

**TPC Benchmark™ E**  
**Full Disclosure Report**  
**for**  
**Lenovo® ThinkSystem™ SR655 V3**  
**using**  
**Microsoft® SQL Server® 2022**  
**Enterprise Edition**  
**and**  
**Microsoft Windows Server® 2022**  
**Standard Edition**

**TPC-E™ Version 1.14.0**



**First Edition**

**Submitted for Review**

**July 26, 2023**

## First Edition – July 2023

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## Notes

<sup>1</sup> GHz and MHz only measures microprocessor internal clock speed, not application performance. Many factors affect application performance.

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

# **Abstract**

Lenovo conducted the TPC Benchmark E (TPC-E) on the Lenovo ThinkSystem SR655 V3. This report documents the full disclosure information required by the TPC Benchmark E Standard Specification, Revision 1.14.0, including the methodology used to achieve the reported results. All testing fully complied with this revision level.

The software used on the Lenovo ThinkSystem SR655 V3 system included Microsoft Windows Server 2022 Standard Edition and Microsoft SQL Server 2022 Enterprise Edition.

Standard metrics, transactions per second-E (tpsE<sup>TM</sup>), price per tpsE (\$/tpsE) and Availability Date, are reported as required by the TPC Benchmark E Standard Specification.

The benchmark results are summarized in the following table:


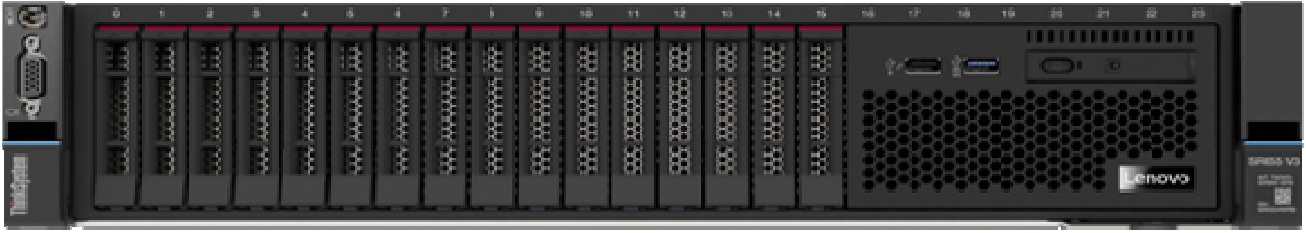
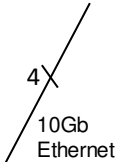
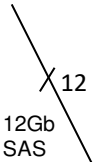

<b>Hardware</b>	<b>Software</b>	<b>Total System Cost (\$USD)</b>	<b>tpsE</b>	<b>\$ USD / tpsE</b>	<b>Total Solution Availability Date</b>
Lenovo ThinkSystem SR655 V3	Microsoft SQL Server 2022 Enterprise Edition Microsoft Windows Server 2022 Standard Edition	\$1,216,136	14,440.28	\$84.22	August 31, 2023

The benchmark implementation and results were audited by Doug Johnson for InfoSizing ([www.sizing.com](http://www.sizing.com)). The auditor's attestation letter is contained in this report.

# **Executive Summary**

*The TPC Executive Summary Statement must be included near the beginning of the Report.*

The Executive Summary is included on the next several pages.

	<b>Lenovo® ThinkSystem™ SR655 V3</b>		<b>TPC-E™ 1.14.0</b> <b>TPC Pricing 2.8.0</b>
			Report Date: July 26, 2023 Revision Date: July 26, 2023
TPC-E Throughput <b>14,440.28</b> <small>tpsE™</small>	Price/Performance <b>\$84.22</b> <small>USD per tpsE</small>	Availability Date <b>August 31, 2023</b>	Total System Cost <b>\$1,216,136</b> <small>USD</small>
<b>Database Server Configuration</b>			
Operating System <b>Microsoft® Windows Server® 2022 Standard Edition</b>	Database Manager <b>Microsoft SQL Server® 2022 Enterprise Edition</b>	Processors/Cores/Threads <b>1/128/256</b>	Memory <b>1536GB</b>
			
			
			
<b>TIER A (Client)</b>		<b>TIER B (Database Server and Storage)</b>	
<b>1 x Lenovo ThinkSystem SR650, with:</b> <ul style="list-style-type: none"> <li>- 2 x Intel Xeon Gold 6248R Processor 3.00GHz (2 Procs/48 Cores/96 Threads)</li> <li>- 96GB Memory</li> <li>- 2 x 600GB 10K SAS HDD (RAID-1)</li> <li>- 1 x ThinkSystem RAID 940-8i</li> <li>- 1 x Onboard Dual Gb Ethernet</li> <li>- 1 x Intel x550 Dual 10Gb-T Enet</li> <li>- 2 x Broadcom Dual 10Gb-T Enet</li> </ul>		<b>1 x Lenovo ThinkSystem SR655 V3, with:</b> <ul style="list-style-type: none"> <li>- 1 x AMD EPYC 9754 128-Core 2.25GHz Processor (1 Proc/128 Cores/256 Threads)</li> <li>- 1536GB Memory</li> <li>- 2 x 480GB SATA SSD (RAID-1)</li> <li>- 8 x 1600GB SAS SSD (RAID-10)</li> <li>- 1 x ThinkSystem RAID 940-16i</li> <li>- 6 x ThinkSystem RAID 940-8e</li> <li>- 1 x Broadcom Quad 10Gb-T Enet</li> <li>- 1 x Broadcom Dual 10Gb-T Enet</li> </ul>	
		<b>6 x Lenovo Storage D1224 DAS Enclosures, with:</b> <ul style="list-style-type: none"> <li>- 138 x 800GB 2.5" SAS SSD (6 x 23-drive RAID-5)</li> </ul>	
		<b>138 Total External Drives</b>	
Initial Database Size <b>61,612 GB</b>	Redundancy Level: <b>1</b>  <b>RAID-10 Log, tempdb</b> <b>RAID-5 Data</b>	Storage <b>138x 800GB 2.5" SAS SSD</b> <b>2x 480GB 2.5" SATA SSD</b> <b>8x 1600GB 2.5" SAS SSD</b>	



# Lenovo ThinkSystem SR655 V3

## TPC-E 1.14.0 TPC Pricing 2.8.0

Report Date: July 26, 2023  
Revision Date: July 26, 2023

Availability Date:  
August 31, 2023

Description	Part Number	Price Source	Unit Price	Quantity	Extended Price	3-Yr. Maint. Price
<b>Server Hardware</b>						
ThinkSystem SR655 V3 Configure-To-Order, includes:	7D9ECTO1WW	1	109,303	1	109,303	
ThinkSystem V3 2U 24x2.5" Chassis	BLKK			1		
ThinkSystem AMD EPYC 9754 128C 360W 2.25GHz Processor	BW9T			1		
ThinkSystem 128GB TruDDR5 4800MHz (4Rx4) 3DS RDIMM-A	BQ3A			12		
ThinkSystem RAID 940-16i 8GB Flash PCIe Gen4 12Gb Adapter	B8NZ			1		
ThinkSystem 2.5" PM1655 1.6TB Mixed Use SAS 24Gb HS SSD	BNW9			8		
ThinkSystem 2.5" S4520 480GB Read Intensive SATA 6Gb HS SSD	BA7G			2		
ThinkSystem 2U 8x2.5" SAS/SATA Backplane	B8LU			2		
ThinkSystem Broadcom 57454 10GBASE-T 4-port OCP Ethernet Adapter	B5T4			1		
ThinkSystem RAID 940-8e 4GB Flash PCIe Gen4 12Gb Adapter	BNWJ			6		
ThinkSystem Broadcom 57416 10GBASE-T 2-Port PCIe Ethernet Adapter	AUKP			1		
ThinkSystem V3 2U x16/x8/x8 PCIe Gen4 Riser1 or 2	BLKL			1		
ThinkSystem V3 2U x16/x8/x8 PCIe Gen4 Riser1 or 2	BLKL			1		
ThinkSystem V3 2U x16/x16 PCIe Gen4 Riser3 Kit with Cage	BPKG			1		
ThinkSystem 1800W 230V Platinum Hot-Swap Gen2 Power Supply	BMJF			2		
2.8m, 13A/100-250V, C13 to C14 Jumper Cord	6400			2		
ThinkSystem 2U V3 Performance Fan Module	BLL6			6		
ThinkSystem Toolless Friction Rail v2	BK7W			1		
ThinkSystem 2U V3 EIA Latch Standard	BQ22			1		
ThinkSystem SR655 V3 MB	BQ80			1		
ThinkSystem 2U MS 3FH Riser 1&2 Cage w/Label1	BPKD			1		
ThinkSystem 2U MS 3FH Riser 1&2 Cage	BLLD			1		
ThinkSystem RAID 930/940 SuperCap	AUNP			7		
ThinkSystem SR635 V3/SR655 V3 RoT Module LV-RoW	BSR6			1		
ThinkSystem SR655 V3 Main Airduct	BQ81			1		
ThinkSystem 2U V3 EIA right with FIO	BQ06			1		
ThinkSystem MS 2U common Airduct Filler	BQ31			1		
Essential Service - 3Yr 24x7 4Hr Resp + YDYD SR655 V3	5PS7B08739	1	1,439	1		1,439
				<b>Subtotal</b>	<b>109,303</b>	<b>1,439</b>
<b>Server Storage</b>						
Lenovo Storage D1224 SFF Chassis, Dual ESM	4587A31	1	2,999	6	17,994	
External MiniSAS HD 8644/MiniSAS HD 8644 1M Cable	00YL848	1	79	12	948	
Lenovo Storage 800GB 3DWD 2.5" SAS SSD	01DC477	1	2,499	138	344,862	
SFF Drive Blank AMS Filler	01DC624	1	39	6	234	
1.5m, 10A/100-250V, C13 to IEC 320-C14 Rack Power Cable	39Y7937	1	49	12	588	
12Gb SAN Rack Mount Kit-Rails 25"-36"	01DC146	1	149	6	894	
Essential Service - 3Yr 24x7 4Hr Resp DS Series Disk Exp	01JR577	1	1,169	6		7,014
				<b>Subtotal</b>	<b>365,520</b>	<b>7,014</b>
<b>Server Software</b>						
SQL Server 2022 Enterprise Edition (2 Core License)	N/A	2	15,123	64	967,872	
Windows Server 2022 Standard Edition (16 Core License)	N/A	2	1,069	8	8,552	
Microsoft Problem Resolution Services (1 Incident)	N/A	2	259	1		259
				<b>Subtotal</b>	<b>976,424</b>	<b>259</b>
<b>Client Hardware</b>						
ThinkSystem SR650 Configure-To-Order, includes:	7X06CTO1WW	1	30,781	1	30,781	
ThinkSystem SR650 2.5" Chassis with 8, 16 or 24 Bays v2	BMN6			1		
Intel Xeon Gold 6248R 24C 205W 3.0GHz Processor	BAZQ			2		
ThinkSystem 8GB TruDDR4 2933MHz (1Rx8 1.2V) RDIMM	B4H1			12		
ThinkSystem 2U/Twr 2.5" SATA/SAS 8-Bay Backplane	AURA			1		
ThinkSystem RAID 940-8i 4GB Flash PCIe Gen4 12Gb Adapter	B8NY			1		
ThinkSystem 2.5" 600GB 10K SAS 12Gb Hot Swap 512n HDD	AULZ			2		
ThinkSystem 2U x8/x8/x8 PCIe FH Riser 1	AUR4			1		
ThinkSystem SR550/SR590/SR650 x16/x8(or x16) PCIe FH Riser 2 Kit	AURC			1		
ThinkSystem 1Gb 2-port RJ45 LOM	AUKG			1		
ThinkSystem Broadcom 57416 10GBASE-T 2-Port PCIe Ethernet Adapter	AUKP			2		
Intel X550-T2 Dual Port 10GbBase-T Adapter	ATPX			1		
ThinkSystem 1100W (230V/115V) Platinum Hot-Swap Power Supply	AWWF			2		
2.8m, 13A/100-250V, C13 to C14 Jumper Cord	6400			2		
ThinkSystem Toolless Friction Rail v2	BK7W			1		
ThinkSystem 2U left EIA Latch Standard	AURD			1		
ThinkSystem SR650 MLK MB	BPZ0			1		
Lenovo ThinkSystem 2U 3FH Riser Bracket	AURQ			1		
Lenovo ThinkSystem 2U 2FH Riser Bracket	AURP			1		
ThinkSystem RAID 930/940 SuperCap	AUNP			1		
Essential Service - 3Yr 24x7 4Hr Resp + YDYD SR650	5PS7A01558	1	2,259	1		2,259
				<b>Subtotal</b>	<b>30,781</b>	<b>2,259</b>
<b>Client Software</b>						
Windows Server 2019 Standard Edition (2 Core License)	N/A	2	123	24	2,952	
				<b>Subtotal</b>	<b>2,952</b>	<b>0</b>
<b>Infrastructure</b>						
S2 42U Standard Rack	93074RX	1	1,565	1	1,565	
0U 36 C13/6 C19 24A/200-240V 1 Phase PDU with NEMA L6-30P line cord	00YJ776	1	869	1	869	
ThinkSystem Pref. Pro II USB Keyboard - US English	AXTL	1	29	1	29	
ThinkSystem Optical Wheel Mouse - USB	BOLN	1	39	1	39	
Lenovo 21.5 inch Monitor - L22i-30	66CAKCC1US	1	115	1	115	
1.0m CAT6 Green Cable	00WE127	1	19	4	76	
Essential Service - 3Yr 24x7 4Hr Response (Rack)	41L2760	1	315	1		315
				<b>Subtotal</b>	<b>2,693</b>	<b>315</b>
Dollar Volume Discount (See Note 1)	54.46%	1				
				<b>Total</b>	<b>1,487,673</b>	<b>11,286</b>

Pricing: 1 - Lenovo 1-877-782-7134; 2 - Microsoft  
 Note 1: Discount applies to all line items where Pricing=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:** \$1,216,136  
**TPC-E Throughput:** 14,440.28  
**\$ USD/tpsE:** \$84.22

Benchmark results and test methodology audited by Doug Johnson 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 Line Items. 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 Line Items. For complete details, see the pricing section of the TPC Benchmark Standard. If you find that the stated prices are not available according to these terms, please inform the TPC at pricing@tpc.org. Thank you.



# Lenovo ThinkSystem SR655 V3

## TPC-E 1.14.0 TPC Pricing 2.8.0

Report Date: July 26, 2023  
Revision Date: July 26, 2023

Availability Date:  
August 31, 2023

### Numerical Quantities Summary

Reported Throughput:  
**14,440.28 tpsE**

Configured Customers:  
**7,500,000**

Response Time (in seconds)	Minimum	Average	90 <sup>th</sup> Percentile	Maximum
Broker-Volume	0.01	0.01	0.02	1.08
Customer-Position	0.01	0.01	0.02	4.97
Market-Feed	0.01	0.01	0.02	5.63
Market-Watch	0.01	0.01	0.01	2.28
Security-Detail	0.01	0.01	0.01	0.22
Trade-Lookup	0.01	0.04	0.06	0.50
Trade-Order	0.01	0.03	0.08	5.25
Trade-Result	0.01	0.02	0.04	3.94
Trade-Status	0.01	0.01	0.01	1.67
Trade-Update	0.01	0.04	0.06	0.41
Data-Maintenance	0.01	0.02	N/A	0.31

Transaction Mix	Transaction Count	Mix %
Broker-Volume	50,934,054	4.900%
Customer-Position	135,131,664	13.000%
Market-Feed	10,397,023	1.000%
Market-Watch	187,105,570	18.000%
Security-Detail	145,526,156	14.000%
Trade-Lookup	83,157,734	8.000%
Trade-Order	104,986,487	10.100%
Trade-Result	103,970,050	10.002%
Trade-Status	197,499,968	19.000%
Trade-Update	20,789,341	2.000%
Data-Maintenance	120	N/A

### Test Duration and Timings

Ramp-up Time (hh:mm:ss)	00:41:04
Measurement Interval (hh:mm:ss)	02:00:00
Business Recovery Time (hh:mm:ss)	00:34:15
Total Number of Transactions Completed in Measurement Interval	1,039,498,047

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# **Clause 0 – Preamble**

## **Introduction**

TPC Benchmark E (TPC-E) is an On-Line Transaction Processing (OLTP) workload. It is a mixture of read-only and update intensive transactions that simulate the activities found in complex OLTP application environments. The database schema, data population, transactions, and implementation rules have been designed to be broadly representative of modern OLTP systems. The benchmark exercises a breadth of system components associated with such environments, which are characterized by:

- The simultaneous execution of multiple transaction types that span a breadth of complexity
- Moderate system and application execution time
- A balanced mixture of disk input/output and processor usage
- Transaction integrity (ACID properties)
- A mixture of uniform and non-uniform data access through primary and secondary keys
- Databases consisting of many tables with a wide variety of sizes, attributes, and relationships with realistic content
- Contention on data access and update

The TPC-E operations are modeled as follows: The database is continuously available 24 hours a day, 7 days a week, for data processing from multiple sessions and data modifications against all tables, except possibly during infrequent (e.g., once a month) maintenance sessions. Due to the worldwide nature of the application modeled by the TPC-E benchmark, any of the transactions may be executed against the database at any time, especially in relation to each other.

## **Goal of the TPC-E Benchmark**

The TPC-E benchmark simulates the OLTP workload of a brokerage firm. The focus of the benchmark is the central database that executes transactions related to the firm's customer accounts. In keeping with the goal of measuring the performance characteristics of the database system, the benchmark does not attempt to measure the complex flow of data between multiple application systems that would exist in a real environment.

The mixture and variety of transactions being executed on the benchmark system is designed to capture the characteristic components of a complex system. Different transaction types are defined to simulate the interactions of the firm with its customers as well as its business partners. Different transaction types have varying run-time requirements.

The benchmark defines:

- Two types of transactions to simulate Consumer-to-Business as well as Business-to-Business activities
- Several transactions for each transaction type
- Different execution profiles for each transaction type
- A specific run-time mix for all defined transactions

For example, the database will simultaneously execute transactions generated by systems that interact with customers along with transactions that are generated by systems that interact with financial markets as well as administrative systems. The benchmark system will interact with a set of driver systems that simulate the various sources of transactions without requiring the benchmark to implement the complex environment.

The performance metric reported by TPC-E is a "business throughput" measure of the number of completed Trade-Result transactions processed per second. Multiple transactions are used to simulate the business activity of processing a trade, and each transaction is subject to a response time constraint. The performance metric for the benchmark is expressed in transactions-per-second-E (tpsE). To be compliant with the TPC-E standard, all references to tpsE results must include the tpsE rate, the associated price-per-tpsE, and the availability date of the priced configuration.

TPC-E uses terminology and metrics that are similar to other benchmarks, originated by the TPC and others. Such similarity in terminology does not imply that TPC-E results are comparable to other benchmarks. The only benchmark results comparable to TPC-E are other TPC-E results that conform to a comparable version of the TPC-E specification.

## **Restrictions and Limitations**

Despite the fact that this benchmark offers a rich environment that represents many OLTP applications, this benchmark does not reflect the entire range of OLTP requirements. In addition, the extent to which a customer can achieve the results reported by a vendor is highly dependent on how closely TPC-E approximates the customer application. The relative performance of systems derived from this benchmark does not necessarily hold for other workloads or environments. Extrapolations to any other environment are not recommended.

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

# Clause 1 – Introduction

## Benchmark Sponsor

A statement identifying the benchmark Sponsor(s) and other participating companies must be reported in the Report.

This benchmark was sponsored by Lenovo.

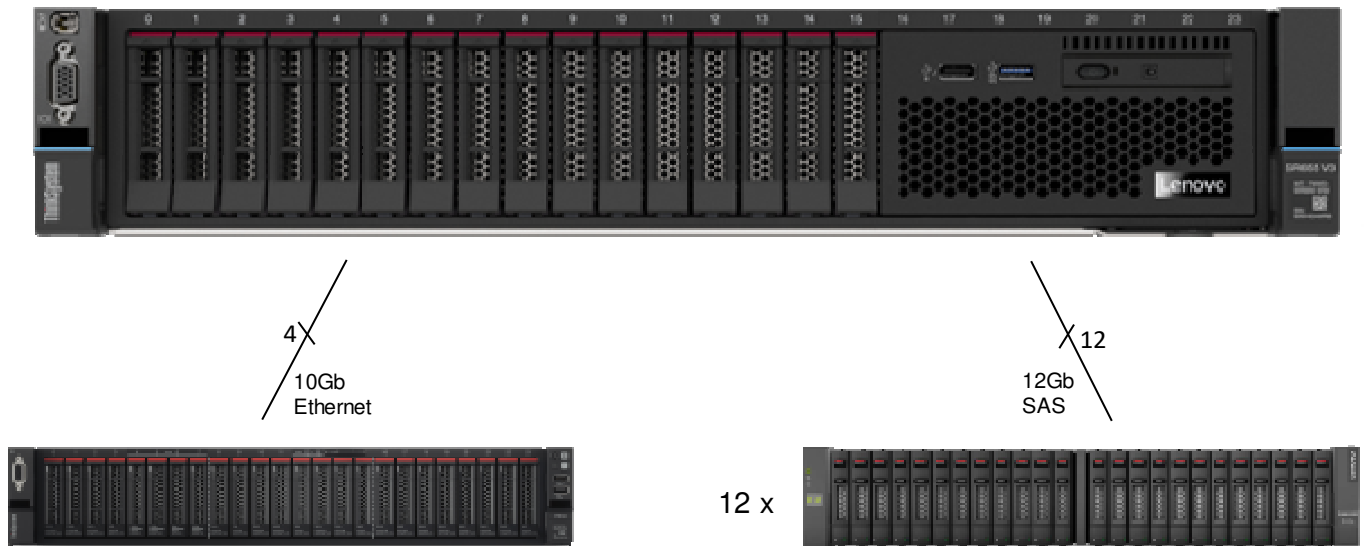
## Configuration Diagrams

Diagrams of both Measured and Priced Configurations must be reported in the Report, accompanied by a description of the differences.

### Measured Configuration

The measured configuration is shown in Figure 1-1.

Figure 1-1. Measured Configuration



#### TIER A (Client)

##### 1 x Lenovo ThinkSystem SR650, with:

- 2 x Intel Xeon Gold 6248R Processor 3.00GHz (2 Procs/48 Cores/96 Threads)
- 96GB Memory
- 2 x 600GB 10K SAS HDD (RAID-1)
- 1 x ThinkSystem RAID 940-8i
- 1 x Onboard Dual Gb Ethernet
- 1 x Intel x550 Dual 10Gb-T Enet
- 2 x Broadcom Dual 10Gb-T Enet

#### TIER B (Database Server and Storage)

##### 1 x Lenovo ThinkSystem SR655 V3, with:

- 1 x AMD EPYC 9754 128-Core 2.25GHz Processor (1 Proc/128 Cores/256 Threads)
- 1536GB Memory
- 2 x 480GB SATA SSD (RAID-1)
- 8 x 1600GB SAS SSD (RAID-10)
- 1 x ThinkSystem RAID 940-16i
- 6 x ThinkSystem RAID 940-8e
- 1 x Broadcom Quad 10Gb-T Enet
- 1 x Broadcom Dual 10Gb-T Enet

##### 12 x Lenovo Storage D1224

- DAS Enclosures, with:**
- 138 x 800GB 2.5" SAS SSD (6 x 23-drive RAID-5)
  - 120 x 1200GB 2.5" 10K SAS (5 x 24-drive RAID-5)
  - 24 x 900GB 2.5" 10K SAS (1 x 24-drive RAID-5)

**282 Total External Drives**

### Priced Configuration

The priced configuration is shown above in the Executive Summary.

## Differences between the Priced and Measured Configurations

Compared to the priced configuration, the measured configuration contained six extra external enclosures and drives used strictly for database backup files and flat file space used during the benchmark database load process. These extra enclosures and drives were not used at all during the benchmark runs.

## Substitution

*Some hardware components of the Priced Configuration may be substituted after the Test Sponsor has demonstrated to the Auditor's satisfaction that the substituting components do not negatively impact the Reported Throughput. All Substitutions must be reported in the Report and noted in the Auditor's Attestation Letter. Any information and/or measurement results used to prove the validity of a Component substitution must be included in the section of the FDR that describes the differences between the Measured Configuration and Priced Configuration. Original and substituted Components must be clearly identified.*

No components were substituted.

## Hardware and Software Configuration Steps

*A description of the steps taken to configure all of the hardware and software must be reported in the Report.*

*Any and all configuration scripts or step by step GUI instructions are reported in the Supporting Files (see Clauses 9.4.1 and 9.4.1.2). The description, scripts and GUI instructions must be sufficient such that a reader knowledgeable of computer systems and the TPC-E specification could recreate the hardware and software environments.*

Detailed instructions for installing and configuring the SUT hardware and software are included in the supporting files:

- Information specific to the Tier A client can be found in:  
SupportingFiles\Introduction\TierA\TierA\_SR650\_Setup.pdf
- Information specific to the Tier B database server and storage can be found in:  
SupportingFiles\Introduction\TierB\TierB\_SR655V3\_Setup.pdf

# **Clause 2- Database Design, Scaling, and Population**

## **Database Creation and Table Definitions**

*A description of the steps taken to create the database for the Reported Throughput must be reported in the Report. Any and all scripts or step by step GUI instructions are reported in the Supporting Files (see Clause 9.4.2). The description, scripts and GUI instructions must be sufficient such that a reader knowledgeable of database software environments and the TPC-E specification could recreate the database.*

The database was created and populated using the Microsoft TPC-E benchmark kit. Instructions for doing so are included in the supporting files. See SupportingFiles\Clause2\MSTPCE Database Setup Reference.pdf.

Changes and customizations were made to some of the kit files. First, the filegroups the database was loaded onto were changed in number from three filegroups to two. Second, several scripts were modified to customize the load to the specific hardware configuration of this SUT.

The default kit files create the database on three filegroups: fixed\_fg, scaling\_fg, and growing\_fg. That was changed so that only two filegroups were used, fixed\_fg and growing\_fg. All of the items that would have been loaded onto scaling\_fg were loaded instead onto fixed\_fg.

The modified files are included as part of SupportingFiles\Clause2:

- Utility\Create\_TID\_Ranges\_Table.sql
- DDL\ Create\_Indexes\_Scaling\_Tables.sql
- DDL\ Create\_Tables\_Scaling.sql

The files that were customized for this specific SUT hardware are included in the folder SupportingFiles\Clause2\7500000.Cust\Database:

- Tempdb\_load.sql specifies the tempdb files to use when loading the database
- Tempdb\_run.sql specifies the tempdb files to use when running the benchmark
- Shrinktempdb.sql removes tempdb files
- Backupdev.sql creates SQL Server database backup devices
- Dropbackupdev.sql removes those database backup devices
- Backup\_Database.sql backs up the tpce database to the specified device names
- Restore\_Database.sql restores the tpce database from the specified device names
- Create\_Database.sql maps the database filegroups and log to physical storage
- Flatfile.txt defines the locations of the flat files during the database load
- Remove\_Database.sql drops the current tpce database

## **Database Physical Organization**

*The physical organization of tables and User-Defined Objects, within the database, must be reported in the Report.*

The following tables and related indexes were on the growing\_fg filegroup:

- CASH\_TRANSACTION
- SETTLEMENT
- TRADE
- TRADE\_HISTORY
- TRADE\_REQUEST
- HOLDING
- HOLDING\_HISTORY
- HOLDING\_SUMMARY

The remaining tables and their related indexes were all on the fixed\_fg filegroup.

## Horizontal/Vertical Partitioning

*While few restrictions are placed upon horizontal or vertical partitioning of tables and rows in the TPC-E benchmark (see Clause 2.3.3), any such partitioning must be reported in the Report.*

Partitioning was not used for this benchmark.

## Replication

*Replication of tables, if used, must be reported in the Report (see Clause 2.3.4).*

Replication was not used for this benchmark.

## Table Attributes

*Additional and/or duplicated columns in any table must be reported in the Report along with a statement on the impact on performance (see Clause 2.3.5).*

No additional attributes were used for this benchmark.

## Cardinality of Tables

*The cardinality (e.g. the number of rows) of each table, as it existed after database load (see Clause 2.6), must be reported in the Report.*

The database was built with 7,500,000 customers. The cardinality is shown in Table 2-1.

**Table 2-1. Initial Cardinality of Tables**

<b>Table Name</b>	<b>Rows</b>
ACCOUNT_PERMISSION	53,247,486
ADDRESS	11,250,004
BROKER	75,000
CASH_TRANSACTION	119,232,012,827
CHARGE	15
COMMISSION_RATE	240
COMPANY	3,750,000
COMPANY_COMPETITOR	11,250,000
CUSTOMER	7,500,000
CUSTOMER_ACCOUNT	37,500,000
CUSTOMER_TAXRATE	15,000,000
DAILY_MARKET	6,704,437,500
EXCHANGE	4
FINANCIAL	75,000,000
HOLDING	6,634,963,334
HOLDING_HISTORY	173,686,299,749
HOLDING_SUMMARY	372,995,944
INDUSTRY	102
LAST_TRADE	5,137,500
NEWS_ITEM	7,500,000
NEWS_XREF	7,500,000
SECTOR	12
SECURITY	5,137,500
SETTLEMENT	129,600,000,000
STATUS_TYPE	5
TAXRATE	320
TRADE	129,600,000,000
TRADE_HISTORY	311,040,050,261
TRADE_REQUEST	0
TRADE_TYPE	5
WATCH_ITEM	750,000,477
WATCH_LIST	7,500,000
ZIP_CODE	14,741

## Distribution of Tables, Partitions and Logs

The distribution of tables, partitions and logs across all media must be explicitly depicted for the Measured and Priced Configurations.

The OS was stored on one RAID-1 array created on two 480GB 2.5” SATA SSDs in the server accessed by the internal ThinkSystem RAID 940-16i SAS/SATA controller. The OS partition was formatted NTFS.

The database log and run-time tempdb were both stored on one RAID-10 array created on eight 1600GB 2.5” SAS SSDs in the server accessed by the internal ThinkSystem RAID 940-16i SAS/SATA controller. This array was broken into three partitions, all NTFS: one for the database log, one for the database MDF, and one for the run-time tempdb files.

The database data was stored on six 23-drive RAID-5 arrays created on 138 800GB 2.5” SAS SSDs in six Lenovo Storage D1224 enclosures, 23 drives each, accessed by six ThinkSystem RAID 940-8e SAS/SATA controllers. Each of these data arrays was broken into three partitions, all NTFS: one for fixed\_fg, one for growing\_fg, and one for extra space.

No extra storage was needed to meet the 60-day space requirements.

In addition to the priced configuration described above, the measured configuration included additional hardware that was used during the database load process and to hold database backup files. This hardware performed no function during benchmark runs:

- One Lenovo Storage D1224 enclosure holding 24 900GB 2.5” 10K SAS HDDs, creating one 24-drive RAID-5 array, partitioned in half and formatted NTFS
- Five Lenovo Storage D1224 enclosures each holding 24 1200GB 2.5” 10K SAS HDDs, creating five 24-drive RAID-5 arrays, each partitioned in half and formatted NTFS

Adapter write caching was disabled for all controllers and arrays.

Further details on the storage configuration are available in the supporting files. See the files in the directory SupportingFiles\Introduction\TierB.

Table 2-2 depicts the database configuration of the measured and priced systems to meet the 8-hour steady state requirement.

**Table 2-2. Data Distribution for the Measured and Priced Configurations**

Disk #	Controller	Drives Enclosure RAID Level (Pricing)	Partition (File System)	Size	Use
0	940-8e #1	23 x 800GB SAS SSD Lenovo D1224 RAID-5	c:\mp\fx1 (NTFS) c:\mp\gw1 (NTFS) c:\mp\xt1 (NTFS)	271.48GB 12,820.31GB 3278.96GB	fixed_fg growing_fg Extra Space
1	940-8e #1	24 x 1200GB SAS HDD Lenovo D1224 RAID-5 (Measured)	c:\mp\bk1 (NTFS) c:\mp\bk2 (NTFS)	12,283.14GB 12,283.14GB	Backup & Load Space
2	940-8e #2	23 x 800GB SAS SSD Lenovo D1224 RAID-5	c:\mp\fx2 (NTFS) c:\mp\gw2 (NTFS) c:\mp\xt2 (NTFS)	271.48GB 12,820.31GB 3278.96GB	fixed_fg growing_fg Extra Space
3	940-8e #2	24 x 1200GB SAS HDD Lenovo D1224 RAID-5 (Measured)	c:\mp\bk3 (NTFS) c:\mp\bk4 (NTFS)	12,283.14GB 12,283.14GB	Backup & Load Space
4	940-8e #3	23 x 800GB SAS SSD Lenovo D1224 RAID-5	c:\mp\fx3 (NTFS) c:\mp\gw3 (NTFS) c:\mp\xt3 (NTFS)	271.48GB 12,820.31GB 3278.96GB	fixed_fg growing_fg Extra Space
5	940-8e #3	24 x 900GB SAS HDD Lenovo D1224 RAID-5 (Measured)	c:\mp\bk9 (NTFS) c:\mp\bk10 (NTFS)	9,209.78GB 9,209.78GB	Backup & Load Space
6	940-8e #4	24 x 1200GB SAS HDD Lenovo D1224 RAID-5 (Measured)	c:\mp\bk11 (NTFS) c:\mp\bk12 (NTFS)	12,283.14GB 12,283.14GB	Backup & Load Space



Disk #	Controller	Drives Enclosure RAID Level (Pricing)	Partition (File System)	Size	Use
7	940-8e #4	23 x 800GB SAS SSD Lenovo D1224 RAID-5	c:\mp\fx4 (NTFS) c:\mp\gw4 (NTFS) c:\mp\xt4 (NTFS)	271.48GB 12,820.31GB 3278.96GB	fixed_fg growing_fg Extra Space
8	940-8e #5	23 x 800GB SAS SSD Lenovo D1224 RAID-5	c:\mp\fx5 (NTFS) c:\mp\gw5 (NTFS) c:\mp\xt5 (NTFS)	271.48GB 12,820.31GB 3278.96GB	fixed_fg growing_fg Extra Space
9	940-8e #5	24 x 1200GB SAS HDD Lenovo D1224 RAID-5 (Measured)	c:\mp\bk5 (NTFS) c:\mp\bk6 (NTFS)	12,283.14GB 12,283.14GB	Backup & Load Space
10	940-8e #6	23 x 800GB SAS SSD Lenovo D1224 RAID-5	c:\mp\fx6 (NTFS) c:\mp\gw6 (NTFS) c:\mp\xt6 (NTFS)	271.48GB 12,820.31GB 3278.96GB	fixed_fg growing_fg Extra Space
11	940-8e #6	24 x 1200GB SAS HDD Lenovo D1224 RAID-5 (Measured)	c:\mp\bk7 (NTFS) c:\mp\bk8 (NTFS)	12,283.14GB 12,283.14GB	Backup & Load Space
12	940-16i	8 x 1600GB SAS SSD internal RAID-10	E: (NTFS) F: (NTFS) T: (NTFS)	3320.31GB 24.41GB 2611.99GB	tpce log MDF tempdb
13	940-16i	2 x 480GB SATA SSD internal RAID-1	C: (NTFS)	445.43GB	OS

## Database Interface and Data Model Implemented

A statement must be provided in the Report that describes:

- The Database Interface (e.g., embedded, call level) and access language (e.g., SQL, COBOL read/write) used to implement the TPC-E Transactions. If more than one interface / access language is used to implement TPC-E, each interface / access language must be described and a list of which interface /access language is used with which Transaction type must be reported.
- The data model implemented by the DBMS (e.g., relational, network, hierarchical).

Microsoft SQL Server 2022 Enterprise Edition is a relational database. The interface used was Microsoft SQL Server stored procedures accessed with Remote Procedure Calls embedded in C++ code using the Microsoft ODBC interface.

## Database Load Methodology

The methodology used to load the database must be reported in the Report.

The database was loaded using the flat files option on the EGenLoader command line. This will generate flat files first, then bulk insert the data into the tables. A further description is provided in SupportingFiles\Clause2\MSTPCE Database Setup Reference.pdf.

## **Clause 3 – Transaction Related Items**

### **Vendor-Supplied Code**

*A statement that vendor-supplied code is functionally equivalent to Pseudo-code in the specification (see Clause 3.2.1.6) must be reported in the Report.*

The stored procedure code for the transactions was functionally equivalent to the pseudo-code. The stored procedures can be seen in SupportingFiles\Clause3\StoredProcedures.

The code to interface the stored procedures can be found in:

- SupportingFiles\Clause3\BaseServer
- SupportingFiles\Clause3\TransactionsSP
- SupportingFiles\Clause3\TxnHarness

### **Database Footprint**

*A statement that the database footprint requirements (as described in Clause 3.3) were met must be reported in the Report.*

The database footprint requirements were met.

## **Clause 4 – SUT, Driver, and Network**

### **Network Configuration**

*The Network configurations of both the Measured and Priced Configurations must be described and reported in the Report. This includes the mandatory Network between the Driver and Tier A (see Clause 4.2.2) and any optional Database Server interface networks (see Clause 4.1.3.12).*

The network configurations of the measured and priced configurations were the same. Refer to Figure 1-1 for a diagram of the network connections.

The Tier A client had eight Ethernet ports. Two of these were provided by the onboard dual-port Gb Ethernet solution and the remaining six were provided by three dual-port 10Gb PCI-e Ethernet adapters.

The Tier B database server had six Ethernet ports. Four of these were provided by the onboard quad-port 10Gb OCP Ethernet solution and the remaining two were provided by a dual-port 10Gb PCI-e Ethernet adapter.

The Tier A client and Tier B database server were connected by four 10Gb Ethernet crossover connections. On one side, these cables were plugged into four of the 10Gb ports in the Tier A client, two per 10Gb PCI-e adapter. On the other side, these cables were plugged into two ports of the 10Gb quad-port OCP adapter and both ports of the 10Gb dual-port PCI-e adapter in the Tier B database server. These crossover networks, all running at 10Gb, handled all of the network traffic between Tier A and Tier B while a measurement was underway.

Two crossover connections were setup between the Tier A client and the Driver. On the client, these cables were both plugged into one dual-port 10Gb PCI-e adapter. These networks, which fulfill the mandatory network between the Driver and Tier A, were used by the client to report its results to the Driver as a benchmark run was underway.

Another network connected the Driver, the Tier B database server, the Tier A client, and a time server. This network, which was connected via a Gb Ethernet switch, used one of the onboard Ethernet ports on the Tier A client and on the Tier B database server. It was used for miscellaneous file sharing and time syncing. It was not used during a benchmark run.

## **Clause 5 – EGen**

### **EGen Version**

*The version of EGen used in the benchmark must be reported in the Report (see Clause 5.3.1).*

EGen v1.14.0 was used in the benchmark.

### **EGen Code and Modifications**

*A statement that all required TPC-provided EGen code was used in the benchmark must be reported in the Report.*

*If the Test Sponsor modified EGen, a statement EGen has been modified must be reported in the Report. All formal waivers from the TPC documenting the allowed changes to EGen must also be reported in the Report (see Clause 5.3.7.1). If any of the changes to EGen do not have a formal waiver that must also be reported in the Report.*

*If the Test Sponsor extended EGenLoader (as described in Appendix A.6), the use of the extended EGenLoader and the audit of the extension code by an Auditor must be reported in the Report (see Clause 5.7.4).*

All required TPC-provided EGen code was used in the benchmark.

EGen was not modified for this benchmark.

EGenLoader was not extended for this benchmark.

### **EGen Files**

*The make/project files used to compile/link EGenLoader and EGenValidate must be reported in the Supporting Files. The compiler/linker options and flags used to compile/link EGen Objects for the SUT must be reported in the Supporting Files.*

See the supporting files directory SupportingFiles\Clause3\prj for the files related to EGenLoader and EGenValidate.

See the supporting files directory SupportingFiles\Clause3\SUT\_CE\_Server for the files related to the SUT\_CE\_Server.

See the supporting files directory SupportingFiles\Clause3\SUT\_MEE\_Server for the files related to the SUT\_MEE\_Server.

# Clause 6 – Performance Metrics and Response Time

## EGen Driver Instances

The number of EGenDriverMEE and EGenDriverCE instances used in the benchmark must be reported in the Report (see Clause 6.2.5).

There were 16 EGenDriverCEs with a total of 1600 EGenDriverCE instances used in the benchmark.

There were 16 EGenDriverMEEs with a dynamic number of instances used in the benchmark.

## Reported Throughput

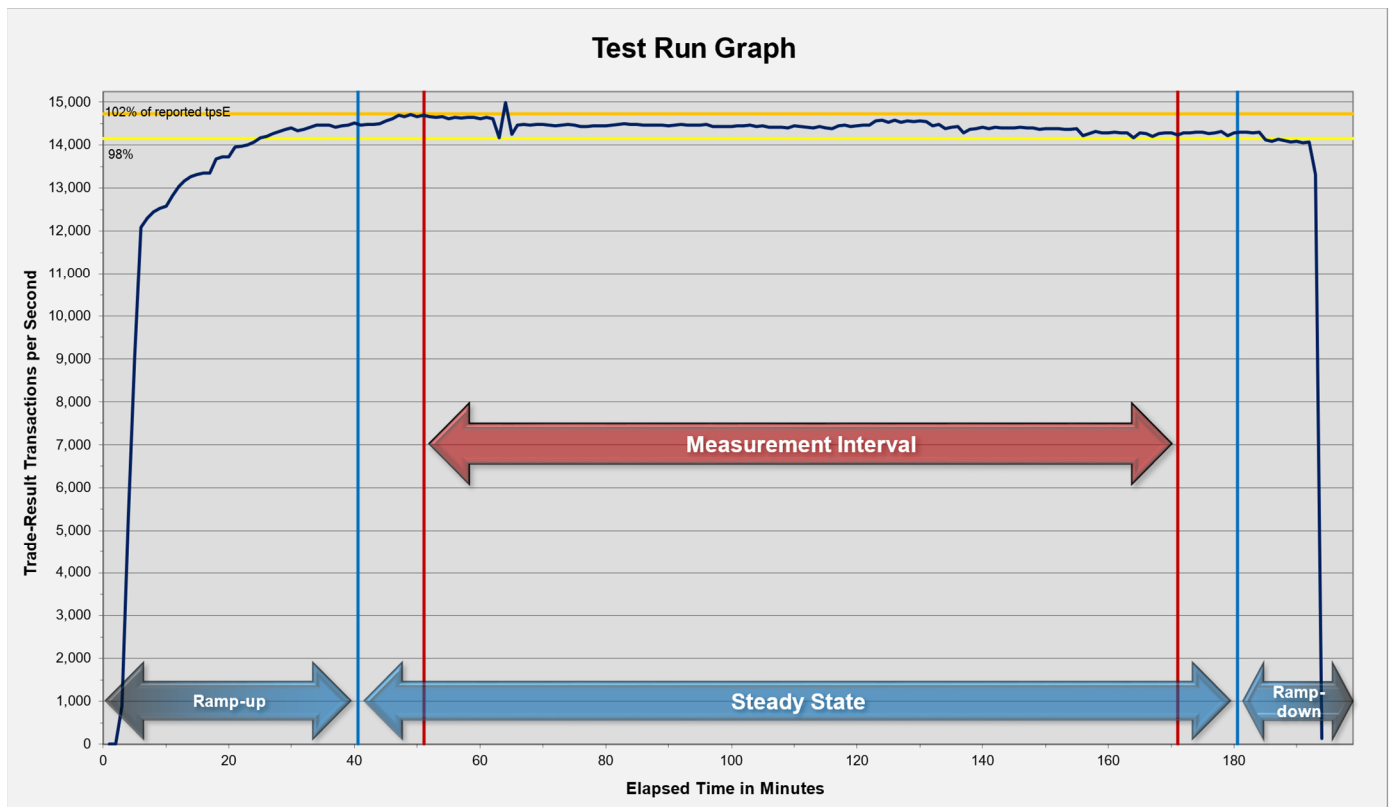
The Reported Throughput must be reported in the Report (see Clause 6.7.1.2).

The Reported Throughput was 14,440.28 tpsE.

## Throughput vs. Elapsed Time for Trade-Result Transaction

A Test Run Graph of throughput versus elapsed wall clock time must be reported in the Report for the Trade-Result Transaction (see Clause 6.7.2).

Figure 6-1. Test Run Graph



## Steady State Methodology

*The method used to determine that the SUT had reached a Steady State prior to commencing the Measurement Interval must be reported in the Report.*

During the run, Steady State was determined by observation of the Trade-Result transactions per second. After the run, Steady State was confirmed by:

1. Looking at the Test Run Graph and verifying that the Trade-Result transactions per second was steady prior to commencing the Measurement Interval.
2. Calculating the average Trade-Result transactions per second over 60-minute windows during Steady State, with the start of each window 10 minutes apart. Then it was confirmed that the minimum 60-minute average Trade-Result transactions per second was not less than 98% of the Reported Throughput, and that the maximum 60-minute average Trade-Result transactions per second was not greater than 102% of the Reported Throughput.
3. Calculating the average Trade-Result transactions per second over 10-minute windows during Steady State, with the start of each window 1 minute apart. Then it was confirmed that the minimum 10-minute average Trade-Result transactions per second was not less than 80% of the Reported Throughput, and the maximum 10-minute average Trade-Result transactions per second was not greater than 120% of the Reported Throughput.

## Work Performed During Steady State

*A description of how the work normally performed during a Test Run, actually occurred during the Measurement Interval must be reported in the Report (for example checkpointing, writing Undo/Redo Log records, etc.).*

Checkpoints had a duration of 430 seconds and were scheduled to run every 447 seconds.

Data-Maintenance was run every 60 seconds.

## Transaction Statistics

*The recorded averages over the Measurement Interval for each of the Transaction input parameters specified by clause 6.4.1 must be reported in the Report.*

Table 6-1 contains the transaction statistics.

Table 6-1. Transaction Statistics

Input Parameter	Value	Actual Percentage	Required Range
<b>Customer-Position</b>			
By Tax ID	1	49.99%	48% to 52%
Get History	1	50.01%	48% to 52%
<b>Market-Watch</b>			
Securities chosen by	Watch List	60.00%	57% to 63%
	Account ID	35.00%	33% to 37%
	Industry	5.00%	4.5% to 5.5%
<b>Security-Detail</b>			
Access LOB	1	1.00%	0.9% to 1.1%
<b>Trade-Lookup</b>			
Frame to execute	1	30.00%	28.5% to 31.5%
	2	30.01%	28.5% to 31.5%
	3	29.99%	28.5% to 31.5%
	4	10.00%	9.5% to 10.5%
<b>Trade-Order</b>			
Transactions requested by a third party		10.00%	9.5% to 10.5%
By Company Name		40.00%	38% to 42%
Buy On Margin	1	8.00%	7.5% to 8.5%
Rollback	1	0.99%	0.94% to 1.04%
LIFO	1	34.99%	33% to 37%
Trade Quantity	100	24.99%	24% to 26%
	200	25.01%	24% to 26%
	400	25.00%	24% to 26%
	800	25.00%	24% to 26%
Trade Type	Market Buy	30.00%	29.7% to 30.3%
	Market Sell	30.00%	29.7% to 30.3%
	Limit Buy	20.00%	19.8% to 20.2%
	Limit Sell	10.00%	9.9% to 10.1%
	Stop Loss	10.00%	9.9% to 10.1%
<b>Trade-Update</b>			
Frame to execute	1	33.01%	31% to 35%
	2	32.98%	31% to 35%
	3	34.00%	32% to 36%

## **Clause 7 – Transaction and System Properties**

*The ACID (Atomicity, Consistency, Isolation, and Durability) properties of transaction processing systems must be supported by the System Under Test during the running of this benchmark. It is the intent of this section to define the ACID properties informally and to specify a series of tests that must be performed to demonstrate that these properties are met.*

*The results of the ACID tests must be reported in the Report along with a description of how the ACID requirements were met, and how the ACID tests were run.*

### **Atomicity Requirements**

*The System Under Test must guarantee that Database Transactions are atomic; the system will either perform all individual operations on the data, or will ensure that no partially completed operations leave any effects on the data.*

All ACID tests were conducted according to specification. The following steps were performed to verify the Atomicity of the Trade-Order transactions:

- *Perform a market Trade-Order Transaction with the roll\_it\_back flag set to 0. Verify that the appropriate rows have been inserted in the TRADE and TRADE\_HISTORY tables.*
- *Perform a market Trade-Order Transaction with the roll\_it\_back flag set to 1. Verify that no rows associated with the rolled back Trade-Order have been added to the TRADE and TRADE\_HISTORY tables.*

The procedure for running the atomicity tests is documented in the file SupportingFiles\Clause7\MSTPCE ACID Procedures.pdf.

The atomicity scripts and outputs are located in the directory SupportingFiles\Clause7\Atomicity.

### **Consistency Requirements**

*Consistency is the property of the Application that requires any execution of a Database Transaction to take the database from one consistent state to another. A TPC-E database when first populated by EGenLoader must meet these consistency conditions.*

*These three consistency conditions must be tested after initial database population and after any Business Recovery tests.*

#### **Consistency condition 1**

*Entries in the BROKER and TRADE tables must satisfy the relationship:*

*$B\_NUM\_TRADES = count(*)$*

*For each broker defined by:*

*$(B\_ID = CA\_B\_ID)$  and  $(CA\_ID = T\_CA\_ID)$  and  $(T\_ST\_ID = "CMPT")$ .*

#### **Consistency condition 2**

*Entries in the BROKER and TRADE tables must satisfy the relationship:*

*$B\_COMM\_TOTAL = sum(T\_COMM)$*

*For each broker defined by:*

*$(B\_ID = CA\_B\_ID)$  and  $(CA\_ID = T\_CA\_ID)$  and  $(T\_ST\_ID = "CMPT")$ .*

#### **Consistency condition 3**

*Entries in the HOLDING\_SUMMARY and HOLDING tables must satisfy the relationship:*

*$HS\_QTY = sum(H\_QTY)$*

*For each holding summary defined by:*

*$(HS\_CA\_ID = H\_CA\_ID)$  and  $(HS\_S\_SYMB = H\_S\_SYMB)$ .*

Consistency conditions 1, 2, and 3 were tested using a batch file to issue queries to the database after the database was loaded and after the Business Recovery Test. The results of the queries demonstrated that the database was consistent for all three tests.

The procedure for running the consistency tests is documented in the file SupportingFiles\Clause7\MSTPCE ACID Procedures.pdf.

The consistency scripts and outputs are located in the directory SupportingFiles\Clause7\Consistency.



## Isolation Requirements

The isolation property of a Transaction is the level to which it is isolated from the actions of other concurrently executing Transactions.

Systems that implement Transaction isolation using a locking and/or versioning scheme must demonstrate compliance with the isolation requirements by executing the tests described in Clause 7.4.2. These isolation tests are designed to verify that the configuration and implementation of the System Under Test provides the Transactions with the required isolation levels defined in Clause 7.4.1.3.

Isolation tests 1 through 4 were successfully done following the procedure documented in the file SupportingFiles\Clause7\MSTPCE ACID Procedures.pdf.

The isolation scripts and outputs are located in the directory SupportingFiles\Clause7\Isolation.

## Durability Requirements

The SUT must provide Durability. In general, state that persists across failures is said to be Durable and an implementation that ensures state persists across failures is said to provide Durability. In the context of the benchmark, Durability is more tightly defined as the SUT's ability to ensure all Committed data persist across any Single Point of Failure.

## Data Accessibility

The System Under Test must be configured to satisfy the requirements for Data Accessibility. Data Accessibility is demonstrated by the SUT being able to maintain database operations with full data access after the permanent irrecoverable failures of any single Durable Medium containing database tables, recovery log data, or Database Metadata. Data Accessibility tests are conducted by inducing failures of Durable Media within the SUT. The failures of Clause 7.6.3 test the ability of the SUT to maintain access to the data. The specific failures addressed in Clause 7.6.3 are defined sufficiently significant to justify demonstration of Data Accessibility across such failures. However, the limited nature of the tests listed must not be interpreted to allow other unrecoverable single points of failure.

The Test Sponsor must report in the Report the Redundancy Level (see Clause 7.6.3.4) and describe the Data Accessibility test(s) used to demonstrate compliance. A list of all combinations of Durable Media technologies tested in Clause 7.6.3.5 must be reported in the Report.

A Data Accessibility Graph for each run demonstrating a Redundancy Level must be reported in the Report (see Clause 7.6.4.2).

This benchmark result used Redundancy Level 1. The test for Redundancy Level 1 is the test for permanent irrecoverable failure of any single Durable Medium.

The combinations of Durable Media technologies that were tested are shown in table 7-1. All unique combinations that contained database data, the database log, and/or the tempdb database were tested.

**Table 7-1. Combinations of Durable Media Technologies Tested for Data Accessibility**

Contents	Durable Media Type	Bus Type	Array Redundancy	Controller
Database Data	SSD	SAS	RAID-5	940-8e
Database Log & tempdb	SSD	SAS	RAID-10	940-16i

To prove Redundancy Level 1, the following steps were successfully performed:

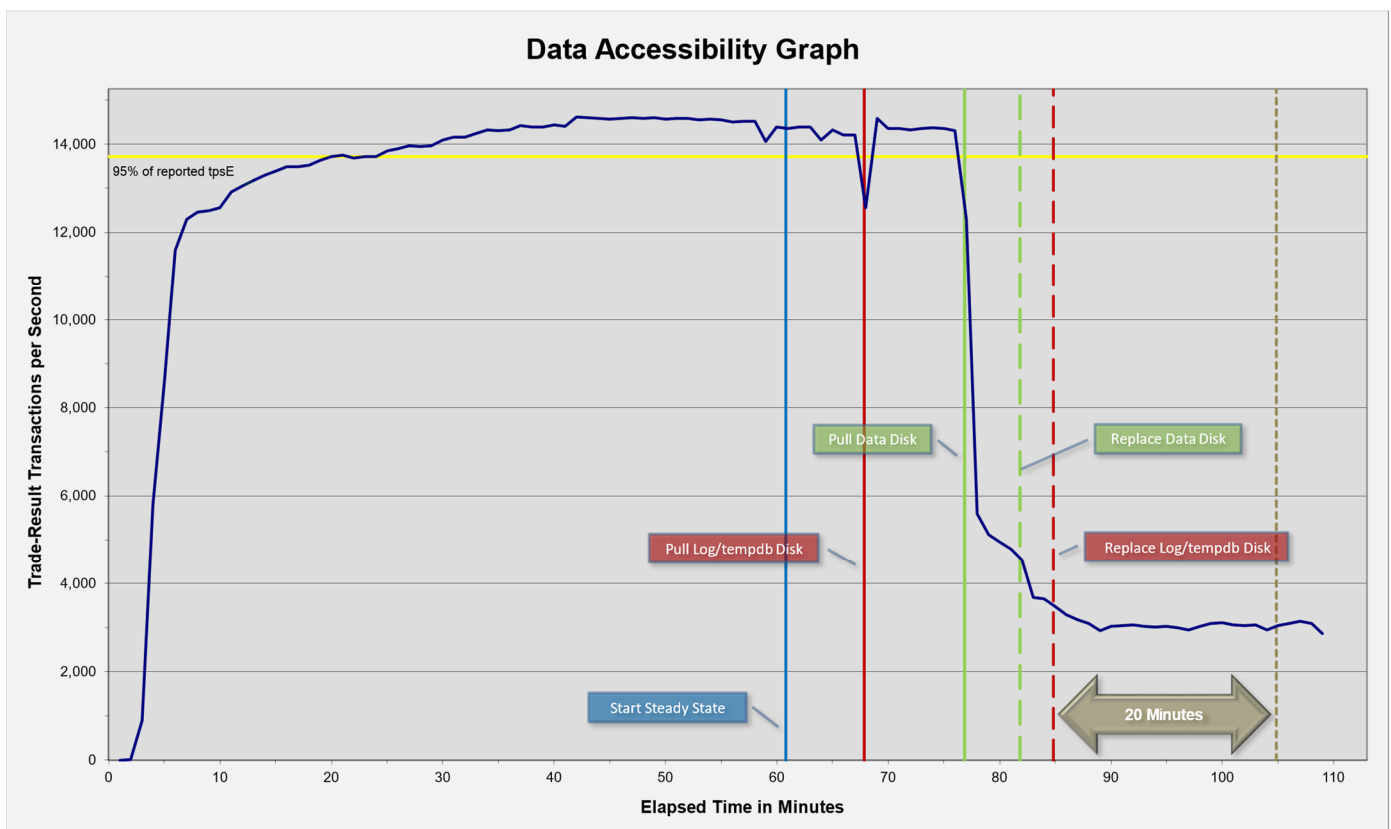
1. Restored the database to its freshly-loaded, proven-consistent state.
2. Determined the current number of completed trades in the database, *count1*.
3. Started a run, using the profile from the measured run, with checkpoints, and met the Data Accessibility Throughput Requirements for at least 5 minutes.
4. Induced the first failure, which in this case was failing a drive in the array containing the database log and tempdb by

physically removing it from the server. Since the array was RAID protected, transaction processing continued.

5. Waited until the Data Accessibility Throughput Requirements were met again for at least 5 minutes.
6. Induced the second failure, which in this case was failing a drive in a database data array by physically removing it from its enclosure. Since the database data array was RAID protected, transaction processing continued.
7. After a few minutes passed, a new drive was inserted into the data enclosure to replace the failed data drive. The array rebuilding process was started.
8. After a few minutes passed, a new drive was inserted into the server to replace the failed log/tempdb drive. The array rebuilding process was started.
9. Continued running the benchmark for at least 20 minutes.
10. Terminated the run gracefully.
11. Retrieved the new number of completed trades in the database by running `select count(*) as count2 from SETTLEMENT`.
12. Verified that  $(count2 - count1)$ , which is the number of actual completed Trade-Result Transactions done during the run, equaled the number of successful Trade-Result transactions reported by the Driver.
13. Allowed the recovery process to complete.

Figure 7-1 is a graph of the measured throughput versus elapsed time for Data Accessibility. The timings of the induced failures as well as the recovery process are indicated.

**Figure 7-1. Data Accessibility Graph**



The files related to this data accessibility test are located in SupportingFiles\Clause7\Durability\DataAccessibility.

## Business Recovery

*Business Recovery is the process of recovering from a Single Point of Failure and reaching a point where the business meets certain operational criteria.*

*The Test Sponsor must describe in the Report the test(s) used to demonstrate Business Recovery.*

*The Business Recovery Time must be reported on the Executive Summary Statement and in the Report. If the failures described in Clauses 7.5.3.1, 7.5.3.2 and 7.5.3.3 were not combined into one Durability test (usually powering off the Database Server during the run), then the Business Recovery Time for the failure described for instantaneous interruption is the Business Recovery Time that must be reported in the Executive Summary Statement. All the Business Recovery Times for each test requiring Business Recovery must be reported in the Report.*

*The Business Recovery Time Graph (see Clause 7.5.8.2) must be reported in the Report for all Business Recovery tests.*

The tests for “Loss of Processing,” “Loss of Vulnerable Storage Component,” and “Loss of all External Power to the SUT” were combined.

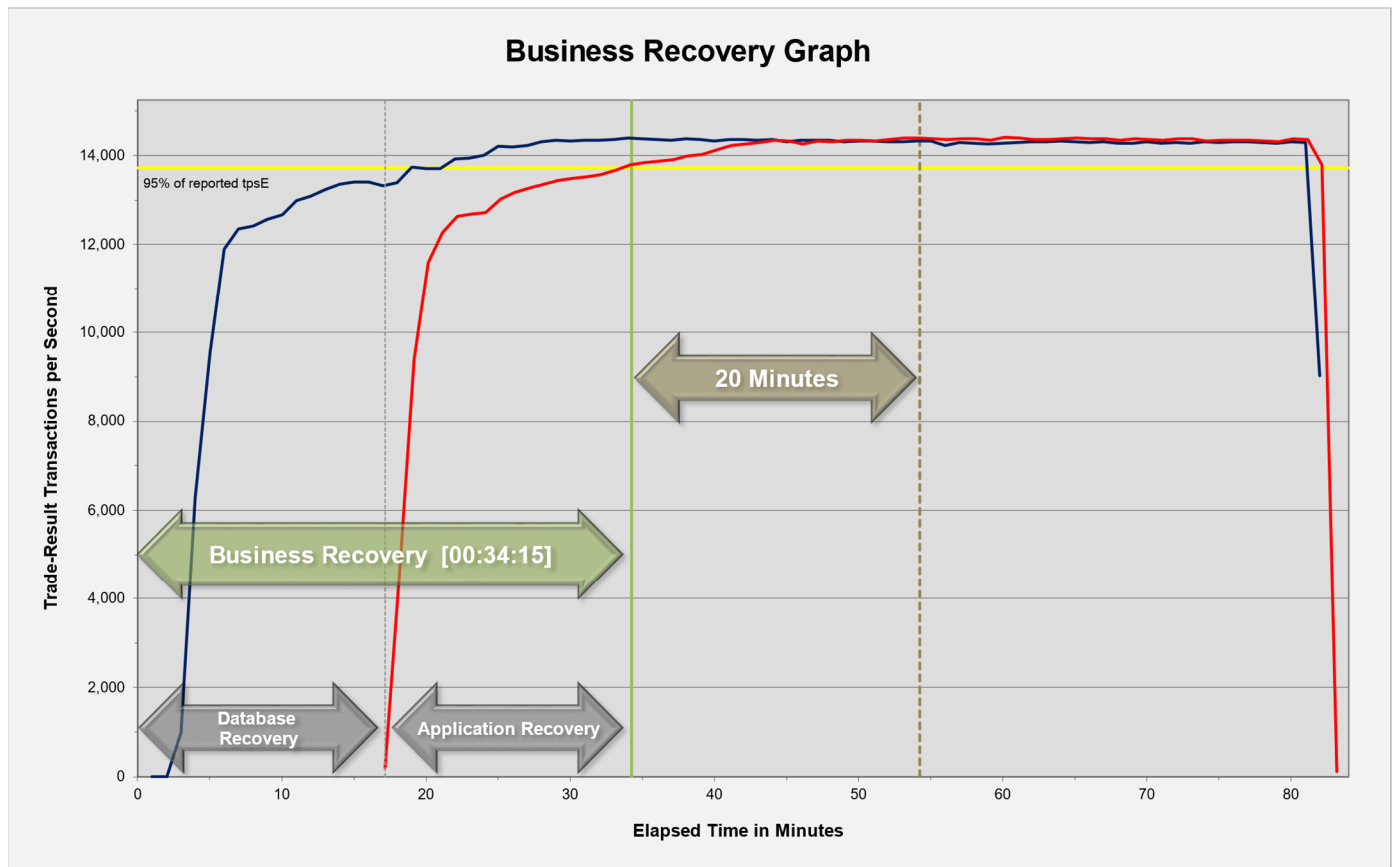
The following steps were successfully performed to test Business Recovery:

1. Restored the database to its freshly-loaded, proven-consistent state.
2. Determined the current number of completed trades in the database, *count1*.
3. Started a run, using the profile from the measured run, with checkpoints, and met the Durability Throughput Requirements for at least 20 minutes.
4. Pulled the power cords from the database server, causing it to immediately cease functioning. All the contents of the server’s main memory and caches were lost. All the disk controllers were inside the server, and none of their batteries were present, so all disk controller cache contents were lost.
5. Stopped submitting Transactions.
6. Plugged in and restarted the database server. It booted a fresh copy of the OS from the OS array.
7. Deleted all of the data and log files for tempdb.
8. Started SQL Server on the database server. It automatically began recovery of the tpce database. The timestamp in the SQL Server ERRORLOG of the first message related to database tpce is considered the start of Database Recovery.
9. Waited for SQL Server to finish recovering the database. The timestamp in the SQL Server ERRORLOG of the message indicating “Recovery is complete” is considered the end of Database Recovery.
10. Since there was a time gap between the end of Database Recovery and the start of Application Recovery, and the Drivers and Transactions needed to be started again (not just continued), the Trade-Cleanup Transaction was executed during this time gap.
11. Started a run, using the profile from the measured run, with checkpoints. The time when the first transaction is submitted to the database is considered the start of Application Recovery.
12. Let the run proceed until a 20-minute window existed such that the first minute of the window and the entire window both scored at least 95% of the Reported Throughput. The time of the beginning of that 20-minute window is considered the end of Application Recovery.
13. Terminated the run gracefully.
14. Verified that no errors were reported during steps 8 through 13.
15. Retrieved the new number of completed trades in the database by running *select count(\*) as count2 from SETTLEMENT*.
16. Verified that (*count2 – count1*), which is the number of actual completed Trade-Result Transactions done during the two runs, was greater than or equal to the combined number of successful Trade-Result Transactions reported by the Driver for both runs. In the case of an inequality, verified that the difference was less than or equal to the maximum number of transactions that could be simultaneously in-flight from the Driver to the SUT.
17. Verified database consistency.

The Database Recovery Time was 00:17:09. The Application Recovery Time was 00:17:06. The Business Recovery Time, which is the sum of the Database Recovery Time and the Application Recovery Time, was 00:34:15.

Figure 7-2 is a graph of the measured throughput versus elapsed time for Business Recovery.

**Figure 7-2. Business Recovery Time Graph**



The files related to this business recovery test are located in SupportingFiles\Clause7\Durability\BusinessRecovery.

# Clause 8 – Pricing

## 60-Day Space

Details of the 60-Day Space computations (see Clause 6.6.6.6) along with proof that the database is configured to sustain a Business Day of growth (see Clause 6.6.6.1) must be reported in the Report.

The 60-day space calculations shown in Table 8-1 are included in SupportingFiles\Clause8\tpce\_space.xls.

**Table 8-1. Disk Space Requirements**

Customers	7,500,000		Measured Throughput			14,440.28	Trade-Results/s	Reported Throughput			14,440.28	tpsE
Table	Initial Rows	Data Size (KB)	Index Size (KB)	Extra 5% (KB)	Total + 5% (KB)	Rows After	After Run (KB)	Growth (KB)	Bus. Day Growth (KB)	Req. Add. (KB)		
BROKER	75,000	6,160	8,592	738	15,490	75,000	14,752	-	-	738		
CASH_TRANSACTION	119,232,012,827	12,424,684,152	26,185,928	622,543,504	13,073,413,584	119,381,154,755	12,478,835,696	27,965,616	71,743,407	71,743,407		
CHARGE	15	8	8	1	17	15	16	-	-	1		
COMMISSION_RATE	240	16	56	4	76	240	72	-	-	4		
SETTLEMENT	129,600,000,000	6,179,828,904	13,041,184	309,643,504	6,502,513,592	129,762,110,259	6,208,443,168	15,573,080	39,951,411	39,951,411		
TRADE	129,600,000,000	15,475,567,416	8,633,699,328	1,205,463,337	25,314,730,081	129,762,955,728	24,191,739,864	82,473,120	211,577,766	211,577,766		
TRADE_HISTORY	311,040,050,261	9,354,588,736	24,391,112	468,948,992	9,847,928,840	311,431,137,969	9,406,765,736	27,785,888	71,282,330	71,282,330		
TRADE_REQUEST	-	-	-	-	-	-	-	-	-	-		
TRADE_TYPE	5	8	1,032	52	1,092	5	1,040	-	-	52		
ACCOUNT_PERMISSION	53,247,486	2,931,768	15,320	147,354	3,094,442	53,247,486	2,947,184	96	247	147,354		
CUSTOMER	7,500,000	1,228,800	357,808	79,330	1,665,938	7,500,000	1,586,648	40	103	79,330		
CUSTOMER_ACCOUNT	37,500,000	3,397,784	829,368	211,358	4,438,510	37,500,000	4,227,152	-	-	211,358		
CUSTOMER_TAXRATE	15,000,000	312,504	2,040	15,727	330,271	15,000,000	314,688	144	370	15,727		
HOLDING	6,634,963,334	445,047,600	304,266,344	37,465,697	786,779,641	6,639,105,287	758,865,696	9,551,752	24,504,207	24,504,207		
HOLDING_HISTORY	173,686,299,749	6,315,866,232	4,219,237,592	526,755,191	11,061,859,015	173,904,879,122	10,567,475,184	32,371,360	83,045,968	83,045,968		
HOLDING_SUMMARY	372,995,944	16,418,040	60,712	823,938	17,302,690	372,996,192	16,478,752	-	-	-		
WATCH_ITEM	750,000,477	21,151,952	77,632	1,061,479	22,291,063	750,000,477	21,229,872	288	739	1,061,479		
WATCH_LIST	7,500,000	186,520	167,904	17,721	372,145	7,500,000	354,424	-	-	17,721		
COMPANY	3,750,000	800,856	236,768	51,881	1,089,505	3,750,000	1,037,624	-	-	51,881		
COMPANY_COMPETITOR	11,250,000	301,816	271,384	28,660	601,860	11,250,000	573,200	-	-	28,660		
DAILY_MARKET	6,704,437,500	315,316,600	924,296	15,812,045	332,052,941	6,704,437,500	316,242,384	1,488	3,818	15,812,045		
EXCHANGE	4	8	8	1	17	4	16	-	-	1		
FINANCIAL	75,000,000	8,451,432	23,456	423,744	8,898,632	75,000,000	8,475,160	272	698	423,744		
INDUSTRY	102	8	24	2	34	102	32	-	-	2		
LAST_TRADE	5,137,500	320,560	1,888	16,122	338,570	5,137,500	322,448	-	-	16,122		
NEWS_ITEM	7,500,000	813,137,120	8,592	40,657,286	853,802,998	7,500,000	813,145,712	-	-	40,657,286		
NEWS_XREF	7,500,000	186,544	2,008	9,428	197,980	7,500,000	188,552	-	-	9,428		
SECTOR	12	8	24	2	34	12	32	-	-	2		
SECURITY	5,137,500	713,664	196,112	45,489	955,265	5,137,500	909,824	48	124	45,489		
STATUS_TYPE	5	8	8	1	17	5	16	-	-	1		
ADDRESS	11,250,004	648,480	2,424	32,545	683,449	11,250,004	650,968	64	165	32,545		
TAXRATE	320	24	56	4	84	320	96	16	42	42		
ZIP_CODE	14,741	488	104	30	622	14,741	592	-	-	30		
<b>TOTALS (KB)</b>		<b>51,381,094,216</b>	<b>13,224,009,112</b>	<b>3,230,255,166</b>	<b>67,835,358,494</b>		<b>64,800,826,600</b>	<b>195,723,272</b>	<b>502,111,395</b>	<b>560,716,129</b>		
Initial Database Size (MB)		63,090,921	61,612 GB									
Database Filegroups	LUN Count	Partition Size (MB)	MB Allocated	MB Loaded	MB Required							
	0	-	-	-	-					OK		
growing_fg	6	13,126,000	78,756,000	61,946,175	62,436,512					OK		
	0	-	-	-	-					OK		
fixed_fg	6	276,000	1,656,000	1,144,746	1,201,983					OK		
Settlements	162,110,259											
Data Space Required (MB)	Data Space Configured (MB)	Log Space Required (MB)	Log Space Configured (MB)									
Initial Growing Space	61,946,175											
Final Growing Space	62,137,309	Data LUNS	6	-	-	Initial Log Size	15,608	Log LUNS	1			
Delta	191,134	Disks per LUN	23	-	-	Final Log Size	1,150,220	Log Disks	8			
Data Space per Trade	0.001179035	Disk Capacity	761,984	-	-	Log Growth	1,134,612	Disk Capacity	1,524,630			
1 Day Data Growth	490,337	RAID Overhead	95.65%	0%	0%	Log Growth/Trade	0.006999014	RAID Overhead	50%			
60 Day Space	92,511,141	Total Space				100,581,888	1 Day Log Space	2,926,359	Log Space	6,098,518		
										OK		

## Configuration Components

*A detailed list of hardware, software, and/or Licensed Compute Services 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, Pricing Source, List Price including the ISO Currency Code, quantity, extended price including the ISO Currency Code, applicable Discounted price including the ISO Currency Code, 3-year maintenance price including the ISO Currency Code. 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 Clause 5.2.*

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.

## Pricing Methodology

*If the Benchmark Standard does not specify the allowed Pricing Methodology, then the Default Pricing Methodology will apply. The price of the entire Priced Configuration must be used, including all hardware (purchase price), software (license charges), Licensed Compute Services, and hardware maintenance/Software Maintenance Update charges over a period of 3 years (36 months).*

The default 3-year Pricing Methodology was used.

## Pricing Locale

*The Priced Locale and Priced Currency of the Priced Configuration must be disclosed. All Line Items of the system must be Generally Available in the Priced Locale by the Availability Date.*

The configuration was priced in \$USD for the United States of America.

## Currency Conversions

*The date, rate(s), and source of any Currency Conversions must be reported. Documentation of all Currency Conversions from the Currency Conversion Source, including the date of the conversion, must be included in the FDR.*

No currency conversions were done.

## Pricing Calculations

*The following items must be included in the Full Disclosure Report and Executive Summary:*

- *the benchmark performance metric*
- *respective calculations for the Pricing Methodology pricing time period (See Clauses 1.7 through 1.10)*
- *price/performance*
- *Availability Date*

*Pricing may use packages and Discounts that are Generally Available (see Clause 1.5). The priced items over which a Discount applies must be specified (see Clause 5.1.2). The percentage, amount, and basis (including type and justification) of all allowed Discounts listed must be disclosed (see Clause 5.1.2).*

The benchmark performance metric, pricing calculations, discount information, price/performance, and Availability Date are all included in the Executive Summary at the front of this report.

## Total Price

*The Total Price, including the ISO Currency Code, of the entire Priced Configuration and the Price/Performance metric must be reported.*

The Total Price and Price/Performance are both included in the Executive Summary at the front of this report.

## Availability Date

*The committed Availability Date of Line Items 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 and/or Licensed Compute Services with different Availability Dates, the reported Availability Date for the priced system must be a date at which all Line Items are committed to be Generally Available. Each Line Item used in the Priced Configuration is considered to be Available on the Availability Date unless an earlier date is specified.*

*For each of the Line Items that are not Orderable on the report date of the FDR, the following information must be included in the FDR:*

- *Name and Part Number of the item that is not Orderable*
- *The date when the Line Item can be ordered (on or before the Availability Date)*
- *The method to be used to order the Component (at or below the quoted price) when the order date arrives*
- *The method for verifying the price*

The total solution as priced will be generally available August 31, 2023.

## Supporting Files Index

*An index for all files required by Clause 9.4 Supporting Files must be provided in the Report.*

An index of the files contained in the supporting files is here: [SupportingFiles\SupportingFilesIndex.pdf](#)

## Auditor's Attestation Letter

*The Auditor's Attestation Letter, which indicates compliance, must be included in the Report.*

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

Michael Crutcher  
Manager - ISG Performance Development  
7001 Development Drive  
Morrisville, NC 27560

July 22, 2023

I verified the TPC Benchmark™ E v1.14.0 performance of the following configuration:

Platform: Lenovo ThinkSystem SR655 V3  
Operating System: Microsoft Windows Server 2022 Standard Edition  
Database Manager: Microsoft SQL Server 2022 Enterprise Edition

The results were:

**Performance Metric 14,440.28 tpsE**  
Trade-Result 90<sup>th</sup> %-tile 0.04 Seconds

**Tier B (Server)**

**Lenovo ThinkSystem SR655 V3**

CPU	1 x AMD EPYC 9754 128-Core 2.25 GHz Processor		
Memory	1,536 GB		
Storage	<b>Qty</b>	<b>Size</b>	<b>Type</b>
	2	480 GB	SATA SSD (RAID-1)
	8	1,600 GB	SAS SSD (RAID-10)
	138	800 GB	SAS SSD (6x 23-drive RAID-5)

**Tier A (Client)**

**Lenovo ThinkSystem SR650**

CPU	2 x Intel Xeon Gold 6248R (3.00 GHz, 24-core, 35.75 MB L3)
Memory	96 GB
Storage	2 x 600 GB 10K rpm SAS HDD (RAID-1)

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:

- All EGen components were verified to be v1.14.0.
- The transactions were correctly implemented.
- The database was properly scaled and populated for 7,500,000 customers.
- The mandatory network between the driver and the SUT was configured.



- The ACID properties were met.
- Input data was generated according to the specified percentages.
- The reported response times were correctly measured.
- All 90% response times were under the specified maximums.
- The measurement interval was 120 minutes.
- The implementation used Redundancy Level 1.
- The Business Recovery Time of 00:34:15 was correctly measured.
- The 60-day storage requirement was correctly computed.
- The system pricing was verified for major components and maintenance.

Additional Audit Notes:

None.

Respectfully Yours,

A handwritten signature in cursive script that reads "Doug Johnson". The signature is written in black ink and has a long, horizontal flourish extending to the right.

Doug Johnson, Certified TPC Auditor

# **Appendix A – Price Quotes**

*Written price quotations from all Third Party Pricing Sources must be included as the final appendix in the FDR.*

Microsoft Corporation  
One Microsoft Way  
Redmond, WA 98052-6399

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

**Microsoft**  
July 12, 2023

Lenovo Corporation  
Ray Engler  
7001 Development Drive  
Morrisville, NC 27560

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

All pricing shown is in US Dollars (\$).

Description	Unit Price	Quantity	Price
<b>Database Management System</b>			
<b>SQL Server 2022 Enterprise Edition</b> <i>2 Core License</i> <i>Open Program - No Level - ERP</i>	\$15,123.00	64	\$967,872.00
<b>Database Server Operating System</b>			
<b>Windows Server 2022 Standard</b> <i>16 Core License</i> <i>Open Program - No Level - ERP</i>	\$1,069.00	8	\$8,552.00
<b>Tier-A Operating System(s)</b>			
<b>Windows Server 2019 Standard</b> <i>2 Core License</i> <i>Open Program - No Level -ERP</i>	\$123.00	24	\$2,952.00
<b>Support</b>			
<b>Microsoft Problem Resolution Services</b> <i>Professional Support</i> <i>(1 Incident).</i>	\$259.00	1	\$259.00

All Microsoft software components are currently orderable and available. 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 120 days.

Reference ID: TPCE\_aopjjpft232412613\_2023