PROWESS

Comparing the TCO of Running Oracle® Database on Intel Versus IBM® Power Systems

Prowess analysis finds that Oracle Database running on 2nd Generation Intel® Xeon® Scalable processor–based solutions offers lower total cost of ownership (TCO) and better relative performance per TCO dollar compared to running on IBM® POWER9™ processor–based servers.

Executive Summary

Businesses use Oracle® Database to run some of their most mission-critical, high-performance, and high-availability workloads. Popular systems for enterprise Oracle Database fall into two camps: servers built around proprietary operating systems, such as IBM® Power Systems running the IBM® AIX® operating system, and systems built around pervasive operating systems, such as industry-standard systems powered by Intel® Xeon® processors. Prowess Consulting put these competing system paradigms to the test to see which can provide the best total cost of ownership (TCO) running the industry's most popular enterprise relational database, Oracle Database.[1] Prowess compared four-socket scale-up and two-socket scale-out IBM processor–based and Intel® processor–based systems. For four-socket systems, we found:

- **As much as 88 percent lower TCO** with a white-box, four-socket server powered by Intel Xeon Platinum 8268 processors over a four-socket IBM Power System E950 (see **appendix**)
- **Up to 11x better relative performance per TCO dollar** with a white-box, four-socket server powered by Intel Xeon Platinum 8268 processors over a four-socket IBM Power System E950 (see **Table 2**)
- **Up to 1.34x better performance per Oracle Database license** on a white-box, four-socket server powered by Intel Xeon Platinum 8268 processors over a four-socket IBM Power System E950 (see **Table 2**)
- **Up to 1.9x better performance per watt** on a white-box, four-socket server powered by Intel Xeon Platinum 8268 processors over a four-socket IBM Power System E950 (see **Table 2**)

4-socket	2-socket
As much as **88%** lower TCO	As much as **64%** lower TCO
Up to **11x** better relative performance per TCO dollar	Up to **4x** better relative performance per TCO dollar
Up to **1.34x** better performance per Oracle Database license	Up to **1.5x** better performance per Oracle Database license
Up to **1.9x** better performance per watt	Up to **2.7x** better performance per watt

Ready for the future with pervasive hardware and software

For two-socket systems, we found:

- **As much as 64 percent lower TCO** with a white-box, two-socket server powered by Intel Xeon Platinum 8268 processors over a two-socket IBM Power System S924 (see **appendix**)
- **Up to 4x better relative performance per TCO dollar** with a white-box, two-socket server powered by Intel Xeon Platinum 8268 processors over a two-socket IBM Power System S924 (see **Table 3**)
- **Up to 1.5x better performance per Oracle Database license** on a white-box, two-socket server powered by Intel Xeon Platinum 8268 processors over a two-socket IBM Power System S924 (see **Table 3**)
- **Up to 2.7x better performance per watt** on a white-box, two-socket server powered by Intel Xeon Platinum 8268 processors over a two-socket IBM Power System S924 (see **Table 3**)

This study underscores that capital expenditures (CapEx) are just the tip of the iceberg. Operating expenses (OpEx) for IBM Power Systems servers running AIX are higher than for more pervasive systems running Intel technology, with additional expenses including high labor costs for specialized administrators for AIX. Moreover, AIX can silo database systems and isolate them from the rest of organizations' data centers, and it creates the risk of vendor lock-in. Intel and Oracle offer validated, cloud-ready operating system, compute, storage, and networking stacks that reduce complexity when deploying Oracle Database on Intel-based systems.

Market Landscape

Reliable and fast access to data is an ever-more-important part of every business. Relational database management systems (RDBMSs) continue to play a vital role in powering business operations in enterprises, and Oracle Database remains the most popular RDBMS.[1]

Oracle Database 19c

Oracle Database 19c continues the line of innovations and improvements that have marked the Oracle Database 12c family of databases. Building upon the multitenant, in-memory, and sharding capabilities of its predecessors, Oracle Database 19c provides critical enterprise database features.

Oracle Database 19c (with its first stable release in 2019) is also the final release of the Oracle Database 12c family of databases (Oracle Database 12c, 18c, and 19c). This status means that Oracle Database 19c will enjoy four years of premium support and a minimum of three years of extended support.[2] It is a database investment that will be powering enterprises and businesses of many sizes for years to come.

Dueling Paradigms: IBM® POWER® Processors vs. Intel® x86 Architecture

The latest IBM® POWER® processor (the IBM® POWER9™ processor) continues IBM's tradition of reliability inherited from some mainframe features and a focus on the performance of individual cores within the processor. However, getting all the enterprise functionality out of servers running on IBM POWER processors requires specialized and increasingly rare administrative skills, such as using IBM's proprietary AIX operating system. AIX can provide other functionality, such as activating and deactivating processors and memory without restarting the server, but such capabilities can come at a steep price.

By optimizing its mainstream x86 processors for the data center and other demanding compute-intensive workloads, Intel has chosen an alternative approach of focusing on overall system performance. And rather than relying on a proprietary operating system, servers powered by 2nd Generation Intel Xeon Scalable processors use pervasive industry-standard operating systems and management tools used by the majority of hardware that organizations run. In addition, this is the processor-design strategy employed by Oracle itself, which uses Intel x86 processors in its high-end Oracle® Exadata® line of engineered database systems.

Prowess wanted to put these competing design philosophies to the test to see which strategy—compute specialization or overall performance—can deliver a better TCO for organizations seeking to modernize their business-critical database servers.

Overview of the Business-Case Comparison

This study compares both the CapEx to acquire the servers to run Oracle Database 19c and the necessary licenses, in addition to the OpEx associated with running those appliances over a three-year period. The factors we considered in the OpEx analysis include:

- Software licensing and support
- Management
- Architectural differences

This study examines the business-case TCO considerations for a four-socket IBM Power System E950 compared to a four-socket white-box server powered by 2nd Generation Intel Xeon Platinum processors for scale-up scenarios and a two-socket IBM Power System S924 compared to a two-socket white-box server built on 2nd Generation Intel Xeon Platinum processors for scale-out scenarios.

Scale-Up Versus Scale-Out

Scale-up server configurations add resources (such as additional compute, memory, and input/output [I/O]) to a single server as needs increase. Scale-out server configurations increase resources by connecting servers together into a single clustered database.

Details of the Comparison Methodology

Stand-out points of comparison include:

- CapEx
- OpEx
- Three-year TCO
- Performance

CapEx: Cost of Acquisition

Assessing four-socket scale-up systems, a white-box server powered by Intel Xeon Platinum 8268 processors (96 cores) with 768 GB of memory provides 94-percent savings on purchase price compared to an IBM Power System E950 with 48 cores and 768 GB of memory.[3] The CapEx comparison between systems running IBM POWER processors and 2nd Generation Intel Xeon Scalable processors played out similarly for two-socket scale-out servers. An Intel Xeon Platinum 8268 processor–based white-box server with 48 cores and 384 GB of memory provides 85-percent savings compared to an IBM Power System S924 with 24 cores and 384 GB of memory.[4] (See the **appendix** for a breakdown of the pricing.)

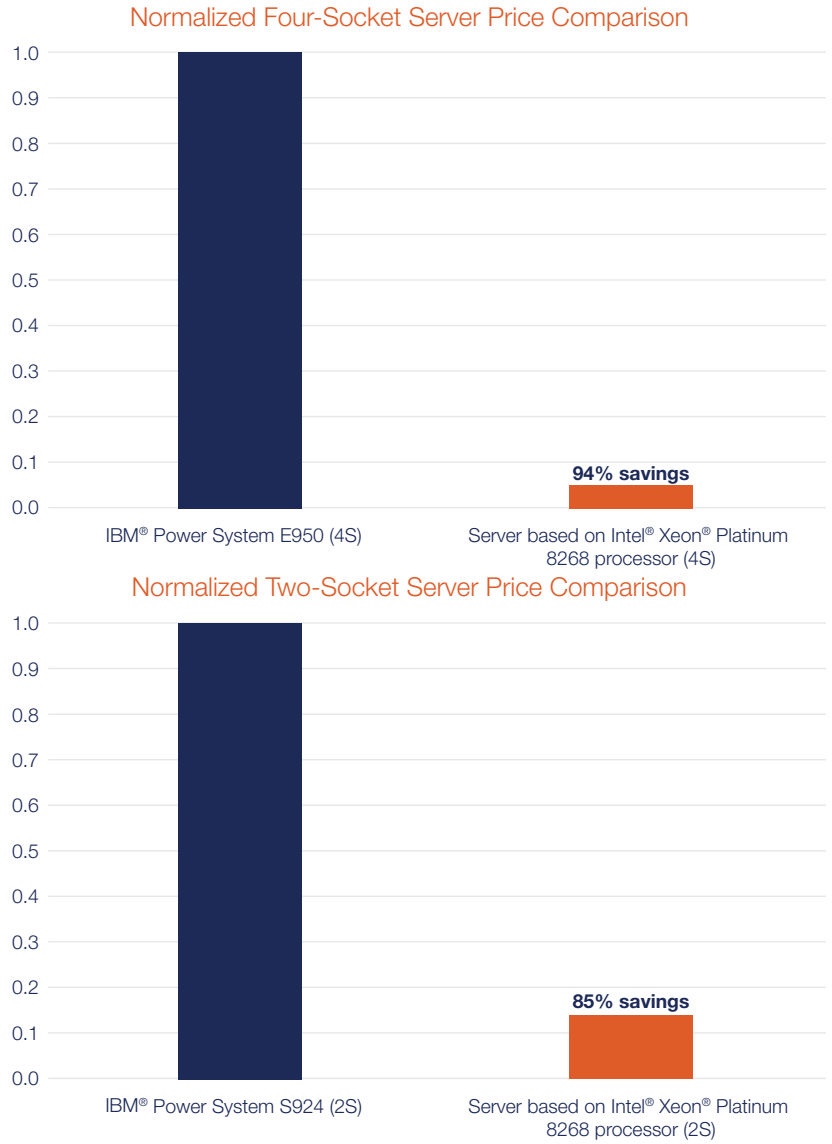

Figure 1. Normalized purchase-price comparisons of four-socket, 768-GB systems and two-socket, 384-GB systems (lower is better)

OpEx: Ongoing Expenses

When evaluating enterprise solution pricing, in addition to software licensing and support, management, and architectural differences included in this study, other key OpEx costs to consider are labor and storage.

Software Licensing and Support Costs

As with other aspects of the IBM POWER processor stack, AIX costs more than competing products. For example, Table 1 compares the cost of AIX 7 Enterprise Edition for an IBM Power System E950 with 48 cores over three years versus a comparable system running Red Hat® Enterprise Linux® 8.2 Server with premium support and all enterprise features, along with enterprise virtualization software from VMware, which is nearly 60 percent less expensive than the AIX offering.

Table 1. Three-year licensing costs of IBM® AIX® 7.2 Enterprise Edition versus Red Hat® Enterprise Linux® and VMware® software for 48 cores

Software	Initial Cost	Annual Support Cost	Total Three-Year Cost[5,6]
IBM			
IBM® AIX® 7.2 Enterprise Edition (48 cores)	$45,504	$11,376	**$109,044**
IBM® PowerVM® Enterprise	–	$4,800	
IBM Proactive 24x7 Support	–	$5,004	
Red Hat® Enterprise Linux® (RHEL) + VMware			
RHEL for Virtual Datacenters Premium Smart Management bundle	–	$5,224	**$43,991**
RHEL for Virtual Datacenters Premium High Availability	–	$1,245	
RHEL for Virtual Datacenters Premium Resilient Storage	–	$2,495	
VMware vSphere® Enterprise Plus Edition™ (with Production Support)	$3,595	$899	
VMware vCenter® Standard (with Production Support)	$6,175	$1,544	

Labor and Management Costs

Beyond the additional complexity of managing AIX itself, the specialized skills required to manage systems running AIX can cost more as well.[7,8] Beyond the cost of specialized administrative skills, the premium for an AIX admin is probably higher still, because the responsibility of administering other Intel-based servers running Linux would be folded into the broader IT organization, rather than being the sole responsibility of a specialist administrator.

AIX can also introduce an opportunity cost for organizations that use it, as a server running AIX can only be used for the workloads dedicated to that particular hardware, and it can detract from organizational flexibility in moving or consolidating workloads as business imperatives change. Architectural differences between AIX and other operating systems (such as Linux) can also necessitate additional programming overhead for applications in order to port them between operating systems.

Three-Year TCO

Altogether, with CapEx and OpEx totaled over a three-year period, a white-box server powered by Intel Xeon Platinum 8268 processors (96 cores) with 768 GB of memory provides up to 88 percent lower TCO than an IBM Power System E950 with 48 cores and 768 GB of memory.[3] The TCO comparison between systems running IBM POWER processors and 2nd Generation Intel Xeon Scalable processors is less dramatic but still considerable for two-socket scale-

out servers. An Intel Xeon Platinum 8268 processor–based white-box server with 48 cores and 384 GB of memory supplies up to 64 percent lower TCO than an IBM Power System S924 with 24 cores and 384 GB of memory.[4] (See the **appendix** for a breakdown of the pricing.)

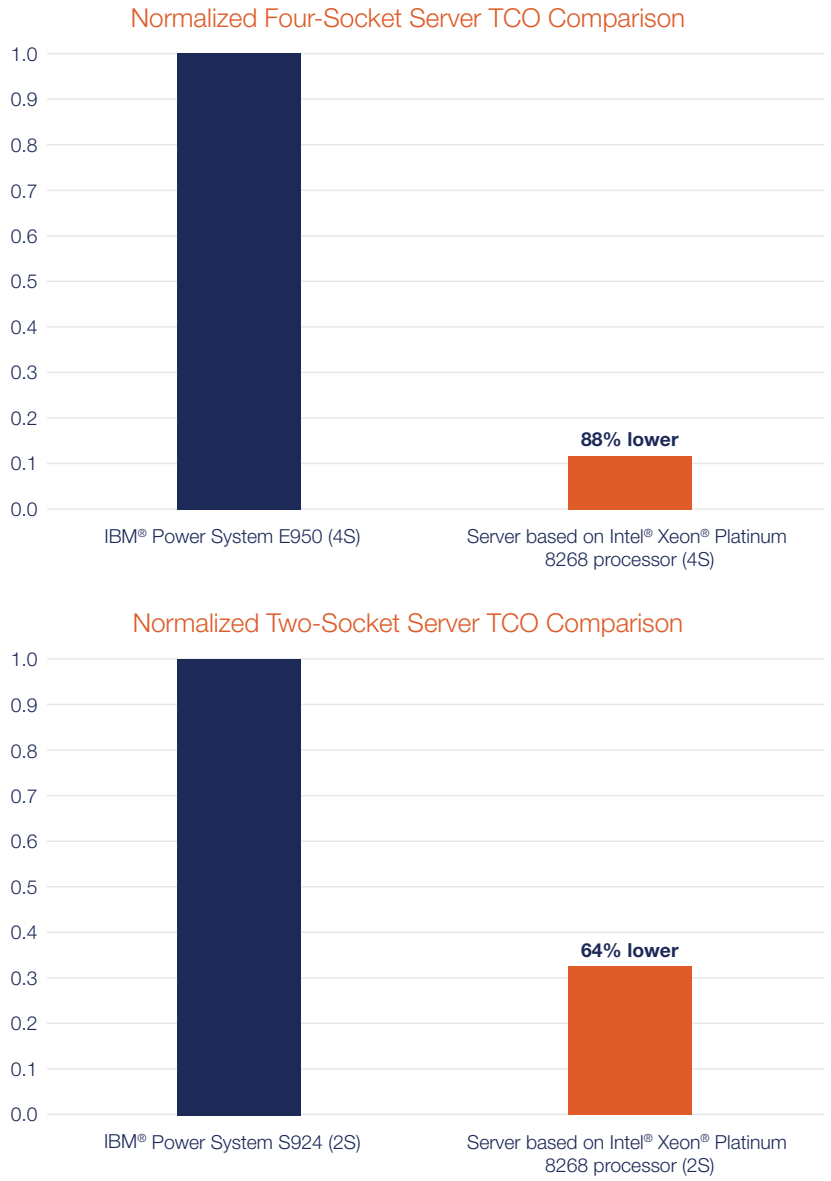

Figure 2. Normalized TCO comparisons of four-socket, 768-GB systems and two-socket, 384-GB systems (lower is better)

Performance

Tables 2 and 3 detail the effective online transaction processing (OLTP) database performance of an IBM POWER9 processor versus an Intel Xeon Platinum 8268 processor in two-socket (2S) and four-socket (4S) systems running the HammerDB benchmark, relative to TCO, Oracle Database licensing costs, and power consumption. Compared to the four-socket IBM Power System E950, the system powered by the Intel Xeon Platinum 8268 processor evaluated in this

study can provide more than 11x better relative performance per TCO dollar (**Table 2**). For two-socket systems, the Intel Xeon Platinum 8268 processor-based system evaluated here provided more than 4x better relative performance per dollar of TCO than the IBM Power System S924 evaluated (**Table 3**).

Systems powered by the Intel Xeon Platinum 8268 processor can provide up to 1.5x more performance per Oracle Database license (Table 3). Oracle not only licenses Oracle Database by active CPU core, it also weights this number of active CPU cores by a *processor-core licensing factor*. Tables 2 and 3 show the relevant core licensing factors for IBM POWER and Intel Xeon processors. Because Oracle Database licenses can present a significant operational investment for companies, increasing performance per license can represent a substantial return on that investment.

Table 2. Performance comparisons between four-socket systems

	IBM® Power System E950 (4S)	Intel® Xeon® Platinum 8268 Processor–Based Server (4S)
Sockets per system	4	4
Cores per system	48	96
Relative OLTP database performance[9]	1.00	1.34
Relative OLTP database performance per TCO dollar (versus IBM Power System E950)[10]	**1.00**	**11.53**
Oracle® Database licensing core factor	1.0	0.5
Number of Oracle Database licenses required (number of system cores times Oracle core factor)	48	48
Relative OLTP database performance per Oracle Database license (versus IBM Power System E950)[11]	**1.00**	**1.34**
Maximum system power consumption[12,13]	1,714 W	1,200 W
Relative performance per watt consumed (versus IBM Power System E950)[14]	**1.00**	**1.93**

Tables 2 and 3 also show the relative performance of IBM Power Systems and white-box Intel-based systems. Servers powered by the Intel Xeon Platinum 8268 processor provide more performance per watt of power consumed. As shown in Table 3, this is particularly true for two-socket servers built on Intel Xeon Platinum 8268 processors, which provided nearly 4x more performance per watt than the two-socket IBM Power System S924.

Table 3. Performance comparisons between two-socket systems

	IBM® Power System S924 (2S)	Intel® Xeon® Platinum 8268 Processor–Based Server (2S)
Sockets per system	2	2
Cores per system	24	48
Relative OLTP database performance (2S)[15]	1.00	1.51
Relative OLTP database performance per TCO dollar (versus IBM Power System S924)[16]	**1.00**	**4.21**
Oracle Database licensing core factor	1.00	0.50
Number of Oracle Database licenses required (number of system cores times Oracle core factor)	24	24
Relative OLTP database performance per Oracle Database license (versus IBM Power System S924)[27]	**1.00**	**1.51**
Maximum system power consumption[18,19]	1,073 W	595 W
Relative performance per watt consumed (versus IBM Power System S924)[20]	**1.00**	**2.72**

2nd Generation Intel Xeon Scalable Processors Overview and Competitive Differentiators

2nd Generation Intel Xeon Scalable processors bring their own advantages for running Oracle Database, notably those stemming from the collaboration between Intel and Oracle and the unique capabilities of Intel® Optane™ persistent memory (PMem).

Advantages of Running Oracle Database 19c on Intel Xeon Scalable Processors

Intel and Oracle have a history of joint investment spanning more than 20 years. This close collaboration helps ensure that Intel architecture capabilities and features are enabled in both Oracle Database and the broader software offerings from Oracle. The Intel® Advanced Vector Extensions 512 (Intel® AVX-512) instruction set in 2nd Generation Intel Xeon Scalable processors can especially benefit in-memory columnstore indexes in Oracle Database 19c. For example, Intel AVX-512 provides a 20 percent performance boost over the previous-generation Intel AVX2 instruction set.[21] And Intel AVX-512, coupled with Intel® AES New Instruction (Intel® AES-NI), accelerates data encryption and decryption to increase data protection compared to software security measures alone.[21]

Beyond instruction sets and silicon-based encryption acceleration, 2nd Generation Intel Xeon Scalable processors boost Oracle Database performance in other ways. The mesh architecture in 2nd Generation Intel Xeon Scalable processors improves performance between all CPU cores (and threads) and memory. And importantly for in-memory database workloads, the large memory capacity of 2nd Generation Intel Xeon Scalable processors (up to 36 TB for an eight-socket server) can accommodate extremely large databases; keeping the database in memory avoids the need to read and write to storage, which can increase application latency (particularly during taxing OLTP activities).

In addition to size, 2nd Generation Intel Xeon Scalable processors support core enterprise features of Oracle Database 19c:

- 2nd Generation Intel Xeon Scalable processor optimizations support multitenancy in Oracle Database 19c in order to deliver isolation, agility, and economies of scale.
- Intel® Run Sure Technology complements reliability, availability, and serviceability (RAS) features in Oracle Database 19c, such as sparing and mirroring.
- Intel® Ultra Path Interconnect (Intel® UPI) speeds up data transfers by connecting distributed shared memory, internal cores, I/O hubs, and other Intel processors for additional performance in Oracle Database 19c.

In addition to optimizations and enterprise features on the compute side, 2nd Generation Intel Xeon Scalable processors open additional memory options that are not available with other processors, such as the opportunities for improving TCO provided by Intel Optane PMem.

Intel Optane Technology Benefits for Oracle Database 19c

Intel Optane PMem provides a new class of storage that provides memory-like performance at a fraction of the cost of DRAM. Intel Optane PMem enables organizations to deploy the equivalent of more memory closer to the processor to enhance analytics performance in Oracle Database 19c. Intel Optane PMem can provide a dramatically lower cost per gigabyte than DRAM,[22] which can make larger in-memory databases viable for a wider range of businesses, particularly as a means of accommodating growing databases in the future.

The collaboration between Intel and Oracle also helps ensure that Intel Optane Solid-State Drives (SSDs) are optimized for Oracle Database 19c. Intel Optane SSDs provide additional performance, reliability, and built-in encryption to support Oracle Database 19c.

Conclusion

The lower system cost balanced with compelling system-level performance powered by Intel Xeon processors—both initially and over time—mean that organizations can get more out of their hardware investment by using mainstream hardware. For four-socket systems, we found:

- **As much as 88 percent lower TCO** with a white-box, four-socket server powered by Intel Xeon Platinum 8268 processors over a four-socket IBM Power System E950 (see **appendix**)
- **Up to 11x better relative performance per TCO dollar** with a white-box, four-socket server powered by Intel Xeon Platinum 8268 processors over a four-socket IBM Power System E950 (see **Table 2**)
- **Up to 1.34x better performance per Oracle Database license** on a white-box, four-socket server powered by Intel Xeon Platinum 8268 processors over a four-socket IBM Power System E950 (see **Table 2**)
- **Up to 1.9x better performance per watt** on a white-box, four-socket server powered by Intel Xeon Platinum 8268 processors over a four-socket IBM Power System E950 (see **Table 2**)

For two-socket systems, we found:

- **As much as 64 percent lower TCO** with a white-box, two-socket server powered by Intel Xeon Platinum 8268 processors over a two-socket IBM Power System S924 (see **appendix**)
- **Up to 4x better relative performance per TCO dollar** with a white-box, two-socket server powered by Intel Xeon Platinum 8268 processors over a two-socket IBM Power System S924 (see **Table 3**)
- **Up to 1.5x better performance per Oracle Database license** on a white-box, two-socket server powered by Intel Xeon Platinum 8268 processors over a two-socket IBM Power System S924 (see **Table 3**)
- **Up to 2.7x better performance per watt** on a white-box, two-socket server powered by Intel Xeon Platinum 8268 processors over a two-socket IBM Power System S924 (see **Table 3**)

As compared to IBM's proprietary server offerings, which can be expensive, harder to administer, and can create "data islands," the Intel systems evaluated by Prowess provide organizations with solutions built on pervasive hardware and software that help prevent server lock-in and help establish a more homogeneous, easier-to-manage data center that can pivot to meet future opportunities. Intel and Oracle offer validated, cloud-ready operating system, compute, storage, and networking stacks that reduce complexity when deploying Oracle on Intel-based systems.

Appendix

Three-year TCO comparison of four-socket, 768-GB systems. TCO does not include costs associated with Oracle Database software licensing and support.

Component	IBM® Power System E950 (48 Cores)	Intel® Xeon® Platinum 8268 Processor–Based Server (96 Cores)
Processors	$356,000	$25,208
Processor activation	$76,800	–
Memory	$22,332	$13,680
Memory activation	$16,000	–
Storage	$2,016	$2,016
Chassis and other hardware costs	$136,762	$7,603
Hardware Total	**$609,910**	**$39,291**
Purchase-price difference (hardware)		***$570,619***
IBM® AIX® 7.2 Enterprise Edition (48 cores, 3 years)	$79,632	–
IBM® PowerVM® Enterprise (3 years)	$14,400	–
IBM Proactive 24x7 Support (3 years)	$15,012	–
Red Hat® Enterprise Linux® (RHEL) for Virtual Datacenters Premium Smart Management bundle (3 years)	–	$15,672
RHEL for Virtual Datacenters Premium High Availability (3 years)	–	$3,735
RHEL for Virtual Datacenters Premium Resilient Storage (3 years)	–	$7,485
VMware vSphere® Enterprise Plus Edition™ (with Production Support, 3 years)	–	$6,292
VMware vCenter® Standard (with Production Support, 3 years)	–	$10,807
Software total	**$109,044**	**$43,991**
Purchase-price difference (software)		***$65,053***
Maximum system power consumption[12,13]	1,714 W	1,200 W
Power-consumption total (3 years [8,766 hours] at $0.1042/kWh[23])	**$1,566**	**$1,096**
Power-consumption difference		***$755***
Grand total	**$720,520**	**$84,378**
Grand-total difference		***$636,427***
Relative difference	**8.5x greater TCO**	**88% lower TCO**

Three-year TCO comparison of two-socket, 384-GB systems. TCO does not include costs associated with Oracle database software licensing and support.

Component	IBM® Power System S924 (24 Cores)	Intel® Xeon® Platinum 8268 Processor–Based Server (48 Cores)
Processors	$67,500	$12,604
Memory	$13,794	$2,232
Storage	$2,016	$2,016
Chassis and other hardware costs	$35,827	$1,300
Hardware total	**$119,187**	**$18,152**
Purchase-price difference (hardware)		***$101,035***
IBM® AIX® 7.2 Enterprise Edition (24 cores, 3 years)	$39,816	–
IBM® PowerVM® Enterprise (3 years)	$7,200	–
IBM Proactive 24x7 Support (3 years)	$7,506	–
Red Hat® Enterprise Linux® (RHEL) for Virtual Datacenters Premium Smart Management bundle (3 years)	–	$15,672
RHEL for Virtual Datacenters Premium High Availability (3 years)	–	$3,735
RHEL for Virtual Datacenters Premium Resilient Storage (3 years)	–	$7,485
VMware vSphere® Enterprise Plus Edition™ (with Production Support, 3 years)	–	$6,292
VMware vCenter® Standard (with Production Support, 3 years)	–	$10,807
Software total	**$54,522**	**$43,991**
Purchase-price difference (software)		***$10,531***
Maximum system power consumption[17,18]	1,073 W	595 W
Power-consumption total (3 years [8,766 hours] at $0.1042/kWh[23])	**$980**	**$543**
Power-consumption difference		***$864***
Grand total	**$174,689**	**$62,686**
Grand-total difference		***$112,430***
Relative difference	**2.8x greater TCO**	**64% lower TCO**

[1] DB-Engines. "DB-Engines Ranking." May 2020. **https://db-engines.com/en/ranking**.

[2] Oracle. "Oracle Database 19c: Introduction and Overview." February 2019. **www.oracle.com/a/tech/docs/database19c-wp.pdf**.

[3] $609,910 for the IBM® Power System E950 versus $39,291 for the Intel®-based white-box server. IBM price provided to Prowess Consulting May 6, 2020, and is for an IBM Power System E950 running 4 x 12-core IBM® POWER9™ processors, 12 x 1-core processor activations, 12 x 64 GB DDR4 memory, and 8 x 100 GB memory activations. Intel price provided to Prowess Consulting May 14, 2020, and is for a white-box server running 4 x 24-core Intel® Xeon® Platinum 8268 processors with 24 x 32 GB DRAM.

[4] $119,187 for the IBM® Power System S924 versus $18,152 for the Intel®-based white-box server. IBM price provided to Prowess Consulting May 6, 2020, and is for an IBM Power System S924 running 2 x 12-core IBM® POWER9™ processors and 6 x 64 GB DDR4 memory. Intel price provided to Prowess Consulting May 14, 2020, and is for 2 x 24-core Intel® Xeon® Platinum 8268 processors and 12 x 32 GB DRAM.

[5] Total IBM software cost = $45,504 initial cost for IBM® AIX® 7.2 Enterprise Edition (48 cores) + ($11,376 annual cost for IBM AIX 7.2 Enterprise Edition [48 cores] + $4,800 annual cost for IBM® PowerVM® Enterprise + $5,004 annual cost for IBM Proactive 24x7 Support) * 3 years = $109,044.

[6] Total software cost for white-box server running Red Hat® Enterprise Linux® (RHEL) = $3,595 initial cost for VMware vSphere® Enterprise Plus Edition™ (with Production Support) + $6,175 initial cost for VMware vCenter® Standard (with Production Support) ($899 annual cost for VMware vSphere Enterprise Plus Edition [with Production Support] + $1,544 annual cost for VMware vCenter Standard [with Production Support] + $5,224 for RHEL for Virtual Datacenters Premium Smart Management bundle + $1,245 annual cost for RHEL for Virtual Datacenters Premium High Availability + $2,495 annual cost for RHEL for Virtual Datacenters Premium Resilient Storage) * 3 years = $43,991.

[7] Average base pay $64,892 per year as of August 6, 2020. Source: Glassdoor. "AIX Systems Administrator Salaries." **www.glassdoor.com/Salaries/aix-systemsadministrator-salary-SRCH_KO0,25.htm**.

[8] Average base pay $56,396 per year as of August 6, 2020. Source: Glassdoor. "IT Administrator Salaries." **www.glassdoor.com/Salaries/it-administrator-salarySRCH_KO0,16.htm**.

[9] Prowess estimate of relative OLTP database performance while running Oracle Database comparing a baseline IBM® Power System E950 running 4 x 12-core IBM® POWER9™ processors, 12 x 64 GB DDR4 memory with a value of 1.0 vs. an Intel®-based white-box server running 4 x 24-core Intel® Xeon® Platinum 8268 processors with 24 x 32 GB DRAM with a value of 1.348.

[10] Prowess estimate for relative performance per TCO dollar, calculated by dividing relative OLTP database performance (see endnote 9) by TCO dollar (see the "Three year TCO comparison of four-socket, 768-GB systems" table in the **appendix**) for both an IBM® Power System E950 running 4 x 12-core IBM® POWER9™ processors, 12 x 64 GB DDR4 memory (relative OLTP database performance (1.0)/TCO ($720,805) = 0.0000014) and an Intel®-based white-box server running 4 x 24-core Intel® Xeon® Platinum 8268 processors with 24 x 32 GB DRAM (relative OLTP database performance (1.0)/TCO ($84,378) = 0.000016). IBM system normalized to 1.0. Intel system relative performance per TCO dollar = 11.52 (0.000016/0.0000014).

[11] Prowess estimate for relative OLTP database performance per Oracle® Database license calculated by dividing relative OLTP database performance (see endnote 9) by the number of Oracle Database licenses (from the "Three-year TCO comparison of four-socket, 768-GB systems" table in the **appendix**) for both an IBM® Power System E950 running 4 x 12-core IBM® POWER9™ processors, 12 x 64 GB DDR4 memory (relative OLTP database performance (1.0)/number of Oracle Database licenses (48) = 0.021) and an Intel®-based white-box server running 4 x 24-core Intel® Xeon® Platinum 8268 processors with 24 x 32 GB DRAM (relative OLTP database performance (1.0)/number of Oracle Database licenses (48) = 0.028). IBM system normalized to 1.0. Intel system relative OLTP database performance per Oracle Database license = 1.348 (0.021/0.028).

[12] Redbooks. "IBM Power System E950." August 2018. **www.redbooks.ibm.com/redpapers/pdfs/redp5509.pdf**. Source for maximum system power, 1,714 watts, for IBM® Power System E950 running 4 x 12-core IBM® POWER9™ processors, 12 x 64 GB DDR4 memory was IBM Energy Estimator tool: **https://see.au-sydmybluemix.net/see/EnergyEstimator**. Accessed July 30, 2020.

[13] Intel power-consumption estimate provided to Prowess Consulting on May 14, 2020 for an Intel®-based white-box server running 4 x 24-core Intel® Xeon® Platinum 8268 processors with 24 x 32 GB DRAM.

[14] Prowess estimate for relative performance per watt calculated by dividing relative OLTP database performance (see endnote 9) by system power (from the "Three-year TCO comparison of four-socket, 768-GB systems" table in the **appendix**) for both an IBM® Power System E950 running 4 x 12-core IBM® POWER9™ processors, 12 x 64 GB DDR4 memory (relative OLTP database performance (1.0)/system power (1,714 watts) = 0.000583) and an Intel®-based white-box server running 4 x 24 core Intel® Xeon® Platinum 8268 processors with 24 x 32 GB DRAM (relative OLTP database performance (1.0)/system power (1,200 watts) = 0.00112). IBM system normalized to 1.0. Intel system relative OLTP database performance per Oracle Database license = 1.925 (0.00112/0.000583).

[15] Prowess estimate of relative OLTP database performance while running Oracle Database comparing a baseline IBM® Power System S924 running 2 x 12-core IBM® POWER9™ processors and 6 x 64 GB DDR4 memory with a value of 1.0 vs. an Intel®-based white-box server running 2 x 12-core IBM® POWER9™ processors and 6 x 64 GB DDR4 memory with a value of 1.50.

[16] Prowess estimate for relative performance per TCO dollar calculated by dividing relative OLTP database performance (see endnote 15) by TCO dollar (from the "Three year TCO comparison of two-socket, 384-GB systems" table in the **appendix**) for both an IBM® Power System S924 running 2 x 12-core IBM® POWER9™ processors and 6 x 64 GB DDR4 memory (relative OLTP database performance (1.0)/TCO ($174,689) = 0.0000057) and an Intel®-based white-box server running 2 x 24-core Intel® Xeon® Platinum 8268 processors and 12 x 32 GB DRAM (relative OLTP database performance (1.0)/TCO ($62,686) = 0.000024). IBM system normalized to 1.0. Intel system relative performance per TCO dollar = 4.20 (0.000024/0.0000057).

[17]Prowess estimate for relative OLTP database performance per Oracle® Database license calculated by dividing relative OLTP database performance (see endnote 15) by number of Oracle Database licenses (from the "Three-year TCO comparison of two-socket, 384-GB systems" table in the **appendix**) for both an IBM® Power System S924 running 2 x 12-core IBM® POWER9™ processors and 6 x 64 GB DDR4 memory (relative OLTP database performance (1.0)/number of Oracle Database licenses (24) = 0.042) and an Intel®-based white-box server running 2 x 24-core Intel® Xeon® Platinum 8268 processors and 12 x 32 GB DRAM (relative OLTP database performance (1.0)/ number of Oracle Database licenses (24) = 0.063). IBM system normalized to 1.0. Intel system relative OLTP database performance per Oracle Database license = 1.507 (0.063/0.042).

[18]Source for maximum system power, 1,073 watts, for IBM® Power System S924 running 2 x 12-core IBM® POWER9™ processors and 6 x 64 GB DDR4 memory was IBM Energy Estimator tool: **https://see.au-syd.mybluemix.net/see/EnergyEstimator**. Accessed July 30, 2020.

[19]Intel power-consumption estimate provided to Prowess Consulting on May 14, 2020 Intel®-based white-box server running 2 x 24-core Intel® Xeon® Platinum 8268 processors and 12 x 32 GB DRAM.

[20]Prowess estimate for performance per watt calculated by dividing relative OLTP database performance (see endnote 15) by system power (from the "Three-year TCO comparison of two-socket, 384-GB systems" table in the **appendix**) for both an IBM® Power System S924 running 2 x 12-core IBM® POWER9™ processors and 6 x 64 GB DDR4 memory (relative OLTP database performance (1.0)/system power (1073 watts) = 0.00093) and an Intel®-based white-box server running 2 x 24-core Intel® Xeon® Platinum 8268 processors and 12 x 32 GB DRAM (relative OLTP database performance (1.0)/ system power (595 watts) = 0.00253). IBM system normalized to 1.0. Intel system relative performance per watt = 2.71 (0.00253/0.00093).

[21]Source: Intel. "Oracle Database and Analytics on Intel® Architecture." September 2018. **https://builders.intel.com/docs/datacenterbuilders/oracle-database-andanalytics-on-intel-architecture-brief.pdf**. **Baseline configuration:** Oracle® Database 12c Release 2 in-memory with Intel® Advanced Vector Extensions 2 (Intel®
AVX2), one node, 2 x Intel® Xeon® Platinum 8168 processor at 2.70 GHz (28 core parts used for test), 12 x 16 GB DDR4, 2,400 MHz DIMM, 1DPC (192 GB total memory) on Linux® 4.11.0 x86_64. Benchmark: Star Schema Benchmark. **Test configuration:** Oracle Database 12c Release 2 in-memory with Intel AVX-512 enabled, one node, 2 x Intel Xeon Platinum 8168 processor at 2.70 GHz (28 core parts used for experiment), 12 x 16 GB DDR4, 2,400 MHz DIMM, 1DPC (192 GB total memory) on Linux 4.11.0 x86_64. Benchmark: Star Schema Benchmark.

[22]Intel. "Affordably Accommodate the Next Wave of Data Demands." June 2020. **www.intel.com/content/www/us/en/architecture-and-technology/optane-dcselection-guide.html**.

[23]United States Energy Information Administration. "Electric Power Monthly." April 2020. **www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a**.

The analysis in this document was done by Prowess Consulting and commissioned by Intel.

Results have been simulated and are provided for informational purposes only. Any difference in system hardware or software design or configuration may affect actual performance.