Dell EMC Unity 400F All-Flash storage

Handle transaction workloads and data mart loads with better performance

The Dell EMC Unity 400F All-Flash storage array offered solid performance compared to the HPE 3PAR 8400

When your company's work demands a new storage array, you have the opportunity to invest in a solution that can support demanding workloads simultaneously—such as online transaction processing (OLTP) and data mart loading.

At Principled Technologies, we compared Dell EMC™ PowerEdge™ R930 servers[1] with the Dell EMC Unity 400F All-Flash storage array to HPE ProLiant DL580 Gen9 servers with the HPE 3PAR 8400 array in three hands-on tests to determine how well each solution could serve a company during these database-intensive tasks.

When we ran an OLTP workload and data mart load in tandem, the Unity array performed better than the HPE 3PAR. In our data mart load test, the Unity array allowed us to import a large set of data in less time than with the 3PAR—an ability that could help companies gather data for analysis in less time. Finally, in our online transaction processing test, the Unity array offered comparable database performance to the 3PAR array, enabling database applications to process a similar volume of customer orders.

Keep work moving during large data writes

Up to 29% more orders per minute while also loading data

Save time on data imports

Load files into a data mart up to 22% faster

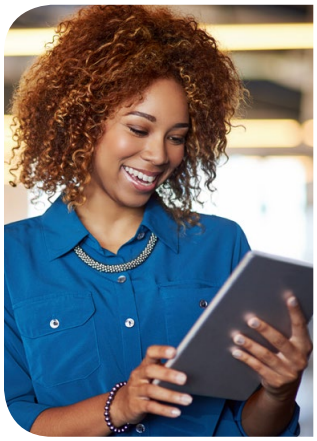
Keep your work going through intensive data mart loads

Writing files to a data mart database is a task usually left to the late hours of the night, or one that involves separate hardware. But what happens if your company needs to run both online transaction and data mart workloads from the same storage environment? With such heavy stress on a system, you might expect a large dip in performance here—large enough to force you to purchase completely separate systems in order to get your work done in a reasonable time. However, in our dual workload test, the Unity array was better able to handle the added stress.

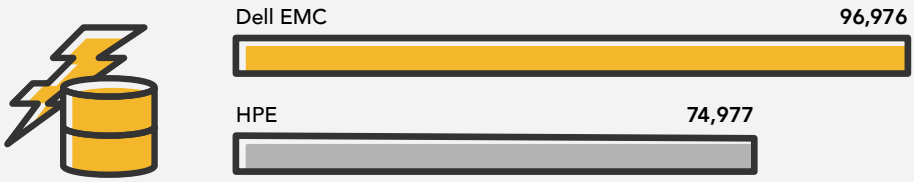
For this test, we measured how long it took for each array to put data from many large text files into a single database while simultaneously fulfilling customer orders as part of an OLTP workload. The Unity array enabled the PowerEdge R930 server to process an average of 96,976 orders per minute—29 percent more than the 74,977 orders per minute the ProLiant DL580 Gen9 processed with the 3PAR array.

What's a data mart?

Your enterprise business collects data from many different departments. Whether it's sales, marketing, or research and development, you will often want to bundle data from these disparate sources and load it into a single location for analysis and reporting. The data mart is a convenient place to store different departments' information for processing and analysis.

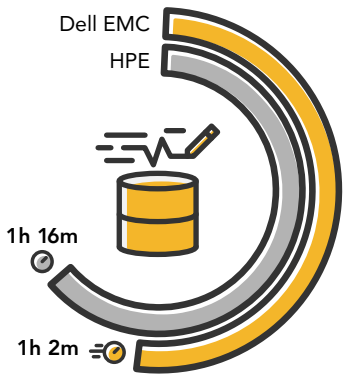


29% more orders per minute during the data load



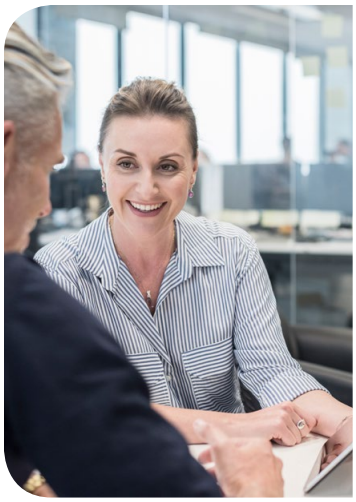
22% faster to import a large data set

Less time is better



Save time during large data mart writes

While it's good to know how much stress your system can handle, you may also choose to run your data mart and OLTP workloads separately. Loading data from various sources into a data mart is a critical step in gathering and organizing data for analysis, and this process often involves loading from flat files. The Dell EMC Unity loaded three terabytes' worth of data into a data mart in 1 hour, 2 minutes—22 percent faster than the 1 hour, 16 minutes it took for the HPE array. Saving time here can speed up the time it takes to start analyzing your data, so you can get business insights sooner.



The value of compression

Both the Unity and the 3PAR arrays employ a variety of techniques to save space so you can fit more data on your hardware. One of these techniques is compression. Compression algorithms reduce the number of bits needed to represent a set of data—the higher the compression ratio, the more space this particular data reduction technique saves.

During our OLTP test, the Unity array achieved a compression ratio of 3.2-to-1 on the database volumes, whereas the 3PAR array averaged a 1.3-to-1 ratio. In our data mart loading test, the 3PAR achieved a ratio of 1.4-to-1 on the database volumes, whereas the Unity array got 1.3 to 1.

Handle demanding online transaction processing (OLTP) work

Even without the added stress of a simultaneous data mart workload, OLTP work is one of the most stressful types for a storage array to handle—especially if it has to satisfy a large volume of users simultaneously. We used an OLTP workload benchmark called DVD Store 2 to test how well the Dell EMC and HPE storage arrays could handle many simulated users completing tasks such as browsing an online catalog and making final purchases.

The solutions handled a comparable number of database orders per minute (OPM); the Dell EMC Unity array enabled the PowerEdge R930 server to process 112,725 OPM, whereas the HPE ProLiant DL580 Gen9 fulfilled 111,761 OPM with the 3PAR array. Being able to process a large volume of customer requests in a timely manner can result in a better experience for the end user.

DVD Store 2

We used a benchmark called DVD Store 2 to test each storage array's capabilities while handling OLTP workloads. DVD Store simulates an online video marketplace, mimicking the way thousands of users might shop in a real-life scenario. The more user-initiated orders a server can fulfill, the better its performance.

To learn more about DVD Store, visit http://linux.dell.com/dvdstore.

Storage fabric using Brocade® Gen 6 hardware

In our tests, we used Connectrix® DS-6620B switches, built on Brocade Gen 6 hardware, known as the Dell EMC Connectrix B-Series Gen 6 Fibre Channel by Brocade. The Connectrix B Series provides out-of-the box tools for SAN monitoring, management, and diagnostics that simplify administration and troubleshooting for administrators.

Brocade Fibre offers Brocade Fabric Vision® Technology, which can provide further visibility into the storage network with monitoring and diagnostic tools. With Monitoring and Alerting Policy Suite (MAPS), admins can proactively monitor the health of all connected storage using policy-based monitoring.

Brocade offers another tool to simplify SAN management for Gen 6 hardware: Connectrix Manager Converged Network Edition (CMCNE). This tool uses an intuitive GUI to help admins automate repetitive tasks and further simplify SAN fabric management in the datacenter.

To learn more about what Brocade Gen 6 has to offer, visit www.brocade.com.

Conclusion

Database work is a big deal—in terms of its importance to your company, and the sheer magnitude of the work. Our tests with the Dell EMC PowerEdge R930 server and Unity 400F All-Flash storage array demonstrated that it could perform comparably to an HPE ProLiant DL580 Gen9 server and 3PAR array during OLTP workloads, with a better compression ratio (3.2-to-1 vs. 1.3-to-1). For loading large sets of data, the Dell EMC Unity finished 22 percent faster than the HPE 3PAR, which can result in less hassle for the administrator in charge of data marts. When running both OLTP and data mart workloads in tandem, the Unity array outperformed the HPE 3PAR in terms of orders processed per minute by 29 percent. For additional product information concerning the Unity 400F storage array, visit DellEMC.com/Unity.

1 http://www.dell.com/en-us/work/shop/productdetails/poweredge-r930

On April 18, 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 May 4, 2017.

Appendix A: System configuration information

Servers under test

Server configuration information	Dell EMC PowerEdge R930	HPE ProLiant DL580 Gen9
BIOS name and version	Dell EMC 2.2.0	U17 v2.30
Non-default BIOS settings	N/A	N/A
Operating system name and version/build number	VMware® ESXi™ 6.5.0 4564106	VMware ESXi 6.5.0 4564106
Date of last OS updates/patches applied	03/31/2017	03/31/2017
Power management policy	Maximum performance	Maximum performance
Processor		
Number of processors	4	4
Vendor and model	Intel® Xeon® E7-8860 v4	Intel Xeon E7-8860 v4
Core count (per processor)	18	18
Core frequency (GHz)	2.20	2.20
Stepping	B0	B0
Memory module(s)		
Total memory in system (GB)	512	512
Number of memory modules	32	32
Vendor and model	Samsung® M393A2G40DB0-CPB	Samsung M393A2G40DB0-CPB
Size (GB)	16	16
Type	PC4-17000	PC4-17000
Speed (MHz)	2,133	2,133
Speed running in the server (MHz)	2,133	2,133
Local storage		
Number of drives	2	2
Drive vendor and model	Seagate® ST300MM0006	Seagate ST300MM0006
Drive size (GB)	300	300
Drive information (speed, interface)	6Gbps, SAS	6Gbps, SAS

Server configuration information	Dell EMC PowerEdge R930	HPE ProLiant DL580 Gen9
Network adapter		
Vendor and model	Intel Ethernet 10GbE 2P X520 Adapter	HP Ethernet 10Gb 2-port 560SFP+
Number and type of ports	2 x 10GbE	2 x 10GbE
Driver version	17.5.10	0x8000088b
Fibre Channel HBA		
Vendor and model	Emulex LightPulse LPe31002-M6 2-Port	Emulex LightPulse LPe31002-M6 2-Port
Number and type of ports	2 x 16Gb Fibre Channel	2 x 16Gb Fibre Channel
Firmware version	11.1.212.0	11.1.212.0
Power supplies		
Vendor and model	Dell EMC 0V1YJ6A00	HPE 656364-B21
Number of power supplies	2	2
Wattage of each (W)	900	1,200

Storage solution

Storage configuration information	Dell EMC Unity 400F	HPE 3PAR 8400
Controller firmware revision	UnityOS 4.1.1.9121942	HPE 3PAR OS 3.3.1.215
Number of storage controllers	2	2
Number of storage shelves	2	4
Drive vendor and model number	24 x Dell EMC V4-2S6FXL-800	24 x HPE DOPM3840S5xnNMRI
Drive size (GB)	800	3,840
Drive information (speed, interface, type)	12Gbps, SAS, SSD	12Gbps, SAS, SSD

Appendix B: How we tested

Our Dell EMC testbed consisted of two Dell EMC PowerEdge R930 servers. Our HPE testbed consisted of two HPE ProLiant DL580 Gen9 servers. On both testbeds, one server hosted each of the OLTP VMs, while the other hosted the data mart VM. We also used a two-socket, 2U server to host our client and infrastructure VMs. Each server had two 10Gb connections to a Dell Networking X1052 for network traffic. Each server under test had two 16Gb Fibre connections to a redundant set of Dell EMC DS6620B Fibre Channel switches. Each array had two 16Gb connections to each fibre channel switch.

Configuring the Fibre Channel switches

We created Fibre Channel zones according to best practices for each all-flash array. We placed each server port in a zone with all storage ports. We used two Dell EMC DS6620B Fibre Channel switches for redundancy and multipathing.

Creating the Fibre Channel zones

1. Log into the Brocade switch GUI.
2. Click Configure→Zone Admin
3. Click the Zone tab.
4. Click New Zone, and enter a zone name.
5. Select all storage WWNs and a single server port WWN.
6. Click the right arrow to add the WWNs to the zone.
7. Repeat steps 4-6 for all remaining server ports.
8. Click the Zone Config tab.
9. Click New Zone Config, and enter a zone configuration name.
10. Select all newly created zones.
11. Click the right arrow to add the zones to the zone config.
12. Click Zoning Actions→Save Config to save the changes.
13. Click Zoning Actions→Enable Config.
14. Click Yes.

Configuring the storage

On each storage array, we created a variety of LUNs to be used in testing. Each OLTP VM had its own LUN for the OS, eight separate LUNs for SQL data (two for each SQL instance), and four separate LUNs for SQL log data (one for each SQL instance). The data mart VM had its own LUN for the OS, eight separate LUNs for SQL data, and a single LUN for SQL logs. The data mart VM also had three PCIe NVMe SSDs on the data mart host to hold the source data. We enabled compression on both arrays for all tests, so all SQL database and log LUNs were compressed on both arrays.

Configuring the Unity 400F array

We created a single RAID 5 storage pool using all available drives. We created one LUN per drive (see Table 1 for drive counts) sized to fit each drive. For each VM, we created a Consistency Group that contained all the LUNs necessary for each VM.

Creating the storage pool

1. Log into the Unity 400F array Unisphere GUI.
2. In the left-hand column, in the Storage category, click Pools.
3. To create a new storage pool, click the plus sign.
4. Enter a name and description, and click Next.
5. Choose Extreme Performance Tier, and check the box for Use FAST Cache.
6. Set the Extreme Performance Tier to RAID 5, and click Next.
7. Leave Create VMware Capability Profile for the Pool unchecked, and click Next.
8. Review your selection, and click Finish.

Creating the block LUNs

1. In the left-hand column, in the Storage category, click Block.
2. To create a new LUN, click the plus sign.
3. Select the number of LUNs to create, give them a name, choose the pool you created in the previous step, leave the Tiering Policy to Extreme Performance Tier.
4. Check the box for Compression for all OLTP LUNs, or leave unchecked for data mart LUNs. Click Next.

5. You will configure access at the Consistency Group level, so leave this blank, and click Next.
6. Leave Enable Automatic Snapshot Creation unchecked, and click Next.
7. Leave Enable Replication unchecked, and click Next.
8. Review your selection, and click Finish.
9. Repeat steps 1 through 8 as necessary to create all LUNs for the environment.

Adding ESXi hosts

1. Complete setup for Installing VMware vCenter 6.5 before proceeding the with storage setup.
2. In the left-hand column, in the Access category, click VMware.
3. To add the vCenter server managing the hosts, click the plus sign.
4. Enter the IP address, username, and password for the vCenter server appliance, and click Find.
5. Check the boxes next to the hosts in the Dell EMC testbed, and click Next.
6. Verify the correct hosts have been selected, and click Finish.

Creating the Consistency Groups

1. In the left-hand column, in the Storage category, click Block.
2. Click the Consistency Groups tab.
3. To create a new Consistency Group, click the plus sign.
4. Add a name, and click Next.
5. Click the plus sign, click Add Existing LUNs to add the LUNs related to the Consistency Group, and click OK. Click Next.
6. Click the plus sign, add the host(s) to connect to, and click Next.
7. Leave Enable Automatic Snapshot Creation unchecked, and click Next.
8. Leave Enable Replication unchecked, and click Next.
9. Review your selection, and click Finish.
10. Repeat steps 1 through 9 until you have a Consistency Group for all three VMs on the servers under test (SUTs).

Configuring the HPE 3PAR 8400 array

We created a single RAID 5 CPG using all available drives. We created one LUN per drive (see Table 1 for drive counts) sized to fit each drive. For each VM, we created a Virtual Volume Set that contained all the LUNs necessary to each VM.

Creating the storage pool

1. Log into the HPE 3PAR SSMC GUI.
2. At the top, click 3PAR StoreServ, and click Common Provisioning Groups under Block Persona.
3. In the left-hand column, under Common Provisioning Groups, click Create CPG.
4. Under the General heading, enter a name, and verify the correct system is selected in the System drop-down menu.
5. Under the Allocation Settings heading, ensure the Device type is set to SSD 100K.
6. Verify the RAID type is set to RAID 5.
7. Change Availability to Cage (Default)
8. Click Create.

Creating the Virtual Volumes

1. At the top, click 3PAR StoreServ, and click Virtual Volumes under Block Persona.
2. In the left-hand column, under Virtual Volumes, click Create virtual volume.
3. Under the General heading, enter a name for the VVol.
4. Verify the correct system is selected in the System drop-down menu.
5. Set the size of the VVol in the Size field, and click Create.
6. Repeat steps 1 through 5 as necessary to create all VVols for the environment.

Creating the Virtual Volume Sets

1. At the top, click 3PAR StoreServ, and click Virtual Volume Sets under Block Persona.
2. In the left-hand column, under Virtual Volume Sets, click Create virtual volume set.
3. Under the General heading, enter a name for the Virtual Volume Set.
4. Verify the correct system is selected in the System drop-down menu.
5. Click Add virtual volumes.
6. Select all the virtual volumes created for the first VM, and click Add.
7. Click Create.
8. Repeat steps 1 through 7 until you have a virtual volume set for all three VMs on the SUTs.

Adding the ESXi hosts

1. Complete setup for installing VMware vCenter 6.5 before proceeding with the storage setup.
2. At the top, click 3PAR StoreServ, and click Hosts under Block Persona.
3. In the left-hand column, under Hosts, click Create host.
4. Under the General heading, enter a name for the host in the Name field.
5. Verify the correct system is selected in the System drop-down menu.
6. Set the Host OS to VMware (ESXi)
7. Under the Paths heading, click Add FC.
8. In the Add FC window, select the WWNs associated with the first host, and click Add.
9. Click Create.
10. Repeat steps 1 through 9 to add the second host.

Creating the host sets

1. At the top, click 3PAR StoreServ, and click Host Sets under Block Persona.
2. In the left-hand column, under Host Sets, click Create host set.
3. Under the General heading, enter a name for the host set in the Name field.
4. Under the Host Set Members heading, click on Add hosts.
5. Select both hosts, and click Add.
6. Click Create.

Assigning Virtual Volume Sets to Host Sets

1. At the top, click 3PAR StoreServ, and click Virtual Volume Sets under Block Persona.
2. In the left-hand column, under Virtual Volume Sets, select the first VVol set.
3. On the right-hand side, click Actions, and click Export.
4. Under the Export To heading, click Add.
5. At the top of the window, select the Host set option.
6. Select the Host set, and click Add.
7. Leave the Export With section at default values, and click Export.

VM and storage summary

	OLTP workload VMs	Data mart workload VMs
vCPUs	32	64
Memory	64 GB	130 GB
OS drive	1x 40 GB	1x 60 GB
Database drives	8x 210 GB	8x 1 TB
Log drives	4x 110 GB	1x 550 GB
PCIe NVMe drives	N/A	3x 1.8 TB

Table 1: VM and storage summary

Installing VMware vSphere 6.5

We installed the VMware vSphere 6.5 hypervisor to a local RAID 1 disk pair. The RAID 1 virtual disk was created using the BIOS utilities on each server.

1. Boot the server to the installation media.
2. At the boot menu screen, choose the standard installer.
3. Press Enter.
4. Press F11 to accept the license terms.
5. Press Enter to install to the local virtual disk.
6. Press Enter to select the US Default keyboard layout.
7. Create a password for the `root` user, and press Enter.
8. Press F11 to begin the installation.

Installing VMware vCenter® 6.5

1. Mount the VCSA ISO to a Windows server that has connectivity to the target vCenter host.
2. Browse to `<mount location>\vcsa-ui-installer\win32` and run installer.exe.
3. Click Install.
4. Click Next.
5. Check I accept the terms of the license agreement, and click Next.
6. Leave vCenter Server with an Embedded Platform Services Controller checked, and click Next.
7. Enter the IP address and credentials for the target vCenter host, and click Next.
8. Enter a name and password for the VCSA appliance, and click Next.
9. Select Tiny for the deployment size, and click Next.
10. Select a datastore to store the appliance, and click Next.
11. Enter network settings for the appliance, and click Next.
12. Review the summary, and click Finish.
13. Once the deployment is complete, click Continue.
14. Click Next.
15. Select Synchronize time with NTP servers from the drop-down menu, and enter the IP address or hostnames of your NTP servers. Select Enabled from the SSH drop-down menu. Click Next.
16. Enter a username and password for the vCenter SSO, and click Next.
17. Uncheck Join the VMware's Customer Experience Improvement Program (CEIP), and click Next.
18. Review the summary, and click Finish.

Installing Microsoft® Windows Server® 2016 Datacenter Edition

1. Boot the VM to the installation media.
2. Press any key when prompted to boot from DVD.
3. When the installation screen appears, leave language, time/currency format, and input method as default, and click Next.
4. Click Install now.
5. When the installation prompts you, enter the product key.
6. Check I accept the license terms, and click Next.
7. Click Custom: Install Windows only (advanced).
8. Select Windows Server 2016 Datacenter Edition (Desktop Experience), and click Next.
9. Select Drive 0 Unallocated Space, and click Next, at which point Windows begins automatically, and restarts automatically after completing.
10. When the Settings page appears, fill in the Password and Reenter Password fields with the same password.
11. Log in with the password you set up previously.

Installing SQL Server® 2016

1. Prior to installing, add the .NET Framework 3.5 feature to the server.
2. Mount the installation DVD for SQL Server 2016.
3. Click Run SETUP.EXE. If Autoplay does not begin the installation, navigate to the SQL Server 2016 DVD, and double-click it.
4. In the left pane, click Installation.
5. Click New SQL Server stand-alone installation or add features to an existing installation.
6. Select the Enter the product key radio button, and enter the product key. Click Next.
7. Click the checkbox to accept the license terms, and click Next.
8. Click Use Microsoft Update to check for updates, and click Next.
9. Click Install to install the setup support files.
10. If there are no failures displayed, click Next.
11. At the Setup Role screen, choose SQL Server Feature Installation, and click Next.
12. At the Feature Selection screen, select Database Engine Services, Full-Text and Semantic Extractions for Search, Client Tools Connectivity, Client Tools Backwards Compatibility. Click Next.
13. At the Installation Rules screen, after the check completes, click Next.
14. At the Instance configuration screen, leave the default selection of default instance, and click Next.
15. At the Server Configuration screen, choose NT Service\SQLSERVERAGENT for SQL Server Agent, and choose NT Service\MSSQLSERVER for SQL Server Database Engine. Change the Startup Type to Automatic. Click Next.
16. At the Database Engine Configuration screen, select the authentication method you prefer. For our testing purposes, we selected Mixed Mode.
17. Enter and confirm a password for the system administrator account.
18. Click Add Current user. This may take several seconds.

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 Next.
22. At the Ready to Install screen, click Install.
23. After installation completes, click Close.
24. Close the installation window.
25. Shut down the VM, and create a clone to be used for the data mart workload.
26. Power on the VM.
27. Repeat steps 2-26 for instances 2, 3, and 4, replacing the default instance name at the Instance configuration screen with MSSQLSERVER2, MSSQLSERVER3, and MSSQLSERVER4 at step 14.
28. Shut down the VM, and create another clone to be used for the second OLTP workload.

Configuring the DVD Store 2 benchmark

Data generation overview

We generated our data using the Install.pl script included with DVD Store version 2.1 (DS2), providing the parameters for our 250GB database size and the Microsoft SQL Server 2016 platform. We ran the Install.pl script on a utility system running Linux®. The Install.pl script also generated the database schema.

After processing the data generation, we transferred the data files and schema creation files to a Windows-based system running SQL Server 2016. We built the 250GB database in SQL Server 2016, and then performed a full backup, storing the backup file on the C: drive for quick access. We used that backup file to restore the server between test runs.

The only modifications we made to the schema creation scripts were the specified file sizes for our database. We explicitly set the file sizes higher than necessary to ensure that no file-growth activity would affect the outputs of the test. Besides this file size modification, the database schema was created and loaded according to the DVD Store documentation. Specifically, we followed the steps below:

1. We generated the data and created the database and file structure using database creation scripts in the DS2 download. We made size modifications specific to our 250GB database and the appropriate changes to drive letters.
2. We transferred the files from our Linux data generation system to a Windows system running SQL Server.
3. We created database tables, stored procedures, and objects using the provided DVD Store scripts.
4. We set the database recovery model to bulk-logged to prevent excess logging.
5. We loaded the data we generated into the database. For data loading, we used the import wizard in SQL Server Management Studio. Where necessary, we retained options from the original scripts, such as Enable Identity Insert.
6. We created indices, full-text catalogs, primary keys, and foreign keys using the database-creation scripts.
7. We updated statistics on each table according to database-creation scripts, which sample 18 percent of the table data.
8. On the SQL Server instance, we created a ds2user SQL Server login using the following Transact-SQL (T-SQL) script:

```
USE [master]
GO
    CREATE LOGIN [ds2user] WITH PASSWORD=N'',
    DEFAULT_DATABASE=[master],
    DEFAULT_LANGUAGE=[us_english],
    CHECK_EXPIRATION=OFF,
    CHECK_POLICY=OFF
GO
```

9. We set the database recovery model back to full.
10. We created the necessary full text index using SQL Server Management Studio.
11. We created a database user and mapped this user to the SQL Server login.
12. We then performed a full backup of the database. This backup allowed us to restore the databases to a pristine state relatively quickly between tests.

Logical name	Filegroup	Initial size (MB)
Database files		
primary	PRIMARY	8
cust1	DS_CUST_FG	50,776
cust2	DS_CUST_FG	50,776

Logical name	Filegroup	Initial size (MB)
cust3	DS_CUST_FG	50,776
cust4	DS_CUST_FG	50,776
ind1	DS_IND_FG	20,118
ind2	DS_IND_FG	20,118
ind3	DS_IND_FG	20,118
ind4	DS_IND_FG	20,118
ds_misc	DS_MISC_FG	392
orders1	DS_ORDERS	25,004
orders2	DS_ORDERS	25,004
orders3	DS_ORDERS	25,004
orders4	DS_ORDERS	25,004
Log files		
ds_log	Not applicable	90,152

Table 2: DS2 initial file size modifications

Configuring the database workload client

For our testing, we used a virtual client for the Microsoft SQL Server client. To create this client, we installed Windows Server 2012 R2, assigned a static IP address, and installed .NET 3.5.

Running the DVD Store tests

We created a series of batch files, SQL scripts, and shell scripts to automate the complete test cycle. DVD Store outputs an orders-per-minute metric, which is a running average calculated through the test. In this report, we report the last OPM reported by each client/target pair.

Each complete test cycle consisted of general steps:

1. Clean up prior outputs from the target system and the client driver system.
2. Drop the databases from the target.
3. Restore the databases on the target.
4. Shut down the target.
5. Reboot the host and client system.
6. Wait for a ping response from the server under test and the client system.
7. Let the test server idle for 10 minutes.
8. Start the DVD Store driver on the client.

We used the following DVD Store parameters for testing:

```
ds2sqlserverdriver.exe --target=<target_IP> --ramp_rate=10 --run_time=180 --n_threads=32 --db_size=250GB
--think_time=0.1 --detailed_view=Y --warmup_time=15 --report_rate=1 --csv_output=<drive path>
```

Configuring the bulk load data mart

We used HammerDB to generate TPCH-compliant source data at scale factor 3000, for a total of 3.31TB of raw data. The generated data exists in the form of pipe-delimited text files, which we placed on NVMe PCIe SSDs for fast reads. We split the six largest tables into 32 separate files for parallel loading. Each chunk had its own table in SQL Server, for a total of 6x32 one-to-one streams. We used batch scripting and SQLCMD to start 32 simultaneous SQL scripts. Each script contained BULK INSERT statements to load the corresponding chunk for each table. For example, the 17th SQL script loaded ORDERS_17.txt into table ORDERS_17, and upon finishing, began loading LINEITEM_17.txt into table LINEITEM_17, and so on through each table.

Generating the data

1. Download HammerDB v2.21, and run hammerdb.bat.
2. Click Options→Benchmark.
3. Select the radio buttons for MSSQL Server and TPC-H, and click OK.
4. In the left pane, expand SQL Server→TPC-H→Datagen, and double-click Options.

5. Select the radio button for 3000, enter a target location for the TPC-H data, and select 32 for the number of virtual users. Click OK.
6. Double-click Generate, and click Yes.

Creating the target database

We used the following SQL script to create the target database (some lines have been removed and replaced with an ellipsis for clarity):

```
IF EXISTS (SELECT name FROM master.dbo.sysdatabases WHERE name = 'tpch3000')
    DROP DATABASE tpch3000
GO
CREATE DATABASE tpch3000
ON PRIMARY
(   NAME        = tpch3000_root,
    FILENAME    = 'F:\tpch\tpch_root.mdf',
    SIZE        = 100MB,
    FILEGROWTH  = 100MB),
FILEGROUP   DATA_FG_MISC
(   NAME  = tpch3000_data_ms,
    FILENAME    = 'F:\tpch\tpch_data_ms.mdf',
    SIZE        = 500MB,
    FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_01 (NAME = tpch3000_data_01, FILENAME = 'F:\tpch\tpch_data_01.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_02 (NAME = tpch3000_data_02, FILENAME = 'G:\tpch\tpch_data_02.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_03 (NAME = tpch3000_data_03, FILENAME = 'H:\tpch\tpch_data_03.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_04 (NAME = tpch3000_data_04, FILENAME = 'I:\tpch\tpch_data_04.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_05 (NAME = tpch3000_data_05, FILENAME = 'J:\tpch\tpch_data_05.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_06 (NAME = tpch3000_data_06, FILENAME = 'K:\tpch\tpch_data_06.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_07 (NAME = tpch3000_data_07, FILENAME = 'L:\tpch\tpch_data_07.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_08 (NAME = tpch3000_data_08, FILENAME = 'M:\tpch\tpch_data_08.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_09 (NAME = tpch3000_data_09, FILENAME = 'F:\tpch\tpch_data_09.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_10 (NAME = tpch3000_data_10, FILENAME = 'G:\tpch\tpch_data_10.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_11 (NAME = tpch3000_data_11, FILENAME = 'H:\tpch\tpch_data_11.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_12 (NAME = tpch3000_data_12, FILENAME = 'I:\tpch\tpch_data_12.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_13 (NAME = tpch3000_data_13, FILENAME = 'J:\tpch\tpch_data_13.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_14 (NAME = tpch3000_data_14, FILENAME = 'K:\tpch\tpch_data_14.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_15 (NAME = tpch3000_data_15, FILENAME = 'L:\tpch\tpch_data_15.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_16 (NAME = tpch3000_data_16, FILENAME = 'M:\tpch\tpch_data_16.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_17 (NAME = tpch3000_data_17, FILENAME = 'F:\tpch\tpch_data_17.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_18 (NAME = tpch3000_data_18, FILENAME = 'G:\tpch\tpch_data_18.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_19 (NAME = tpch3000_data_19, FILENAME = 'H:\tpch\tpch_data_19.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_20 (NAME = tpch3000_data_20, FILENAME = 'I:\tpch\tpch_data_20.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_21 (NAME = tpch3000_data_21, FILENAME = 'J:\tpch\tpch_data_21.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_22 (NAME = tpch3000_data_22, FILENAME = 'K:\tpch\tpch_data_22.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_23 (NAME = tpch3000_data_23, FILENAME = 'L:\tpch\tpch_data_23.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_24 (NAME = tpch3000_data_24, FILENAME = 'M:\tpch\tpch_data_24.mdf', SIZE = 112640MB,
```

```
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_25 (NAME = tpch3000_data_25, FILENAME = 'F:\tpch\tpch_data_25.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_26 (NAME = tpch3000_data_26, FILENAME = 'G:\tpch\tpch_data_26.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_27 (NAME = tpch3000_data_27, FILENAME = 'H:\tpch\tpch_data_27.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_28 (NAME = tpch3000_data_28, FILENAME = 'I:\tpch\tpch_data_28.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_29 (NAME = tpch3000_data_29, FILENAME = 'J:\tpch\tpch_data_29.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_30 (NAME = tpch3000_data_30, FILENAME = 'K:\tpch\tpch_data_30.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_31 (NAME = tpch3000_data_31, FILENAME = 'L:\tpch\tpch_data_31.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB),
FILEGROUP DATA_FG_32 (NAME = tpch3000_data_32, FILENAME = 'M:\tpch\tpch_data_32.mdf', SIZE = 112640MB,
FILEGROWTH  = 100MB)
LOG ON
(   NAME        = tpch3000_log,
    FILENAME    = 'N:\LOG\tpch3000\tpch3000_log.ldf',
    SIZE        = 360000MB,
    FILEGROWTH  = 100MB)
GO
/*set db options*/
ALTER DATABASE tpch3000 SET RECOVERY SIMPLE
ALTER DATABASE tpch3000 SET AUTO_CREATE_STATISTICS OFF
ALTER DATABASE tpch3000 SET AUTO_UPDATE_STATISTICS OFF
ALTER DATABASE tpch3000 SET PAGE_VERIFY NONE
USE tpch3000
GO
create table CUSTOMER_1 ([c_custkey] [bigint] NOT NULL,[c_mktsegment] [char](10) NULL,[c_nationkey] [int]
NULL,[c_name] [varchar](25) NULL,[c_address] [varchar](40) NULL,[c_phone] [char](15) NULL,[c_acctbal]
[money] NULL,[c_comment] [varchar](118) NULL) on DATA_FG_01
create table CUSTOMER_2 ([c_custkey] [bigint] NOT NULL,[c_mktsegment] [char](10) NULL,[c_nationkey] [int]
NULL,[c_name] [varchar](25) NULL,[c_address] [varchar](40) NULL,[c_phone] [char](15) NULL,[c_acctbal]
[money] NULL,[c_comment] [varchar](118) NULL) on DATA_FG_02
…
create table CUSTOMER_32 ([c_custkey] [bigint] NOT NULL,[c_mktsegment] [char](10) NULL,[c_nationkey]
[int] NULL,[c_name] [varchar](25) NULL,[c_address] [varchar](40) NULL,[c_phone] [char](15) NULL,[c_
acctbal] [money] NULL,[c_comment] [varchar](118) NULL) on DATA_FG_32

create table LINEITEM_1 ([l_shipdate] [date] NULL,[l_orderkey] [bigint] NOT NULL,[l_discount] [money] NOT
NULL,[l_extendedprice] [money] NOT NULL,[l_suppkey] [int] NOT NULL,[l_quantity] [bigint] NOT NULL,[l_
returnflag] [char](1) NULL,[l_partkey] [bigint] NOT NULL,[l_linestatus] [char](1) NULL,[l_tax] [money] NOT
NULL,[l_commitdate] [date] NULL,[l_receiptdate] [date] NULL,[l_shipmode] [char](10) NULL,[l_linenumber]
[bigint] NOT NULL,[l_shipinstruct] [char](25) NULL,[l_comment] [varchar](44) NULL) on DATA_FG_01
create table LINEITEM_2 ([l_shipdate] [date] NULL,[l_orderkey] [bigint] NOT NULL,[l_discount] [money] NOT
NULL,[l_extendedprice] [money] NOT NULL,[l_suppkey] [int] NOT NULL,[l_quantity] [bigint] NOT NULL,[l_
returnflag] [char](1) NULL,[l_partkey] [bigint] NOT NULL,[l_linestatus] [char](1) NULL,[l_tax] [money] NOT
NULL,[l_commitdate] [date] NULL,[l_receiptdate] [date] NULL,[l_shipmode] [char](10) NULL,[l_linenumber]
[bigint] NOT NULL,[l_shipinstruct] [char](25) NULL,[l_comment] [varchar](44) NULL) on DATA_FG_02
…
create table LINEITEM_32 ([l_shipdate] [date] NULL,[l_orderkey] [bigint] NOT NULL,[l_discount] [money]
NOT NULL,[l_extendedprice] [money] NOT NULL,[l_suppkey] [int] NOT NULL,[l_quantity] [bigint] NOT NULL,[l_
returnflag] [char](1) NULL,[l_partkey] [bigint] NOT NULL,[l_linestatus] [char](1) NULL,[l_tax] [money] NOT
NULL,[l_commitdate] [date] NULL,[l_receiptdate] [date] NULL,[l_shipmode] [char](10) NULL,[l_linenumber]
[bigint] NOT NULL,[l_shipinstruct] [char](25) NULL,[l_comment] [varchar](44) NULL) on DATA_FG_32

create table ORDERS_1 ([o_orderdate] [date] NULL,[o_orderkey] [bigint] NOT NULL,[o_custkey] [bigint]
NOT NULL,[o_orderpriority] [char](15) NULL,[o_shippriority] [int] NULL,[o_clerk] [char](15) NULL,[o_
orderstatus] [char](1) NULL,[o_totalprice] [money] NULL,[o_comment] [varchar](79) NULL) on DATA_FG_01
create table ORDERS_2 ([o_orderdate] [date] NULL,[o_orderkey] [bigint] NOT NULL,[o_custkey] [bigint]
NOT NULL,[o_orderpriority] [char](15) NULL,[o_shippriority] [int] NULL,[o_clerk] [char](15) NULL,[o_
orderstatus] [char](1) NULL,[o_totalprice] [money] NULL,[o_comment] [varchar](79) NULL) on DATA_FG_02
…
create table ORDERS_32 ([o_orderdate] [date] NULL,[o_orderkey] [bigint] NOT NULL,[o_custkey] [bigint]
NOT NULL,[o_orderpriority] [char](15) NULL,[o_shippriority] [int] NULL,[o_clerk] [char](15) NULL,[o_
```

```
orderstatus] [char](1) NULL,[o_totalprice] [money] NULL,[o_comment] [varchar](79) NULL) on DATA_FG_32

create table PART_1 ([p_partkey] [bigint] NOT NULL,[p_type] [varchar](25) NULL,[p_size] [int] NULL,[p_
brand] [char](10) NULL,[p_name] [varchar](55) NULL,[p_container] [char](10) NULL,[p_mfgr] [char](25)
NULL,[p_retailprice] [money] NULL,[p_comment] [varchar](23) NULL) on DATA_FG_01
create table PART_2 ([p_partkey] [bigint] NOT NULL,[p_type] [varchar](25) NULL,[p_size] [int] NULL,[p_
brand] [char](10) NULL,[p_name] [varchar](55) NULL,[p_container] [char](10) NULL,[p_mfgr] [char](25)
NULL,[p_retailprice] [money] NULL,[p_comment] [varchar](23) NULL) on DATA_FG_02
…
create table PART_32 ([p_partkey] [bigint] NOT NULL,[p_type] [varchar](25) NULL,[p_size] [int] NULL,[p_
brand] [char](10) NULL,[p_name] [varchar](55) NULL,[p_container] [char](10) NULL,[p_mfgr] [char](25)
NULL,[p_retailprice] [money] NULL,[p_comment] [varchar](23) NULL) on DATA_FG_32

create table PARTSUPP_1 ([ps_partkey] [bigint] NOT NULL,[ps_suppkey] [int] NOT NULL,[ps_supplycost]
[money] NOT NULL,[ps_availqty] [int] NULL,[ps_comment] [varchar](199) NULL) on DATA_FG_01
create table PARTSUPP_2 ([ps_partkey] [bigint] NOT NULL,[ps_suppkey] [int] NOT NULL,[ps_supplycost]
[money] NOT NULL,[ps_availqty] [int] NULL,[ps_comment] [varchar](199) NULL) on DATA_FG_02
…
create table PARTSUPP_32 ([ps_partkey] [bigint] NOT NULL,[ps_suppkey] [int] NOT NULL,[ps_supplycost]
[money] NOT NULL,[ps_availqty] [int] NULL,[ps_comment] [varchar](199) NULL) on DATA_FG_32

create table SUPPLIER_1 ([s_suppkey] [int] NOT NULL,[s_nationkey] [int] NULL,[s_comment] [varchar]
(102) NULL,[s_name] [char](25) NULL,[s_address] [varchar](40) NULL,[s_phone] [char](15) NULL,[s_acctbal]
[money] NULL) on DATA_FG_01
create table SUPPLIER_2 ([s_suppkey] [int] NOT NULL,[s_nationkey] [int] NULL,[s_comment] [varchar]
(102) NULL,[s_name] [char](25) NULL,[s_address] [varchar](40) NULL,[s_phone] [char](15) NULL,[s_acctbal]
[money] NULL) on DATA_FG_02
…
create table SUPPLIER_32 ([s_suppkey] [int] NOT NULL,[s_nationkey] [int] NULL,[s_comment] [varchar]
(102) NULL,[s_name] [char](25) NULL,[s_address] [varchar](40) NULL,[s_phone] [char](15) NULL,[s_acctbal]
[money] NULL) on DATA_FG_32
```

Inserting the data into Microsoft SQL Server

We used 32 individual SQL scripts to create a BULK INSERT process on each filegroup. The first script is shown here as an example:

```
bulk insert tpch3000..CUSTOMER_1 from 'O:\CUSTOMER_1.tbl' with
(TABLOCK,DATAFILETYPE='char',CODEPAGE='raw',FieldTerminator='|',BATCHSIZE=14062500)
bulk insert tpch3000..LINEITEM_1 from 'O:\LINEITEM_1.tbl' with
(TABLOCK,DATAFILETYPE='char',CODEPAGE='raw',FieldTerminator='|',BATCHSIZE=562500000)
bulk insert tpch3000..ORDERS_1 from 'O:\ORDERS_1.tbl' with
(TABLOCK,DATAFILETYPE='char',CODEPAGE='raw',FieldTerminator='|',BATCHSIZE=140625000)
bulk insert tpch3000..PART_1 from 'O:\PART_1.tbl' with
(TABLOCK,DATAFILETYPE='char',CODEPAGE='raw',FieldTerminator='|',BATCHSIZE=18750000)
bulk insert tpch3000..PARTSUPP_1 from 'O:\PARTSUPP_1.tbl' with
(TABLOCK,DATAFILETYPE='char',CODEPAGE='raw',FieldTerminator='|',BATCHSIZE=75000000)
bulk insert tpch3000..SUPPLIER_1 from 'O:\SUPPLIER_1.tbl' with
(TABLOCK,DATAFILETYPE='char',CODEPAGE='raw',FieldTerminator='|',BATCHSIZE=937500)
```

Starting the SQL BULK INSERT scripts

We used Windows CMD and SQLCMD to start the 32 BULK INSERT scripts with CPU affinity:

```
start /node 0 /affinity 1 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_1.sql
start /node 0 /affinity 2 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_2.sql
start /node 0 /affinity 4 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_3.sql
start /node 0 /affinity 8 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_4.sql
start /node 0 /affinity 10 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_5.sql
start /node 0 /affinity 20 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_6.sql
start /node 0 /affinity 40 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_7.sql
start /node 0 /affinity 80 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_8.sql
start /node 0 /affinity 100 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_9.sql
start /node 0 /affinity 200 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_10.sql
start /node 0 /affinity 400 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_11.sql
start /node 0 /affinity 800 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_12.sql
start /node 0 /affinity 1000 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_13.sql
start /node 0 /affinity 2000 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_14.sql
start /node 0 /affinity 4000 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_15.sql
start /node 0 /affinity 8000 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_16.sql
start /node 1 /affinity 1 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_17.sql
start /node 1 /affinity 2 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_18.sql
start /node 1 /affinity 4 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_19.sql
start /node 1 /affinity 8 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_20.sql
start /node 1 /affinity 10 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_21.sql start /node 1 /affinity 20 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\
Users\Administrator\Documents\gen_22.sql
start /node 1 /affinity 40 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_23.sql
start /node 1 /affinity 80 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
```

```
Documents\gen_24.sql
start /node 1 /affinity 100 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_25.sql
start /node 1 /affinity 200 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_26.sql
start /node 1 /affinity 400 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_27.sql
start /node 1 /affinity 800 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_28.sql
start /node 1 /affinity 1000 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_29.sql
start /node 1 /affinity 2000 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_30.sql
start /node 1 /affinity 4000 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_31.sql
start /node 1 /affinity 8000 sqlcmd -S localhost -d tpch3000 -U sa -P ****** -i C:\Users\Administrator\
Documents\gen_32.sql
```

This project was commissioned by Dell EMC.

Facts matter.®