TPC Benchmark™ H
Full Disclosure Report
for
Lenovo® System x®3850 X6
using
Microsoft® SQL Server® 2016
Enterprise Edition
and
Microsoft Windows Server® 2016
Standard Edition

TPC-H™ Version 2.17.1

Second Edition

Submitted for Review

July 26, 2016

Second Edition – July 2016

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Notes

[1] GHz and MHz only measures microprocessor internal clock speed, not application performance. Many factors affect application performance.

[2] When referring to hard disk capacity, GB, or gigabyte, means one thousand million bytes. Total user-accessible capacity may be less.

Abstract

Lenovo Corporation conducted the TPC Benchmark H (TPC-H) on the Lenovo System x3850 X6. This report documents the full disclosure information required by the TPC Benchmark H Standard Specification, Revision 2.17.1, including the methodology used to achieve the reported results. All testing fully complied with this revision level.

The software used on the Lenovo System x3850 X6 system included Microsoft Windows Server 2016 Standard Edition and Microsoft SQL Server 2016 Enterprise Edition.

Standard metrics, Composite Query-per-Hour (QphH™@size), price per QphH ($/QphH@size) and Availability Date, are reported as required by the TPC Benchmark H Standard Specification.

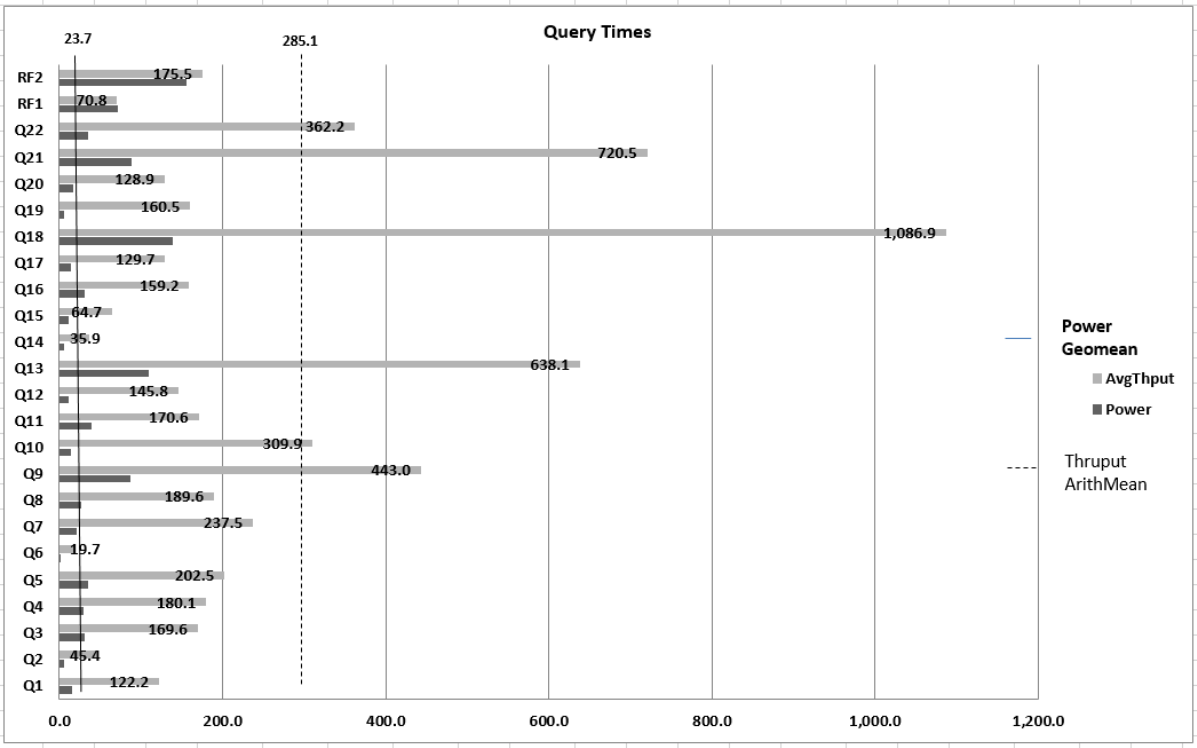
The benchmark results are summarized in the following table:

Hardware	Software	Total System Cost	QphH @10,000	$ USD / QphH @10,000	Total Solution Availability Date
Lenovo System x3850 X6	Microsoft SQL Server 2016 Enterprise Edition Microsoft Windows Server 2016 Standard Edition	$983,870.88 USD	1,106,832.6 QphH @10,000GB	$0.89 USD per QphH @10,000GB	September 30, 2016

The benchmark implementation and results were audited by Francois Raab for InfoSizing (www.sizing.com). The auditor's attestation letter is contained in this report.

Lenovo	**Lenovo® System x®3850 X6** **Microsoft® SQL Server® 2016**	TPC-H™ 2.17.1 TPC Pricing 2.0.0 Report Date: 7/26/16 Revision Date: 7/26/16
Total System Cost	TPC-H Composite Query per Hour Metric	Price/Performance
$983,870.88 USD	**1,106,832.6** QphH™@10,000GB	**$0.89** $ / QphH@10,000GB

Database Size	DBMS Manager	Operating System	Other Software	System Availability Date
10,000GB	**Microsoft SQL Server 2016 Enterprise Edition**	**Microsoft Windows Server® 2016 Standard Edition**	**N/A**	**September 30, 2016**



Database Load Time	Total Disk/Database Size	Memory/Database Size Percentage	Load Includes Backup
00d 06h 48m 42s	**5.12**	**61.4%**	**Y**

Storage Redundancy Level	Base Tables	Auxiliary Structures	DBMS Temp Space	OS and DBMS
Zero	**No RAID**	**No RAID**	**No RAID**	**RAID-1**

System Configuration		
Processors/Cores/Threads	**4/96/192**	**Intel® Xeon® Processor E7-8890 v4, 2.20GHz, 60MB L3 Cache**
Memory	**96**	**64GB PC4-19200 ECC DDR4 2400MHz LP LRDIMM**
Total Memory		**6TB**
Storage Controllers	**1**	**Lenovo ServeRAID™ M5210 SAS/SATA Controller**
Storage Devices	**2**	**300GB SAS 2.5" 10K RPM HDD**
	4	**800GB SATA 2.5" MLC G3HS Enterprise Value SSD**
	8	**6.4TB Enterprise io3 Flash PCIe Adapter**
Total Storage		**55TB**

Database Size includes only raw data (e.g., no temp, index, redundant storage space, etc.).

Lenovo System x3850 X6
Microsoft SQL Server 2016

TPC-H 2.17.1
TPC Pricing 2.0.0
Report Date: 7/26/16
Revision Date: 7/26/16

Description	Part Number	Price Source	Unit Price	Quantity	Extended Price	3-Yr. Maint. Price
Server Hardware						
Lenovo System x3850 X6 Configure-To-Order, includes:	6241AC1	1	249,891	1	249,891	
X6 Half-length I/O Book	A4A2			2		
4x 2.5" HDD Riser	A4A6			2		
Line cord - 2.8m, 10A/250V, C13 to NEMA 6-15P (US)	6372			4		
ServeRAID M5210 SAS/SATA Controller	A3YZ			1		
Intel I350-T4 ML2 Quad Port GbE Adapter	A40R			1		
X6 Storage Book	A4A1			1		
x3850/x3950 X6 I/O Planar IV	ATYH			1		
Rail Kit	A4AA			1		
Midplane for 4U Chassis	A4A4			1		
64GB TruDDR4 Memory (4Rx4, 1.2V) PC4-19200 PC4 2400MHz LP LRDIMM	ATGG			96		
800GB SATA 2.5" MLC G3HS Enterprise Value SSD	A57A			4		
300GB 10K 12Gbps SAS 2.5" G3HS HDD	AT89			2		
X6 Compute Book Intel Xeon Processor E7-8890 v4 24C 2.2GHz 60M 165W	ATX9			1		
Addl X6 Compute Book Intel Xeon Processor E7-8890 v4 24C 2.2GHz 165W	ATXZ			3		
x3850 X6 4U Chassis	ASMH			1		
1400W HE Redundant Power Supply	A54E			4		
Lightpath LCD Op Panel	A4VH			1		
3YR Tech Install Parts 24x7x4 x3850 x6	01HV226	1	1,949	1		1,949
				Subtotal	249,891	1,949
ServerStorage						
io3 6.4TB Enterprise Mainstream Flash Adapter	00YA809	1	39,779	8	318,232	
				Subtotal	318,232	
Server Software						
SQL Server 2016 Enterprise Edition (2 Core License)		2	13,472.50	48	646,680	
Windows Server 2016 Standard Edition (2 Core Pack)		2	92	48	4,416	
Microsoft Problem Resolution Services (1 Incident)		2	259	1		259
				Subtotal	651,096	259
Infrastructure						
S2 42U Standard Rack	93074RX	1	1,565	1	1,565	
Preferred Pro Keyboard USB - US English 103P RoHS v2	00AM600	1	29	1	29	
2-Button Optical Mouse - Black - USB	40K9200	1	19	1	19	
ThinkVision E2054 19.5-inch LED Backlit LCD Monitor	60DFAAR1US	1	94	1	94	
ServicePac for 3-Year 24x7x4 Support (Rack)	41L2760	1	315	1		315
				Subtotal	1,707	315
				Total	1,220,926	2,523
Dollar Volume Discount (See Note 1)	41.88%	1			239,578	

Pricing: 1 - Lenovo 1-877-782-7134; 2 - Microsoft
Note 1: Discount applies to all line items where Source=1; pricing is for these or similar quantities. Discounts for similarly sized configurations will be similar to what is quoted here, but may vary based on the specific components priced.

Three-Year Cost of Ownership USD:	$983,870.88
QphH@10000GB:	1,106,832.6
$ USD/QphH@10000GB:	$0.89

Benchmark results and test methodology audited by Francois Raab for InfoSizing, Inc. (www.sizing.com)

Prices used in TPC benchmarks reflect the actual prices a customer would pay for a one-time purchase of the stated components. Individually negotiated discounts are not permitted. Special prices based on assumptions about past or future purchases are not permitted. All discounts reflect standard pricing policies for the listed components. For complete details, see the pricing section of the TPC benchmark specifications. If you find that stated prices are not available according to these terms, please inform the TPC at pricing@tpc.org. Thank you.

Measurement Results:

Database Scale Factor	**10,000**
Total Data Storage/Database Size	**5.12**
Memory/Database Size	**61.4%**
Start of Database Load	**06/26/2016 12:17:31**
End of Database Load	**06/26/2016 19:06:13**
Database Load Time	**00d 06h 48m 42s**
Query Streams for Throughput Test	**9**
TPC-H Power (QppH™@10,000)	**1,517,082.8**
TPC-H Throughput (QthH™@10,000)	**807,522.4**
TPC-H Composite Query-per-Hour Metric (QphH@10,000GB)	**1,106,832.6**
Total System Price over 3 Years	**$983,870.88 USD**
TPC-H Price/Performance Metric ($/QphH@10,000GB)	**$ 0.89 USD**

Measurement Intervals:

Measurement Interval in Throughput Test (Ts)	**8,827**

Duration of Stream Execution:

Power Run	Seed	Query Start Time Query End Time	Duration (sec)	RF1 Start Time RF1 End Time	RF2 Start Time RF2 End Time
	626190613	2016-06-27 12:42:58 2016-06-27 12:55:54	776	2016-06-27 12:41:46 2016-06-27 12:42:58	2016-06-27 12:55:54 2016-06-27 12:58:29

Throughput Stream	Seed	Query Start Time Query End Time	Duration (sec)	RF1 Start Time RF1 End Time	RF2 Start Time RF2 End Time
1	626190614	2016-06-27 12:58:28 2016-06-27 14:39:09	6,041	2016-06-27 14:48:15 2016-06-27 14:49:21	2016-06-27 14:49:22 2016-06-27 14:52:01
2	626190615	2016-06-27 12:58:28 2016-06-27 14:39:03	6,035	2016-06-27 14:52:01 2016-06-27 14:53:18	2016-06-27 14:53:18 2016-06-27 14:56:25
3	626190616	2016-06-27 12:58:29 2016-06-27 14:45:31	6,422	2016-06-27 14:56:25 2016-06-27 14:57:42	2016-06-27 14:57:42 2016-06-27 15:00:34
4	626190617	2016-06-27 12:58:29 2016-06-27 14:31:52	5,603	2016-06-27 15:00:35 2016-06-27 15:01:43	2016-06-27 15:01:43 2016-06-27 15:04:46
5	626190618	2016-06-27 12:58:29 2016-06-27 14:47:30	6,541	2016-06-27 15:04:46 2016-06-27 15:05:54	2016-06-27 15:05:55 2016-06-27 15:08:44
6	626190619	2016-06-27 12:58:29 2016-06-27 14:42:30	6,241	2016-06-27 15:08:45 2016-06-27 15:09:58	2016-06-27 15:09:59 2016-06-27 15:13:00
7	626190620	2016-06-27 12:58:29 2016-06-27 14:47:50	6,561	2016-06-27 15:13:01 2016-06-27 15:14:11	2016-06-27 15:14:11 2016-06-27 15:17:28
8	626190621	2016-06-27 12:58:29 2016-06-27 14:48:15	6,586	2016-06-27 15:17:28 2016-06-27 15:18:37	2016-06-27 15:18:38 2016-06-27 15:21:39
9	626190622	2016-06-27 12:58:29 2016-06-27 14:45:34	6,425	2016-06-27 15:21:39 2016-06-27 15:22:46	2016-06-27 15:22:46 2016-06-27 15:25:35

Timing Intervals (in seconds):

Stream ID	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
0	15.2	6.3	31.6	30.1	35.3	0.9	21.6	27.1	87.7	13.4	39.5	10.9
1	179.6	55.3	222.0	159.5	235.7	35.4	175.5	246.0	541.5	274.9	178.1	308.3
2	51.6	67.3	177.8	176.9	232.9	22.6	288.6	202.2	595.3	201.2	148.1	173.2
3	75.5	36.4	73.1	161.3	214.0	8.6	301.5	197.1	465.4	855.2	163.9	54.0
4	219.2	45.5	189.8	176.3	219.3	8.5	255.6	231.1	345.1	152.2	216.9	182.5
5	205.7	46.6	168.6	181.4	228.7	42.4	331.9	171.4	195.0	197.8	203.7	177.2
6	101.2	42.5	177.4	164.4	253.9	28.5	345.3	223.5	581.0	185.2	211.5	217.5
7	165.2	53.1	180.1	156.2	223.3	12.5	132.9	174.9	625.4	148.6	236.6	12.8
8	157.1	47.6	186.7	393.2	250.8	29.9	276.4	223.4	436.1	786.0	69.6	196.0
9	51.5	53.1	288.6	201.4	130.9	7.2	245.2	198.8	557.3	284.8	238.2	125.6
Min	15.2	6.3	31.6	30.1	35.3	0.9	21.6	27.1	87.7	13.4	39.5	10.9
Avg	122.2	45.4	169.6	180.1	202.5	19.7	237.5	189.6	443.0	309.9	170.6	145.8
Max	219.2	67.3	288.6	393.2	253.9	42.4	345.3	246.0	625.4	855.2	238.2	308.3

Stream ID	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	RF1	RF2
0	108.9	5.7	11.1	31.0	13.5	138.8	5.0	16.7	88.9	35.8	71.7	155.5
1	368.8	35.0	37.3	110.5	116.7	1,151.6	222.9	134.1	830.6	420.1	65.8	159.3
2	663.7	43.3	116.2	249.0	86.6	1,302.7	44.1	122.3	759.2	308.5	76.5	186.9
3	847.3	50.0	41.5	117.6	89.0	1,249.0	41.1	133.4	747.4	499.6	77.4	172.0
4	513.8	41.9	61.9	253.4	66.3	772.8	277.3	151.8	810.3	411.0	68.5	182.6
5	790.1	20.5	90.3	229.9	63.1	1,623.7	194.8	127.3	831.4	419.0	68.1	169.6
6	803.3	41.4	148.6	209.3	77.2	955.8	259.7	149.0	690.7	373.1	73.9	181.9
7	786.0	16.8	17.0	84.9	467.5	1,457.7	174.0	192.3	860.4	382.0	69.7	197.0
8	553.0	66.2	67.5	218.4	87.8	1,086.1	193.9	143.2	741.8	374.6	69.4	181.2
9	945.7	37.7	55.6	88.3	229.7	1,130.3	192.4	118.5	844.5	398.7	66.8	169.4
Min	108.9	5.7	11.1	31.0	13.5	138.8	5.0	16.7	88.9	35.8	65.8	155.5
Avg	638.1	35.9	64.7	159.2	129.7	1,086.9	160.5	128.9	720.5	362.2	70.8	175.5
Max	945.7	66.2	148.6	253.4	467.5	1,623.7	277.3	192.3	860.4	499.6	77.4	197.0

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Preface

TPC Benchmark H Standard Specification was developed by the Transaction Processing Performance Council (TPC). It was initially released on February 26, 1999. Revision 2.17.1 is the most recent version. This is the full disclosure report for benchmark testing of the Lenovo System x3850 X6 according to the TPC Benchmark H Standard Specification.

The TPC Benchmark H is a decision support benchmark. It consists of a suite of business-oriented ad hoc queries and concurrent data modifications. The queries and the data populating the database have been chosen to have broad industrywide relevance while maintaining a sufficient degree of ease of implementation. This benchmark illustrates decision support systems that:

- Examine large volumes of data;
- Execute queries with a high degree of complexity;
- Give answers to critical business questions.

TPC-H evaluates the performance of various decision support systems by the execution of set of queries against a standard database under controlled conditions. The TPC-H queries:

- Give answers to real-world business questions;
- Simulate generated ad-hoc queries (e.g., via a point-and-click GUI interface);
- Are far more complex than most OLTP transactions;
- Include a rich breadth of operators and selectivity constraints;
- Generate intensive activity on the part of the database server component of the system under test;
- Are executed against a database complying with specific population and scaling requirements;
- Are implemented with constraints derived from staying closely synchronized with an on-line production database.

The TPC-H operations are modeled as follows:

- The database is continuously available 24 hours a day, 7 days a week, for ad-hoc queries from multiple end users and data modifications against all tables, except possibly during infrequent (e.g., once a month) maintenance sessions.
- The TPC-H database tracks, possibly with some delay, the state of the OLTP database through ongoing refresh functions, which batch together a number of modifications impacting some part of the decision support database.
- Due to the worldwide nature of the business data stored in the TPC-H database, the queries and the refresh functions may be executed against the database at any time, especially in relation to each other. In addition, this mix of queries and refresh functions is subject to specific ACIDity requirements, since queries and refresh functions may execute concurrently.
- To achieve the optimal compromise between performance and operational requirements, the database administrator can set, once and for all, the locking levels and the concurrent scheduling rules for queries and refresh functions.

The minimum database required to run the benchmark holds business data from 10,000 suppliers. It contains almost 10 million rows representing a raw storage capacity of about 1 gigabyte. Compliant benchmark implementations may also use one of the larger permissible database populations (e.g., 100 gigabytes), as defined in Clause 4.1.3.

The performance metrics reported by TPC-H is called the TPC-H Composite Query-per-Hour Performance Metric (QphH@Size), and reflects multiple aspects of the capability of the system to process queries. These aspects include the selected database size against which the queries are executed, the query processing power when queries are submitted by a single stream, and the query throughput when queries are submitted by multiple concurrent users. The TPC-H Price/Performance metric is expressed as $/QphH@Size. To be compliant with the TPC-H standard, all references to TPC-H results for a given configuration must include all required reporting components (see Clause 5.4.6). The TPC believes that comparisons of TPC-H results measured against different database sizes are misleading and discourages such comparisons.

The TPC-H database must be implemented using a commercially available database management system (DBMS), and the queries executed via an interface using dynamic SQL. The specification provides for variants of SQL, as implementers are not required to have implemented a specific SQL standard in full.

Benchmarks results are highly dependent upon workload, specific application requirements, and systems design and implementation. Relative system performance will vary as a result of these and other factors. Therefore, TPC-H should not be used as a substitute for specific customer application benchmarking when critical capacity planning and/or product evaluation decisions are contemplated.

General Items

Benchmark Sponsor

A statement identifying the benchmark sponsor(s) and other participating companies must be provided.

This benchmark was sponsored by Lenovo Corporation.

Parameter Settings

Settings must be provided for all customer-tunable parameters and options that have been changed from the defaults found in actual products, including but not limited to:

- *Database tuning options*
- *Optimizer/Query execution options*
- *Query Processing tool/language configuration parameters*
- *Recovery/commit options*
- *Consistency/locking options*
- *Operating system and configuration parameters*
- *Configuration parameters and options for any other software component incorporated into the pricing structure*
- *Compiler optimization options*

See the Supporting Files, "Tunable Parameters," which contains a list of all database parameters and operating system parameters.

Configuration Diagrams

Diagrams of both measured and priced configurations must be provided, accompanied by a description of the differences. This includes, but is not limited to:

- *Total number of nodes used, total number and type of processors used/total number of cores used/total number of threads used (including sizes of L2 and L3 caches);*
- *Size of allocated memory, and any specific mapping/partitioning of memory unique to the test;*
- *Number and type of disk units (and controllers, if applicable);*
- *Number of channels or bus connections to disk units, including their protocol type;*
- *Number of LAN (e.g., Ethernet) connections, including routers, workstations, terminals, etc., that were physically used in the test or are incorporated into the pricing structure;*
- *Type and the run-time execution location of software components (e.g., DBMS, query processing tools/languages, middleware components, software drivers, etc.).*

Measured Configuration

Lenovo System x3850 X6

Table 0-1. Measured Configuration Details

Quantity	Lenovo System x3850 X6 Configure-To-Order, includes:
1	x3850 X6 4U Chassis + Midplane
4	X6 Compute Book with Intel Xeon Processor E7-8890 v4 2.2GHz 4 / 96 / 192 Total Processors/Cores/Threads 2 x 30MB L3 cache per processor 24 x 256KB L2 cache per processor
96	64GB DDR4 2400MHz LP LRDIMM 6TB Total System Memory
1	X6 Primary I/O Book + X6 Storage Book
2	Half-Length PCIe I/O Book
2	4x 2.5" HDD Riser
1	ServeRAID M5210 SAS/SATA Controller
4	1400W HE Redundant Power Supply
2	300GB 10K 12Gbps SAS 2.5" G3HS HDD
4	800GB SATA 2.5" MLC G3HS Enterprise Value SSD
8	6.4TB io3 Enterprise Flash PCIe Adapter
1	Intel I350-T4 ML2 Quad Port GbE Adapter
1	3YR Tech Install Parts 24x7x4 x3850 x6
	SQL Server 2016 Enterprise Edition
	Windows Server 2016 Standard Edition

Priced Configuration

The measured and priced configurations were the same. See the measured configuration details above.

Clause 1 – Logical Database Design Related Items

Database Table Definitions

Listings must be provided for all table definition statements and all other statements used to set-up the test and qualification databases.

See the Supporting Files for the scripts that were used to set up the TPC-H test and qualification databases.

Database Physical Organization

The physical organization of tables and indices within the test and qualification databases must be disclosed. If the column ordering of any table is different from that specified in Clause 1.4, it must be noted.

See the Supporting Files for the scripts that were used to create the indexes on the test and qualification databases.

No column reordering was used.

Horizontal/Vertical Partitioning

Horizontal partitioning of tables and rows in the test and qualification databases (see Clause 1.5.4) must be disclosed.

Horizontal partitioning on L_SHIPDATE and O_ORDERDATE was used and granularity was week.

Replication

Any replication of physical objects must be disclosed and must conform to the requirements of Clause 1.5.7.

Replication was not used.

Clause 2 – Query and Refresh Function Related Items

Query Language

The query language used to implement the queries must be identified (e.g., "RALF/SQL-Plus").

SQL was the query language used.

QGen

The version number, release number, modification number, and patch level of QGen must be disclosed.

QGen version 2.17.0 was used to generate all database populations.

Query Text and Output Data from Database

The executable query text used for query validation must be reported in the supporting files archive along with the corresponding output data generated during the execution of the query text against the qualification database. If minor modifications (see Clause 2.2.3) have been applied to any functional query definitions or approved variants in order to obtain executable query text, these modifications must be disclosed and justified. The justification for a particular minor query modification can apply collectively to all queries for which it has been used.

See the Supporting Files for the query text and query output. The following modifications were used:

- In Q1, Q4, Q5, Q6, Q10, Q12, Q14, Q15 and Q20, the "dateadd" function is used to perform date arithmetic.
- In Q7, Q8 and Q9, the "datepart" function is used to extract part of a date (e.g., "YY").
- In Q2, Q3, Q10, Q18 and Q21, the "top" function is used to restrict the number of output rows.
- In Q1, the "count_big" function is used in place of "count".

Query Substitution Parameters and Seeds Used

All the query substitution parameters used during the performance test must be disclosed in tabular format, along with the seeds used to generate these parameters.

See the Supporting Files for the seed and query substitution parameters used.

Query Isolation Level

The isolation level used to run the queries must be disclosed. If the isolation level does not map closely to one of the isolation levels defined in Clause 3.4, additional descriptive detail must be provided.

The queries and transactions were run with repeatable read isolation level.

Refresh Function Implementation

The details of how the refresh functions were implemented must be reported in the supporting files archive (including source code of any non-commercial program used).

See the Supporting Files for the source code for the refresh function.

Clause 3 – Database System Properties Related Items

The results of the ACID tests must be disclosed along with a description of how the ACID requirements were met.

All ACID tests were conducted according to specifications. The Atomicity, Isolation, Consistency and Durability tests were performed on the Lenovo System x3850 X6 server. See the Supporting Files for the ACID transaction source code.

Atomicity Requirements

The system under test must guarantee that transactions are atomic; the system will either perform all individual operations on the data, or will assure that no partially-completed operations leave any effects on the data.

Atomicity of Completed Transactions

Perform the ACID Transaction (see Clause 3.1.5) for a randomly selected set of input data and verify that the appropriate rows have been changed in the ORDERS, LINEITEM, and HISTORY tables.

The following steps were performed to verify the Atomicity of completed transactions:

1. The total price from the ORDER table and the extended price from the LINEITEM table were retrieved for a randomly selected order key.
2. The ACID Transaction was performed using the order key from step 1.
3. The ACID Transaction committed.
4. The total price from the ORDER table and the extended price from the LINEITEM table were retrieved for the same order key. It was verified that the appropriate rows had been changed.

Atomicity of Aborted Transactions

Perform the ACID Transaction for a randomly selected set of input data, substituting a ROLLBACK of the transaction for the COMMIT of the transaction. Verify that the appropriate rows have not been changed in the ORDERS, LINEITEM, and HISTORY tables.

The following steps were performed to verify the Atomicity of the aborted ACID transaction:

1. The total price from the ORDER table and the extended price from the LINEITEM table were retrieved for a randomly selected order key.
2. The ACID Transaction was performed using the order key from step 1. The transaction was stopped prior to the commit.
3. The ACID Transaction was ROLLED BACK.
4. The total price from the ORDER table and the extended price from the LINEITEM table were retrieved for the same order key used in steps 1 and 2. It was verified that the appropriate rows had not been changed.

Consistency Requirements

Consistency is the property of the application that requires any execution of transactions to take the database from one consistent state to another. A TPC-H database, when populated as defined in Clause 4.2, must meet the consistency condition defined in Clause 3.3.2.1:

> *A consistent state for the TPC-H database is defined to exist when O_TOTALPRICE = SUM(trunc(trunc(L_EXTENDEDPRICE *(1 - L_DISCOUNT),2) * (1+L_TAX),2)) for each ORDERS and LINEITEM defined by (O_ORDERKEY = L_ORDERKEY)*

If data is replicated, as permitted under Clause 1.5.7, each copy must meet the consistency condition defined in Clause 3.3.2.1.

Consistency Tests

To verify the consistency between the ORDERS and LINEITEM tables, perform the following steps:

1. *Verify that the ORDERS and LINEITEM tables are initially consistent as defined in Clause 3.3.2.1, based on a random sample of at least 10 distinct values of O_ORDERKEY.*
2. *Submit at least 100 ACID Transactions from each of at least the number of execution streams (# query streams + 1 refresh stream) used in the reported throughput test (see Clause 5.3.4). Each transaction must use values of (O_KEY, L_KEY, DELTA) randomly generated within the ranges defined in Clause 3.1.6.2. Ensure that all the values of O_ORDERKEY chosen in Step 1 are used by some transaction in Step 2.*
3. *Re-verify the consistency of the ORDERS, and LINEITEM tables as defined in Clause 3.3.2.1 based on the same sample values of O_ORDERKEY selected in Step 1.*

Consistency was tested as part of the durability tests.

Isolation Requirements

Operations of concurrent transactions must yield results which are indistinguishable from the results which would be obtained by forcing each transaction to be serially executed to completion in some order.

The six tests described here are designed to verify that the system under test is configured to support the required isolation levels, as defined in Clause 3.4.1. All Isolation Tests are performed using a randomly selected set of values (P_KEY, S_KEY, O_KEY, L_KEY, DELTA).

Isolation Test 1 - Read-Write Conflict with Commit

This test demonstrates isolation for the read-write conflict of a read-write transaction and a read-only transaction when the read-write transaction is committed.

The following steps were performed to satisfy the test of isolation for a read-only and a read-write committed transaction:

1. An ACID Transaction was started for a randomly selected O_KEY, L_KEY and DELTA. The ACID Transaction was suspended prior to Commit.
2. An ACID query was started for the same O_KEY used in step 1. The ACID query blocked and did not see any uncommitted changes made by the ACID Transaction.
3. The ACID Transaction was resumed and committed.
4. The ACID query completed. It returned the data as committed by the ACID Transaction.

Isolation Test 2 - Read-Write Conflict with Rollback

This test demonstrates isolation for the read-write conflict of a read-write transaction and a read-only transaction when the read-write transaction is rolled back.

The following steps were performed to satisfy the test of isolation for read-only and a rolled back read-write transaction:

1. An ACID transaction was started for a randomly selected O_KEY, L_KEY and DELTA. The ACID Transaction was suspended prior to Rollback.
2. An ACID query was started for the same O_KEY used in step 1. The ACID query did not see any uncommitted changes made by the ACID Transaction.
3. The ACID Transaction was ROLLED BACK.
4. The ACID query completed.

Isolation Test 3 - Write-Write Conflict with Commit

This test demonstrates isolation for the write-write conflict of two update transactions when the first transaction is committed.

The following steps were performed to verify isolation of two update transactions:

1. An ACID Transaction T1 was started for a randomly selected O_KEY, L_KEY and DELTA. The ACID transaction T1 was suspended prior to Commit.
2. Another ACID Transaction T2 was started using the same O_KEY and L_KEY and a randomly selected DELTA.
3. T2 waited.
4. The ACID transaction T1 was allowed to Commit and T2 completed.
5. It was verified that:
   T2.L_EXTENDEDPRICE = T1.L_EXTENDEDPRICE+(DELTA1*(T1.L_EXTENDEDPRICE/T1.L_QUANTITY))

Isolation Test 4 - Write-Write Conflict with Rollback

This test demonstrates isolation for the write-write conflict of two update transactions when the first transaction is rolled back.

The following steps were performed to verify the isolation of two update transactions after the first one is rolled back:

1. An ACID Transaction T1 was started for a randomly selected O_KEY, L_KEY and DELTA. The ACID Transaction T1 was suspended prior to Rollback.
2. Another ACID Transaction T2 was started using the same O_KEY and L_KEY used in step 1 and a randomly selected DELTA.
3. T2 waited.
4. T1 was allowed to ROLLBACK and T2 completed.
5. It was verified that T2.L_EXTENDEDPRICE = T1.L_EXTENDEDPRICE.

Isolation Test 5 - Concurrent Read and Write Transactions on Different Tables

This test demonstrates the ability of read and write transactions affecting different database tables to make progress concurrently.

The following steps were performed:

1. An ACID Transaction T1 for a randomly selected O_KEY, L_KEY and DELTA. The ACID Transaction T1 was suspended prior to Commit.
2. Another ACID Transaction T2 was started using random values for PS_PARTKEY and PS_SUPPKEY.
3. T2 completed.
4. T1 completed and the appropriate rows in the ORDER, LINEITEM and HISTORY tables were changed.

Isolation Test 6 - Update Transactions during Continuous Read-Only Query Stream

This test demonstrates that the continuous submission of arbitrary (read-only) queries against one or more tables of the database does not indefinitely delay update transactions affecting those tables from making progress.

The following steps were performed:

1. An ACID Transaction T1 was started, executing Q1 against the qualification database. The substitution parameter was chosen from the interval [0..2159] so that the query ran for a sufficient amount of time.
2. Before T1 completed, an ACID Transaction T2 was started using randomly selected values of O_KEY, L_KEY and DELTA.
3. T2 completed before T1 completed.
4. It was verified that the appropriate rows in the ORDER, LINEITEM and HISTORY tables were changed.

Durability Requirements

The SUT must guarantee durability: the ability to preserve the effects of committed transactions and ensure database consistency after recovery from any one of the failures listed in Clause 3.5.3.

The test sponsor is required to guarantee that the test system will preserve the database and the effects of committed updates after recovery from any of the failures listed below. The intent of these tests is to demonstrate that all transactions whose output messages have been received by the driver have in fact been committed in spite of any single failure from the list in Clause 3.5.3 and that all consistency conditions are still met after the database is recovered.

Permanent Irrecoverable Failure of Any Single Durable Medium (Database Tables)

Guarantee the database and committed updates are preserved across a permanent irrecoverable failure of any single durable medium containing TPC-H database tables. The media to be failed is to be chosen at random by the auditor and cannot be specially prepared.

The OS was stored on a RAID-1 protected array of two physical drives. The database files were stored on eight non-RAIDed Enterprise io3 Flash drives. The log was stored on a 4-disk RAID-10 array. The tests were conducted on the qualification database. The steps performed are shown below:

1. The database was backed up to the RAID-10 array.
2. The consistency of the ORDERS and LINEITEM tables was verified.
3. Ten streams of ACID transactions were started. Each stream executed a minimum of 100 transactions.
4. A checkpoint was issued.
5. While the test was running, one of the disks holding database table data was logically removed.
6. A checkpoint was issued to force a failure.
7. The 10 streams of ACID transactions failed and recorded their number of committed transaction in success files.
8. The database log was dumped to disk.
9. A new database drive was attached.
10. A database restore from back up was done.
11. A command was issued causing the database to run through its roll-forward recovery.
12. The success file and the HISTORY table counts were compared and were found to match.
13. The consistency of the ORDERS and LINEITEM tables was verified.

Permanent Irrecoverable Failure of Any Single Durable Medium (Database Log)
System Crash
Memory Failure
SUT Power Failure

Guarantee the database and committed updates are preserved across a permanent irrecoverable failure of any single durable medium containing TPC-H recovery log data. The media to be failed is to be chosen at random by the auditor and cannot be specially prepared.

Guarantee the database and committed updates are preserved across an instantaneous interruption (system crash/system hang) in processing which requires system reboot to recover.

Guarantee the database and committed updates are preserved across the failure of all or part of memory (loss of contents) which may be caused by a loss of external power or the permanent failure of a memory board.

Guarantee the database and committed updates are preserved across the loss of all external power to the SUT for an indefinite time period.

These tests were all combined. The following steps were performed:

1. The consistency of the ORDERS and LINEITEM tables was verified.
2. Ten streams of ACID transactions were started. Each stream executed a minimum of 100 transactions.
3. While the test was running, one of the disks from the RAID-10 database log was logically removed.
4. It was determined that the test would still run with the loss of a log disk; the system was powered off.
5. When power was restored, the system booted and the log array was rebuilt.
6. When the array finished rebuilding, the database was restarted.
7. The database went through a recovery period.
8. The success file and the HISTORY table counts were compared and were found to match.
9. The consistency of the ORDERS and LINEITEM tables was verified.

Clause 4 – Scaling and Database Population Related Items

Initial Cardinality of Tables

The cardinality (e.g., the number of rows) of each table of the test database, as it existed at the completion of the database load (see Clause 4.2.5), must be disclosed.

Table 4-1. Initial Cardinality of Tables

Table Name	Row Count
Order	15,000,000,000
Lineitem	59,999,994,267
Customer	1,500,000,000
Part	2,000,000,000
Supplier	100,000,000
Partsupp	8,000,000,000
Nation	25
Region	5

Distribution of Tables and Logs

The distribution of tables and logs across all media must be explicitly described for both the tested and priced systems.

The measured and priced configurations were the same.

The database data files and tempdb were spread out across the eight Enterprise io3 Flash PCIe adapters. The database log was configured on a 4-disk RAID-10 array of 800GB SATA 2.5" SSDs. The database and log distribution is shown in table 4-2.

Table 4-2. Physical Distribution of Tables and Logs

Controller	Drives	RAID	Vol size GB	Format	Files	LUN
Slot 11	2x 300G	Raid-1	279	NTFS	OS, SQL	C:
ServeRaid M5210	4x 800G	Raid-10	1450	NTFS	LOG	C:\mt\LOG
Slot 1	1x 6.4TB	Raid 0	5960	NTFS	Data, Tempdb	C:\mt\Fio1, C:\mt\Fio9
Slot 2	1x 6.4TB	Raid 0	5960	NTFS	Data, Tempdb	C:\mt\Fio2, C:\mt\Fio10
Slot 3	1x 6.4TB	Raid 0	5960	NTFS	Data, Tempdb	C:\mt\Fio3, C:\mt\Fio11
Slot 4	1x 6.4TB	Raid 0	5960	NTFS	Data, Tempdb	C:\mt\Fio3, C:\mt\Fio12
Slot 5	1x 6.4TB	Raid 0	5960	NTFS	Data, Tempdb	C:\mt\Fio4, C:\mt\Fio13
Slot 6	1x 6.4TB	Raid 0	5960	NTFS	Data, Tempdb	C:\mt\Fio6, C:\mt\Fio14
Slot 7	1x 6.4TB	Raid 0	5960	NTFS	Data, Tempdb	C:\mt\Fio7, C:\mt\Fio15
Slot 8	1x 6.4TB	Raid 0	5960	NTFS	Data, Tempdb	C:\mt\Fio8, C:\mt\Fio16
Totals	**55000**		**49409**			

Database Partition / Replication Mapping

The mapping of database partitions/replications must be explicitly described.

The database was not replicated.

Storage Redundancy

Implementations may use data redundancy mechanism(s). The type of data redundancy mechanism(s) and any configuration parameters (e.g., RAID level used) must be disclosed for each device. If data redundancy mechanism(s) are used in an implementation, the logical intent of their use must be disclosed.

The Storage Redundancy Level of this result is zero (no redundancy).

RAID-1 was used for the array that held the operating system and database software.

RAID-10 was used for the array that held the database log.

The database data and the temporary tablespace were placed on non-RAIDed drives.

DBGen

The version number, release number, modification number, and patch level of DBGen must be disclosed.

The standard distribution DBGen version 2.17.0 was used for database population. No modifications were made.

Database Load Time

The database load time for the test database (see Clause 4.3) must be disclosed.

The database load time was 6h 48m 42s.

Data Storage Ratio

The data storage ratio must be disclosed. It is computed by dividing the total data storage of the priced configuration (expressed in GB) by the size chosen for the test database as defined in Clause 4.1.3.1.

The calculation of the data storage ratio is shown in table 4-3.

Table 4-3. Data Storage Ratio Calculations

Disk Type	Number of Disks	Space per Disk (GB)	Total Disk Space (GB)	Scale Factor	Storage Ratio
300GB 2.5” SAS HDDs	2	279	558		
800GB 2.5” SATA SSDs	4	745	2,980		
6.4TB Enterprise io3 Flash PCIe Adapters	8	5,960	47,680		
Total			**51,218**	**10,000**	**5.12**

The data storage ratio is 5.12, derived by dividing 51,218 GB by the database size of 10,000 GB.

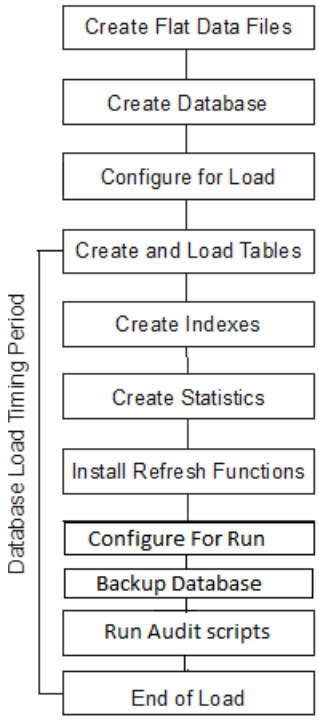
Database Load Details

The details of the database load must be disclosed including a block diagram illustrating the overall process.

Flat files for each of the tables were created using DBGen.

The tables were loaded as depicted in Figure 4.1.

Figure 4-1. Database Load Procedure



Qualification Database Configuration

Any differences between the configuration of the qualification database and the test database must be disclosed.

The qualification database used identical scripts and disk structure to create and load the data with adjustments for size difference.

Memory to Database Size Percentage

The memory to database size percentage must be disclosed. It is computed by multiplying by 100 the total memory size priced on the SUT (see clause 6.2.1) and dividing this number by the size chosen for the test database as defined in Clause 4.1.3.1.

The memory to database size percentage is 61.4%, derived by multiplying 6,144 GB * 100 and then dividing by the database size of 10,000 GB.

Clause 5 – Performance Metrics and Execution Rules Related Items

System Activity between Load and Performance Tests

Any system activity on the SUT that takes place between the conclusion of the load test and the beginning of the performance test must be fully reported in the supporting files archive including listings of scripts, command logs and system activity.

There was no activity between the load test and performance test.

Power Test Steps

The details of the steps followed to implement the power test (e.g., system boot, database restart, etc.) must be reported.

The following steps were used to implement the power test:

1. RF1 Refresh function
2. Stream 00 Execution
3. RF2 Refresh function

Timing Intervals for Each Query and Refresh Function

The timing intervals (see Clause 5.3.7) for each query and for both refresh functions must be reported for the power test.

See the Numerical Quantities Summary in the Executive Summary at the beginning of this report.

Number of Query Streams Used for the Throughput Test

The number of query streams used for the throughput test must be disclosed.

Nine query streams and nine refresh stream were used for the throughput test.

Start and End Date/Times for Each Query Stream

The start time and finish time for each query stream for the throughput test must be disclosed.

See the Numerical Quantities Summary in the Executive Summary at the beginning of this report.

Total Elapsed Time for the Measurement Interval

The total elapsed time of the measurement interval (see Clause 5.3.6) must be disclosed for the throughput test.

See the Numerical Quantities Summary in the Executive Summary at the beginning of this report.

Refresh Function Start Date/Time and Finish Date/Time

The start time and finish time for each refresh function in the refresh stream for the throughput test must be disclosed.

See the Numerical Quantities Summary in the Executive Summary at the beginning of this report.

Performance Metrics

The computed performance metric, related numerical quantities and the price/performance metric must be disclosed.

See the Numerical Quantities Summary in the Executive Summary at the beginning of this report.

Performance Metric and Numerical Quantities from Both Runs

The performance metric (QphH@Size) and the numerical quantities (TPC-H Power@Size and TPC-H Throughput@Size) from both of the runs must be disclosed (see Clause 5.4).

Two consecutive runs of the TPC-H benchmark were performed. Table 5-1 contains the results for both runs.

Table 5-1. Performance Metrics from Both Runs

	QppH @ 10,000GB	QthH @ 10,000GB	QphH @ 10,000GB
Run1	1,460,938.6	867,998.1	1,126,095.9
Run2	1,517,082.8	807,522.4	1,106,832.6

System Activity between Tests

Any activity on the SUT that takes place between the conclusion of Run1 and the beginning of Run2 must be fully disclosed including system activity, listings of scripts or command logs along with any system reboots or database restarts.

There was no activity between Run1 and Run2.

Clause 6 – SUT and Driver Implementation Related Items

Driver

A detailed textual description of how the driver performs its functions, how its various components interact and any product functionalities or environmental settings on which it relies and all related source code, scripts and configuration files must be reported in the supporting files archive. The information provided should be sufficient for an independent reconstruction of the driver.

The TPC-H benchmark was implemented using a Microsoft tool called StepMaster, which is a general purpose test tool that can drive ODBC and shell commands. Within StepMaster, the user designs a workspace corresponding to the sequence of operations (or steps) to be executed. When the workspace is executed, StepMaster records information about the run into a database as well as a log file for later analysis.

StepMaster provides a mechanism for creating parallel streams of execution. This is used in the throughput tests to drive the query and refresh streams. Each step is timed using a millisecond resolution timer. A timestamp T1 is taken before beginning the operation and a timestamp T2 is taken after completing the operation. These times are recorded in a database as well as in a log file for later analysis.

Two types of ODBC connections are supported. A dynamic connection is used to execute a single operation and is closed when the operation finishes. A static connection is held open until the run completes and may be used to execute more than one step. A connection (either static or dynamic) can only have one outstanding operation at any time.

In TPC-H, static connections are used for the query streams in the power and throughput tests. StepMaster reads an Access database to determine the sequence of steps to execute. These commands are represented as the Implementation Specific Layer. StepMaster records its execution history, including all timings, in the Access database. Additionally, StepMaster writes a textual log file of execution for each run.

The stream refresh functions were executed using multiple batch scripts. The initial script is invoked by StepMaster, subsequent scripts are called from within the scripts.

The source for StepMaster and the RF Scripts is disclosed in the supported file archive.

Implementation Specific Layer

If an implementation specific layer is used, then a detailed description of how it performs its functions, how its various components interact and any product functionalities or environmental setting on which it relies must be disclosed. All related source code, scripts and configuration files must be reported in the supporting files archive. The information provided should be sufficient for an independent reconstruction of the implementation specific layer.

See the Driver section above for details.

Profile-Directed Optimization

If profile-directed optimization as described in Clause 5.2.9 is used, such use must be disclosed.

Profile-directed optimization was not used.

Clause 7 – Pricing Related Items

Hardware and Software Components

A detailed list of hardware and software used in the Priced Configuration must be reported. The listing for each separately Orderable item must have vendor Part Number, description and applicable release/revision level, price source, unit price, quantity, extended price, applicable Discounted price and 3-year maintenance price. If package-pricing is used, the vendor Part Number of the package and a description uniquely identifying each of the Components of the package must be disclosed to a sufficient level of detail to meet the requirements of 1.4.1.1.

A detailed list of all hardware, software, and maintenance is provided in the Executive Summary at the front of this report. Price quotations are included in Appendix A.

Three-Year Cost of System Configuration

The total 3-year price of the entire Priced Configuration must be reported, including: hardware, software, and maintenance charges. The justification of any Discounts applied must be disclosed in the price sheet. Sufficient detail of what items are being discounted and by how much they are being discounted must be provided so that the Discount amount used in the computation of the total system cost can be independently reproduced.

A detailed list of all hardware, software, and maintenance, including the total 3-year price and discount information, is provided in the Executive Summary at the front of this report. Price quotations are included in Appendix A.

Availability Date

The committed Availability Date of Components used in the price calculations must be reported. The Availability Date must be reported on the first page of the Executive Summary and with a precision of one day. When the priced system includes products with different availability dates, the reported Availability Date for the priced system must be a date at which all Components are committed to be Generally Available. Each Component used in the Priced Configuration is considered to be Available on the Availability Date unless an earlier date is specified.

The Availability Date is September 30, 2016.

Country-Specific Pricing

Pricing must be reported in the currency of the country where the system is priced.

The configuration is priced for the United States of America.

Clause 8 – Full Disclosure Report Related Items

Supporting Files Index

An index for all files and/or directories included in the Supporting Files Archive as required by Clauses 8.3.2 through 8.3.8 must be provided in the report..

Table 8-1. Supporting Files Index

Clause	Description	Pathname
Clause 1	OS and DB settings	SupportingFilesArchive\Clause1
Clause 2	Qualification Queries and Output	SupportingFilesArchive\Clause2
Clause 3	ACID scripts and output	SupportingFilesArchive\Clause3
Clause 4	DB load scripts	SupportingFilesArchive\Clause4
Clause 5	Queries and output for measured runs	SupportingFilesArchive\Clause5
Clause 6	Implementation code for measured runs	SupportingFilesArchive\Clause6
Clause 7	There are no required files for Clause 7	
Clause 8	RFs source and parameters	SupportingFilesArchive\Clause8

Clause 9 – Audit Related Items

Auditor

The auditor's agency name, address, phone number, and attestation letter with a brief audit summary report indicating compliance must be included in the full disclosure report. A statement should be included specifying whom to contact in order to obtain further information regarding the audit process.

This implementation of the TPC Benchmark H was audited by Francois Raab of Infosizing. Further information regarding the audit process may be obtained from:

InfoSizing
20 Kreg Lane
Manitou Springs, CO 80829
Telephone: (719) 473-7555
Web address: www.sizing.com

For a copy of this disclosure, go to www.tpc.org

Attestation Letter

The auditor's Attestation Letter is on the next two pages.

InfoSizing
The Right Metric For Sizing IT

TPC Transaction Processing Performance Council
Certified Auditors

Benchmark sponsor: Vinay Kulkarni
Data Center Group
Lenovo Corporation
3260 Carillon Point
Kirkland, WA 98033

July 26, 2016

I verified the TPC Benchmark H (TPC-H™ v2.17.1) performance of the following configuration:

Platform:	Lenovo® System x®3850 X6
Operating System:	Microsoft Windows Server 2016 Standard Edition
Database Manager:	Microsoft SQL Server 2016 Enterprise Edition
Other Software:	n/a

The results were:

Performance Metric	**1,106,832.6 QphH@10,000GB**
TPC-H Power	1,517,082.8
TPC-H Throughput	807,522.4
Database Load Time	06h 48m 42s

Server	**Lenovo System x3850 X6**		
CPUs	4 x Intel Xeon Processor E7-8890 v4 (2.2GHz, 60MB L3)		
Memory	6,000 GB		
Disks	***Qty***	***Size***	***Type***
	2	300 GB	SAS 2.5” 10Krpm HDD
	4	800 GB	800GB SATA 2.5" MLC G3HS Enterprise Value SSD
	8	6,400 GB	Enterprise Io3 Flash PCIe

In my opinion, these performance results were produced in compliance with the TPC requirements for the benchmark.

The following verification items were given special attention:

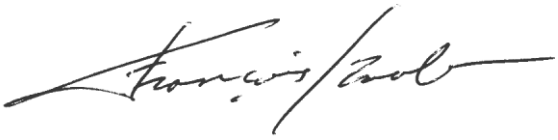
- The database records were defined with the proper layout and size
- The database population was generated using DBGen
- The database was properly scaled to 10,000GB and populated accordingly
- The compliance of the database auxiliary data structures was verified
- The database load time was correctly measured and reported

- The required ACID properties were verified and met
- The query input variables were generated by QGen
- The query text was produced using minor modifications and no query variant
- The execution of the queries against the SF1 database produced compliant answers
- A compliant implementation specific layer was used to drive the tests
- The throughput tests involved 9 query streams
- The ratio between the longest and the shortest query was such that no query timings were adjusted
- The execution times for queries and refresh functions were correctly measured and reported
- The repeatability of the measured results was verified
- The system pricing was verified for major components and maintenance
- The major pages from the FDR were verified for accuracy

Additional Audit Notes:

The second edition of the FDR was verified.

Respectfully Yours,



François Raab, President

Microsoft Corporation
One Microsoft Way
Redmond, WA 98052-6399

Tel 425 882 8080
Fax 425 936 7329
http://www.microsoft.com/

Microsoft

July 5, 2016

Lenovo
Vinay Kulkarni
3260 Carillon Point
Kirkland, WA 98033

Here is the information you requested regarding pricing for several Microsoft products to be used in conjunction with your TPC-H benchmark testing.

All pricing shown is in US Dollars ($).

Description	Unit Price	Quantity	Price
Database Management System			
SQL Server 2016 Enterprise Edition *2 Core License* *Open Program - Level C*	$13,472.50	48	$646,680.00
Database Server Operating System			
Windows Server 2016 Standard Edition *2-Core Pack* *Open Program - Level C*	$92.00	48	$4,416.00
Support			
Microsoft Problem Resolution Services *Professional Support* *(1 Incident).*	$259.00	1	$259.00

SQL Server 2016 Enterprise Edition is currently orderable available. Windows Server 2016 Standard Edition is currently orderable and will be generally available by September 30, 2016. A list of Microsoft's resellers can be found in the Microsoft Product Information Center at **http://www.microsoft.com/products/info/render.aspx?view=22&type=how**

Defect support is included in the purchase price. Additional support is available from Microsoft PSS on an incident by incident basis at $259 call.

This quote is valid for the next 90 days.
Reference ID: TPCH_qhtplylGYLKTVUKf32845dhwi_2016_lvk.