)
Minutes of Ramp-up Time	15
Minutes for Test Duration	45

6. Click OK.
7. In the left pane, double-click Load to load the driver script.
8. In the left pane, expand Virtual User, and double-click Options.
9. Set the Virtual Users field to 11, and check all of the checkboxes.
10. Click OK.
11. Repeat steps 1–10 for each remaining client.
12. Click the green arrow button in each client to begin the test.

This project was commissioned by Dell EMC.



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