

White Paper
Intel Information Technology
Computer Manufacturing
Server Virtualization

Virtualization with the Intel® Xeon® Processor 5500 Series: A Proof of Concept

Intel IT, together with Intel's Digital Enterprise Group, End User Platform Integration, and Intel's Software and Services Group, conducted proof-of-concept testing and total cost of ownership (TCO) analysis to assess the virtualization capabilities of Intel® Xeon® processor 5500 series. A server based on Intel® Xeon® processor X5570 delivered up to 2.6x the performance and up to 2.05x the performance per watt of a server based on Intel® Xeon® processor E5450, resulting in the ability to support approximately twice as many virtual machines for the same TCO. We also verified seamless live migration between servers based on Intel Xeon processor 5500 series and previous Intel® processor generations using VMware Enhanced VMotion* and Intel® Virtualization Technology FlexMigration assist.

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Executive Summary

Our results show that, compared with the previous server generation, two-socket servers based on Intel Xeon processor 5500 series can support approximately 2x as many VMs for the same TCO.

Intel IT, together with Intel's Digital Enterprise Group, End User Platform Integration, and Intel's Software and Services Group, conducted proof-of-concept testing and total cost of ownership (TCO) analysis to assess the virtualization capabilities of Intel® Xeon® processor 5500 series. Our results show that two-socket servers based on Intel Xeon processor 5500 series can offer substantial improvements in virtualization performance and energy efficiency, resulting in lower TCO per virtual machine (VM) in multiple Intel IT virtualization deployment scenarios.

We analyzed performance and energy consumption of a two-socket server based on Intel® Xeon® processor X5570 compared with a server based on Intel® Xeon® processor E5450 in tests using the vConsolidate virtualization benchmark suite. Based on our test results, we compared TCO for each server.

The server based on Intel Xeon processor X5570 delivered:

- Up to 2.6x faster performance
- Up to 2.05x better performance per watt, resulting in approximately double the number of VMs in the same data center thermal envelope
- Approximately 2x the number of VMs for the same TCO

We also verified that servers based on Intel Xeon processor 5500 series are live-migration-compatible with servers based on previous processor generations, using VMware Enhanced VMotion* and Intel® Virtualization Technology FlexMigration assist.

Our tests show that servers based on Intel Xeon processor 5500 series can deliver significant value and flexibility to Intel IT. We expect to standardize on Intel Xeon processor 5500 series for new two-socket virtualization host servers.

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Background

Like many IT organizations, Intel IT is pursuing server virtualization to reduce costs and create a more agile, dynamic data center computing environment.

As part of this strategy, we test new server platforms to assess their virtualization performance and energy consumption, and analyze how well they help us meet the compute requirements of the Intel business groups we support.

We also perform tests to verify virtual machine (VM) live migration compatibility with other server platforms in our virtualized environment. This compatibility enables us to create higher capacity virtualization resource pools that combine servers based on multiple generations of Intel® processors.

Intel® Xeon® processor 5500 series, based on the Intel® microarchitecture formerly code-named Nehalem, includes new features designed to increase performance and reduce

energy consumption. These include Intel® Hyper-Threading Technology; Intel® Turbo Boost Technology; Intel® QuickPath Technology; an integrated memory controller with next-generation DDR3 memory; and 8-MB L3 cache. Servers based on the Intel Xeon processor 5500 series can have up to 2.25x the memory capacity compared to the previous server generation.

To determine the potential benefits, Intel IT recently performed proof-of-concept (PoC) testing of the virtualization capabilities of two-socket server platforms based on Intel Xeon processor 5500 series in collaboration with Intel's Digital Enterprise Group, End User Platform Integration, and Intel's Software and Services Group.

Proof of Concept

Our PoC focused on a number of critical areas.

Virtualization performance and power efficiency.

We tested a server based on Intel Xeon processor 5500 series, compared to the previous-generation Intel Xeon processor 5400 series, using a standard benchmark suite. We measured each platform's performance, scalability, and power consumption.

Live migration compatibility. We tested live migration between a two-socket server based on Intel Xeon processor 5500 series and two- and four-socket servers based on several other generations of Intel processors using Intel® Virtualization Technology (Intel® VT) FlexMigration assist and VMware Enhanced VMotion*.

Total cost of ownership (TCO) analysis. Based on our performance test results and other factors such as platform and data center costs, we calculated relative virtualization TCO for servers based on Intel Xeon processor 5500 series compared to Intel Xeon processor 5400 series.

Test Setup

We conducted two separate sets of tests, one to measure virtualization performance and power efficiency, and one to verify live migration compatibility.

Virtualization Performance and Power Efficiency

We performed testing to compare a two-socket server based on Intel® Xeon® processor X5570 (2.93 GHz) with a server based on the previous-generation Intel® Xeon® processor E5450 (3 GHz). We tested each platform's performance, scalability, and power consumption when running a standard virtualization benchmark suite. System specifications are shown in Table 1.

For our tests, we required a benchmark suite that:

- Represented good approximations of IT workloads.
- Produced objective measurements.
- Adequately stressed each of the systems.
- Produced repeatable results.

To meet these needs, we selected the vConsolidate benchmark suite. This tests virtualization performance by simulating real server performance in a typical environment.

We used vConsolidate (profile-2) to generate consistent application workloads for the performance analysis.¹

The test suite runs consolidated stack units (CSUs), each comprising five simultaneously running VMs, including one idle VM, as shown in Table 2. CSUs can be added to increase the system load and CPU utilization.

Our PoC test environment is shown in Figure 1. We connected each tested server to a LAN and to a storage area network (SAN). Also connected to the LAN were driver systems that generated each CSU workload and controller nodes that managed the CSUs. We created a single set of test VMs and migrated it between test systems using the SAN.

When running the benchmark tests, we added CSUs until the systems under test attained high system utilization levels in excess of 80 percent—levels that we would rarely expect to reach in production. This allowed us to more fully exploit the scalability of each platform. If a system has enough headroom, adding CSUs increases the aggregate throughput of the system, which results in a greater vConsolidate score.

We executed three passes of the tests on each system while monitoring CPU utilization and power consumption, and selected the median set of results. For reference, we used the scores from test runs on a reference platform consisting of a two-socket server based on Intel® Xeon® processor 5160.

We analyzed the capabilities of the tested servers by comparing performance, performance-per-unit cost, and performance per watt for each system.

Live Migration Compatibility

We performed tests of live migration of representative IT workloads between servers based on Intel Xeon processor 5500 series and other Intel® server platforms, using Intel VT FlexMigration assist and VMware Enhanced VMotion.

Live migration is an essential technology for an agile, dynamic data center environment based on server

¹ See www.intel.com/technology/itj/2006/v10i3/7-benchmarking/6-vconsolidate.htm and <http://software.intel.com/en-us/videos/virtualization-performance-testing-with-vconsolidate/>.

Table 1. Virtualization Performance Test System Specifications

	Intel® Xeon® Processor E5450	Intel® Xeon® Processor X5570
Number of processors	2	2
Number of cores	4	4
Core frequency	3 GHz	2.93 GHz
Interconnect	1.33 GHz Front Side Bus (FSB)	6.4 GT/s Intel® QuickPath Interconnect
Cache	12 MB L2	8 MB L3
RAM	16 GB (8x 2 GB) 667 MHz DDR2	48 GB (12x 4 GB) 1067 MHz DDR3
Intel® Virtualization Technology	Enabled	Enabled
Intel® Turbo Boost Technology	N/A	Enabled
Intel® Hyper-Threading Technology	N/A	Enabled
Hypervisor	VMware ESX 4.0 RC2*	VMware ESX 4.0 RC2

virtualization. Live migration enables us to perform VM migrations within a server cluster without interrupting the services the VMs are providing. It provides the foundation for advanced data center capabilities such as dynamic load balancing and maintenance without VM downtime.

Dynamic load balancing, when combined with failover capabilities that enable fast, automated recovery of VMs, lowers the risk associated with consolidating many VMs onto each VM host. This makes it more feasible to target higher consolidation ratios that fully exploit increasing server performance and capacity.

Until recently, successful live migration between servers within a cluster has required the servers to be based on the same generation of processors, with the same instruction set. This limited our ability to implement large resource pools, creating islands of servers and hindering the implementation of advanced data center capabilities.

Combined, Intel VT FlexMigration assist and Enhanced VMotion, a feature of VMware ESX 3.5 U2* and subsequent software versions, are designed to overcome this limitation by enabling all servers to expose the same instruction set to applications, even if they are based on different Intel processor generations. This means we can create clusters that combine servers from multiple generations, allowing full implementation of advanced data center capabilities. We can create higher-capacity resource pools that help avoid potential issues with VM performance and response times.

We previously performed tests² to verify that we could use Intel VT FlexMigration assist to perform live migration of essential Intel IT workloads between two-socket and four-socket servers based on generations of Intel Xeon processors with the Intel® Streaming SIMD Extensions (SSE) 3 instruction set—Intel Xeon processor 5300 series and Intel Xeon processor 7300 series—and the SSE 4.1 instruction

Table 2. vConsolidate Consolidated Stack Unit (CSU)

	Workload	Operating System	Memory	vCPUs
VM 1	Database	64-bit Microsoft Windows Server 2003*	2.0 GB	2
VM 2	Web	32-bit Microsoft Windows Server 2003*	1.5 GB	2
VM 3	Mail	32-bit Microsoft Windows Server 2003	1.5 GB	1
VM 4	Java*	64-bit Microsoft Windows Server 2003	2.0 GB	2
VM 5	Idle	32-bit Microsoft Windows Server 2003	0.4 GB	1

vCPU: virtual CPU, VM: virtual machine

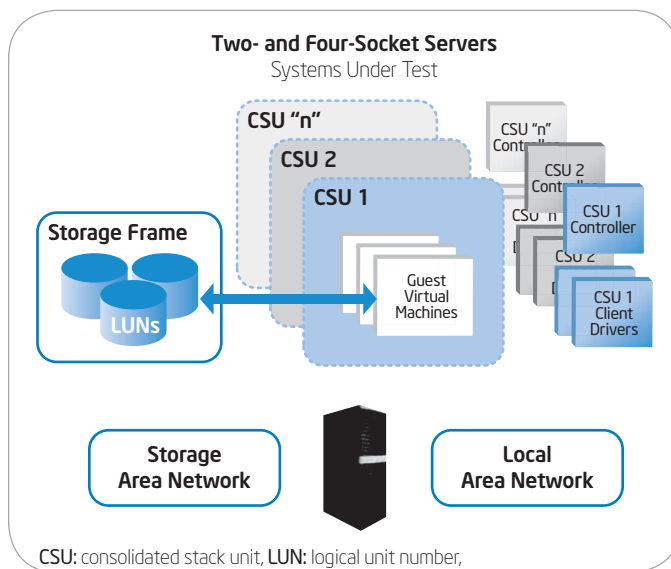


Figure 1. Virtualization performance test environment.

² See <http://communities.intel.com/docs/DOC-2538>.

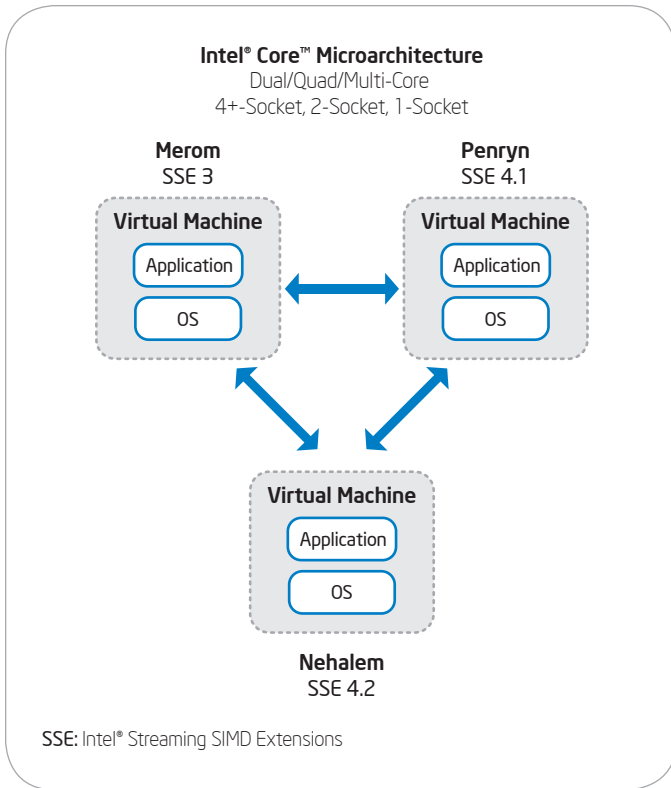


Figure 2. Intel® Virtualization Technology FlexMigration assist and VMware Enhanced VMotion* enable live migration between servers with different generations of Intel® processors.

While the individual servers support different instruction sets, only SSE 3 is exposed in compatibility mode.

set—Intel Xeon processor 5400 series and Intel Xeon processor 7400 series. These results verified that we can combine these multiple processor generations within the same cluster.

The Intel Xeon processor 5500 series includes the new SSE 4.2 instruction set, which provides additional instructions to boost performance and cut energy consumption. We wanted to verify that, using Intel VT FlexMigration assist and VMware Enhanced VMotion, we can perform live migration of representative IT workloads between servers based on Intel Xeon processor 5500 series and servers based on previous generations of Intel processors that lack SSE 4.2, as shown in Figure 2.

Live migration test design

- We designed our PoC to test a wide variety of configurations and migration scenarios representative of our production IT environment:
- We used manual and automated migration modes across two different platform architectures (two-socket and four-socket) and three processor generations.
- We used the server based on Intel Xeon processor X5570 as both a source and destination during migrations
- We used Intel IT standard 64-bit and 32-bit Microsoft Windows* builds.
- Our VMs were virtualized servers based on IT-standard configurations for database servers, reporting services, network load balancing, and Web servers.
- We tested heavily loaded 32-bit and 64-bit VMs.

Test system specifications are shown in Table 3.

Test workload

We employed an Intel IT business reporting application workload as well as VMs from our vConsolidate test workload.

The business reporting workload represents a highly utilized set of enterprise reports served to a large number of users. Tests also include some general Web site navigation. The workload includes

Table 3. Live Migration Test System Specifications

Processor	Cores	Intel® Microarchitecture	SSE	Core Frequency	Interconnect	RAM	Server Architecture
Intel® Xeon® processor 5148	2	Merom	SSE 3	2.33 GHz	1.33 GHz FSB	16 GB	Two socket
Intel® Xeon® processor X5365	4	Merom	SSE 3	3 GHz	1.33 GHz FSB	16 GB	Two socket
Intel® Xeon® processor X7350	4	Merom	SSE 3	2.93 GHz	1.06 GHz FSB	32 GB	Four socket
Intel® Xeon® processor X5450	4	Penryn	SSE 4.1	3 GHz	1.33 GHz FSB	32 GB	Two socket
Intel® Xeon® processor X7460	6	Penryn	SSE 4.1	2.67 GHz	1.06 GHz FSB	32 GB	Four socket
Intel® Xeon® processor X5570	4	Nehalem	SSE 4.1	2.93 GHz	6.4 GT/s Intel® QPI	32 GB	Two socket

FSB: Front Side Bus, Intel® QPI: Intel® QuickPath Interconnect, SSE: Intel® Streaming SIMD Extensions

Hypertext Transfer Protocol (HTTP) and network load-balancing traffic and is designed to stress compute, memory, and multi-protocol network capacity within the virtual environment under test. The workload is generated by an external physical driver client.

The workload consists of seven VMs: a database reporting server running within a VM, four load-balanced Web servers used to handle user requests, a domain controller, and a network load balancing controller.

Test setup

The test host servers were connected to a SAN. The servers were also connected to two 1-Gbps LANs used for VMware Enhanced VMotion and for internal communications within our test cluster, as shown in Figure 3.

For each test, we installed VMware vSphere 4* on each of the test systems. We created a cluster, enabling VMware Enhanced VMotion Compatibility (EVC)*, and added our test systems to the cluster. Intel VT FlexMigration assist enabled the hypervisor to report the appearance of the same instruction set to the VMs.

We performed a series of manual and automated live migration tests using different combinations of host servers. We initiated the test by using an external load generator client system to direct application queries to the VMs running the test workload on the selected source host.

Once the targeted loading level was attained on the source host, live migration with VMware Enhanced VMotion was initiated. This live migration to the destination host or hosts was initiated either automatically or manually, depending on the test. We monitored the tests until live migration completed successfully. This included verifying that migration completed successfully without VM outage and that application operation was uninterrupted during the live migration. We recorded the time required to complete the migration, and we monitored application performance and related statistics as well as host system utilization information for the duration of each test.

We performed two sets of live migration tests:

Manual migration. We tested manual migration of our IT business reporting workload between pairs of test servers. In each test, we migrated all seven VMs from the source to the destination server. The server based on Intel Xeon processor X5570 was used as one of the destination servers.

Automated Migration. In these tests, the server based on Intel Xeon processor X5570 was used as the source server. We created a VMware Distributed Resource Scheduler* (VMware DRS*) cluster that included all six servers that were described in Table 3. Our

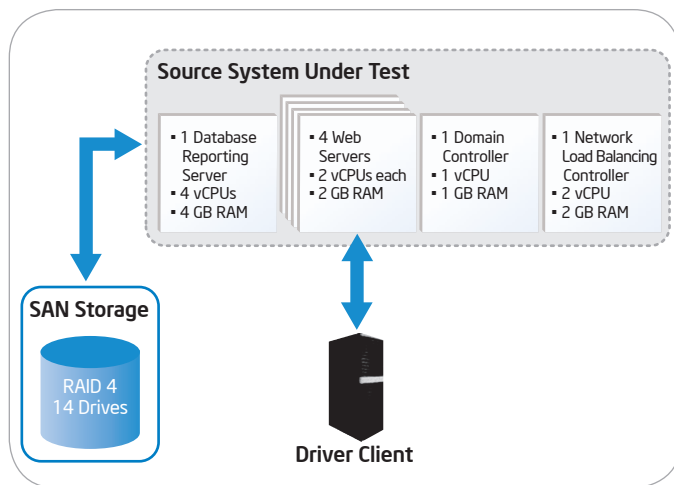


Figure 3. Live migration test setup.

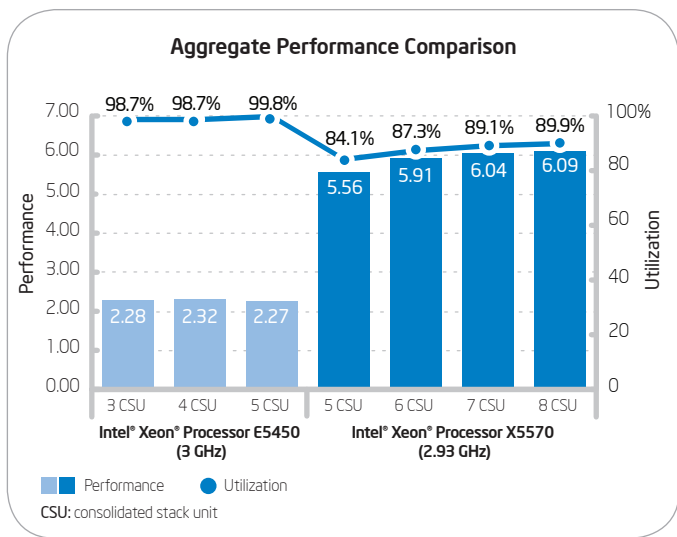


Figure 4. Performance and utilization with vConsolidate benchmark. Intel internal measurements, April 2009.

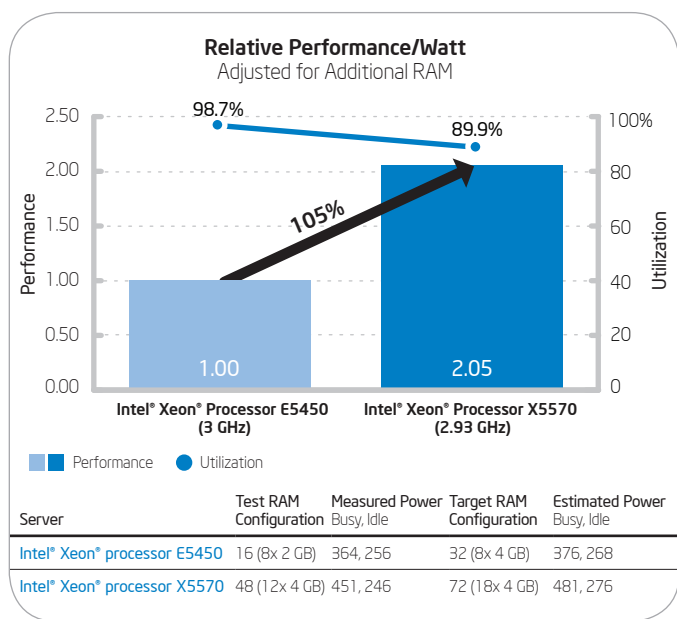


Figure 5. Power consumption and performance per watt. Intel internal measurements, April 2009.

goal was to show automated load balancing within a cluster of servers based on multiple generations of Intel processors.

In each test, we initially loaded multiple VM workloads on the source server. To help ensure this source server was sufficiently loaded with VMs to distribute and load-balance among the servers in the cluster, we added two vConsolidate CSUs as well as our business reporting application.

Then we used VMware DRS to automatically migrate the VMs to the other servers in the cluster. In separate tests, we used different VMware DRS cluster modes ranging from 1 (conservative) to 5 (aggressive). With higher settings, the software performed additional migrations to more evenly balance workloads within the cluster, based on the workloads that were running and the capacity of the available servers.

Results

In our performance tests, the server based on Intel Xeon processor X5570 was considerably more scalable than the server based on the Intel Xeon processor E5450. All of our live migration tests completed successfully.

Virtualization Performance and Scalability

The server based on Intel Xeon processor X5570 was considerably more scalable than the server based on the Intel Xeon processor E5450, delivering up to 2.6x the aggregate throughput at lower utilization levels.

Aggregate throughput on the server based on Intel Xeon processor X5570 continued to increase as we increased the number of CSUs to eight, with utilization at about 90 percent. In contrast, performance on the server based on Intel Xeon processor E5450 reached a maximum with four CSUs, with utilization at about 98 percent.

Maximum server throughput and utilization are compared in Figure 4.

Performance per Watt

We measured power consumed by each server when running the tests. Details are shown in Figure 5.

The memory configurations of our two test systems were adequate to evaluate and compare performance. However, in real deployments, we would expect to use slightly larger memory configurations. This additional memory would slightly increase power consumption. Therefore, for our analysis, we created an adjusted power consumption estimate that takes into account this additional memory. Our adjusted estimate was based on 32 GB of RAM on the server based on Intel Xeon processor E5450, and 72 GB on the server based on Intel Xeon processor X5570.

We then normalized performance per watt relative to the server based on Intel Xeon processor E5450. Based on the adjusted power

consumption, the server based on Intel Xeon processor X5570 with 72 GB of RAM delivered approximately 105 percent better performance per watt compared with the server based on Intel Xeon processor E5450 with 32 GB of RAM.

Live Migration

In our manual migration tests, all migrations with VMware Enhanced VMotion completed successfully with no loss of service, as shown in Figure 6.

All of our automated migration tests with VMware Enhanced VMotion also completed successfully. As shown in Figure 7, higher VMware DRS settings resulted in an increasing number of migrations, resulting in a redistribution of the VMs among the available servers that reflected each server’s relative capacity. The idle VMs were not migrated, even with the most aggressive VMware DRS setting; because idle VMs do not consume processor resources, migrating them does not help balance resource utilization within the cluster.

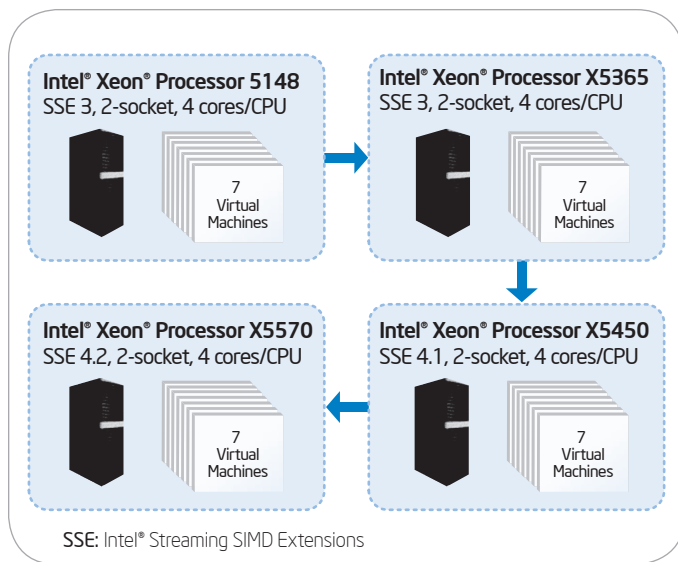


Figure 6. Manual migration results.

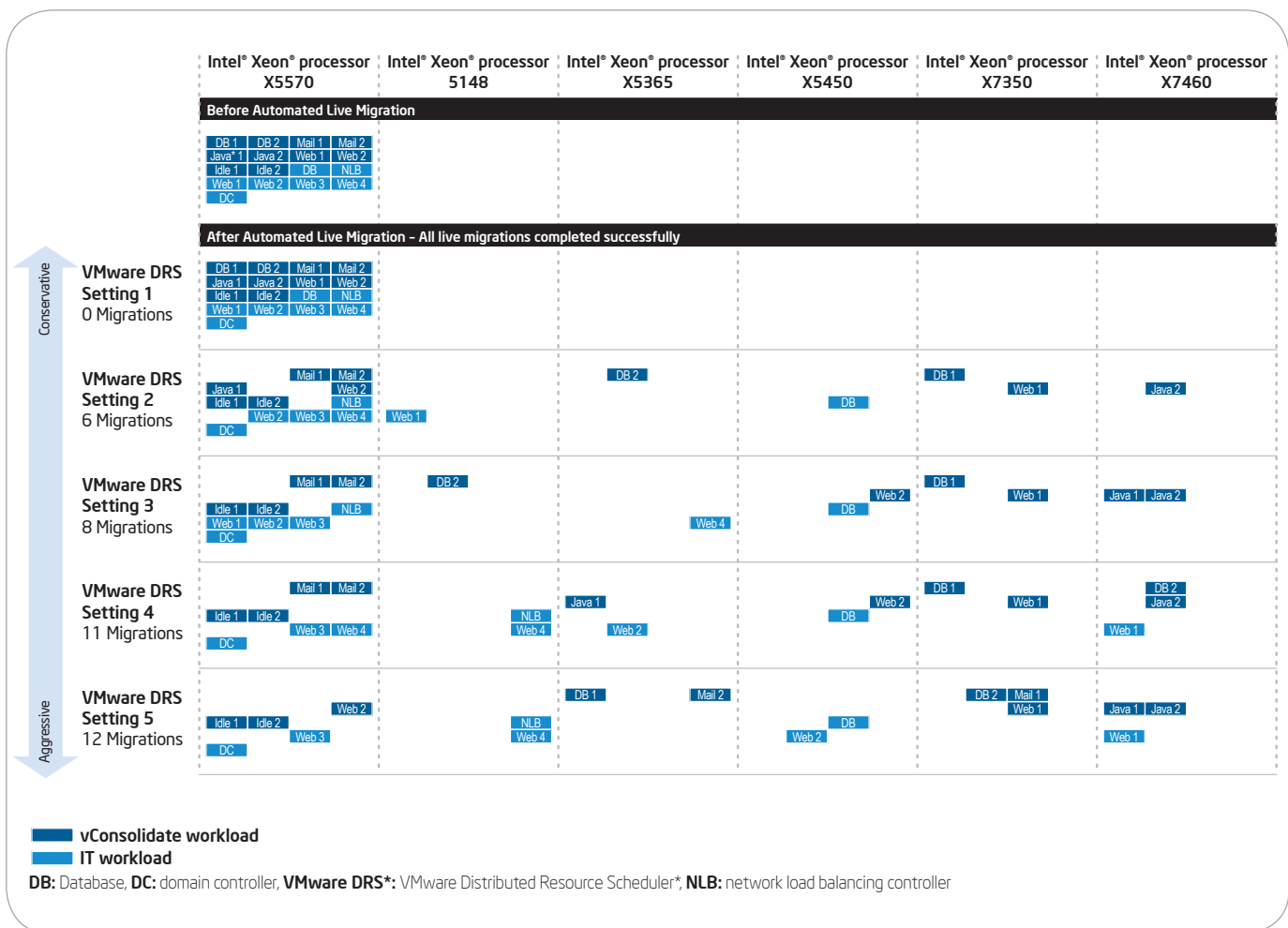


Figure 7. Results of automated migrations.

Table 4. TCO assumptions

Category	Assumption
Data Center Physical Plant	<ul style="list-style-type: none"> Space per rack: 25 square feet Depreciation cycle: 15 years Power use: 80 watts per square foot at USD 0.08 per kilowatt-hour Busy time: 12 hours per day Cooling power multiplier: 2.0
LAN, Storage Area Network (SAN), and Cabling	<ul style="list-style-type: none"> Copper and fiber pre-wiring per rack: USD 3,000 over 10 years Gigabit Ethernet (GbE) LAN port costs per server USD 300 over 4 years Fibre Channel (FC) SAN port costs per server: USD 700 over 4 years LAN/SAN ports per server: 7 GbE (LAN), 2 FC (SAN)
Personnel	<ul style="list-style-type: none"> USD 100,000 per support employee per year One support employee per 250 servers (physical server support only, including installation, break, fix and de-installation). Virtual machine operating system and application support is not included, as it is the same for all alternatives.

Total Cost of Ownership Analysis

Different groups of users have a variety of business requirements, resulting in multiple virtualization deployment TCO scenarios. Based on our performance test results and other data, we calculated relative TCO of the server based on Intel Xeon processor X5570, compared with the server based on Intel Xeon processor E5450, when used to support each of these TCO scenarios.

In our TCO calculations, we assumed that we would deploy typical rack-mounted servers. We compared a server based on Intel Xeon processor X5570 with 72 GB RAM to a server based on Intel Xeon processor E5450 with 32 GB RAM.

Our TCO calculations took into account costs in the following areas:

- Hardware (including configured RAM) and software acquisition; we based our analysis on list prices from major manufacturers
- Depreciation and amortization
- Data center annual depreciation and operating expenses
- Server support personnel
- LAN, SAN, and cabling

Key TCO assumptions are shown in Table 4.

Virtualization Deployment TCO Scenarios

We focused on two types of scenario and estimated TCO for each platform when supporting each scenario. Results are shown in Figure 8.

Performance-centric SLA-focused

These scenarios emphasize the need to meet performance service-level agreements (SLAs). Typical examples include end-of-quarter financial processing and trading applications. IT must meet SLAs that specify response times for interactive applications and completion times for batch jobs. Therefore, application responsiveness or throughput are paramount.

To meet these SLAs, servers must consistently deliver a specific level of performance or throughput. In our TCO analysis, we therefore limited the number of VMs on each server, based on their relative performance in our tests. The server based on Intel Xeon processor X5570 delivered 2.6x the performance of the server based on Intel Xeon processor E5450, so in our TCO model we assumed that it would support a total of 2.6x as many VMs.

Our TCO analysis showed that compared with the server based on Intel Xeon processor E5450, the server based on Intel Xeon processor X5570 supported 2.28x as many VMs for the same TCO, due to its increased throughput and greater performance per watt.

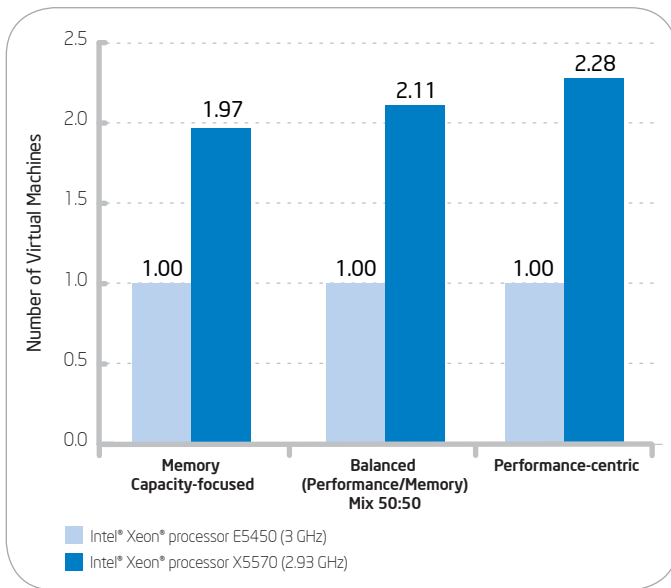


Figure 8. Relative number of virtual machines for the same total cost of ownership for different virtualization scenarios.

Memory capacity-focused

These scenarios focus on provisioning large numbers of VMs as cost-effectively as possible; performance is secondary. Typically, this means maximizing the number of VMs per system. Examples include systems used for testing and development, and production applications with light transaction loads.

Because performance is secondary, the number of VMs per system tends to be constrained by memory capacity rather than processor performance. We assumed that each server could support as many VMs as the host server physical memory could accommodate.

The server based on Intel Xeon processor X5570 could support 1.97x as many as the Intel Xeon processor E5450-based server for the same TCO.

Balance of performance-centric and memory capacity-focused workloads

In situations where a server runs a mix of performance-centric SLA-focused and memory capacity-focused workloads, the server based on Intel Xeon processor X5570 offered a clear TCO advantage. This suggests

that this server would also be a good choice if we do not know in advance which workloads the server will be required to support.

Blade and specialized server considerations

Our TCO analysis is based on mainstream rack-mounted virtualization server configurations. TCO comparisons using blade servers and specialized niche server configurations will depend on the specifics of the server and the target deployment scenario or usage model.

Other scenarios

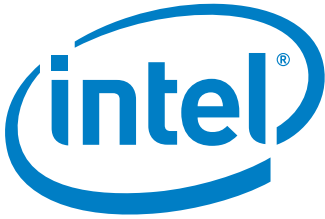
The virtualization performance, memory capacity, and power efficiency of servers based on Intel Xeon processor 5500 series makes them well suited for a variety of additional scenarios. In data centers facing constraints in power, cooling, or LAN or SAN ports, servers based on Intel Xeon processor 5500 series can allow us to host more VMs within the same data center capacity. The increased performance and memory capacity also means that we can increase the flexibility and efficiency of our environment by increasing the number of VMs we can include within a cluster.

Virtualization and Four-Socket Servers

The growing performance and capacity of two-socket servers makes them suitable for many general-purpose enterprise virtualization roles. However, Intel IT has found that some specialized roles require the even greater capacity of four-socket servers. For example, supporting virtualized enterprise resource planning (ERP) systems may require more memory per virtual machine (VM) or a greater processor core count per VM. This means four-socket servers, which have a greater memory capacity and core count than two-socket servers, may be a better fit. We expect that four-socket servers will be able to take on even more demanding virtualization host requirements when the Nehalem microarchitecture, which includes the virtualization hardware assists Intel® Virtualization Technology for Directed I/O (Intel® VT-d) and Intel® Virtualization Technology for Connectivity (Intel® VT-c), becomes available in four-socket servers with the planned introduction of Nehalem-EX systems.

Conclusion

Servers based on Intel Xeon processor 5500 series delivered significant improvements in virtualization performance, energy efficiency, and TCO compared with previous generations. They add significant capacity and flexibility to our virtualization environment: We can integrate them into clusters with other server processor generations and perform live migration across multiple generations, protecting our server investment and creating higher-capacity virtualization resource pools. We expect to standardize on the Intel Xeon processor 5500 series for new two-socket virtualization host servers.



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Acronyms

VMware DRS	VMware Distributed Resource Scheduler	Intel® VT-c	Intel® Virtualization Technology for Connectivity
ERP	enterprise resource planning	Intel® VT-d	Intel® Virtualization Technology for Directed I/O
EVC	Enhanced VMotion Compatibility	PoC	proof of concept
FC	Fibre Channel	SAN	storage area network
GbE	gigabit Ethernet	SLA	service-level agreement
Intel® VT FlexMigration assist	Intel® Virtualization Technology FlexMigration assist	TCO	total cost of ownership
		VM	virtual machine

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