February 2021

Virtual Machines versus containers

How IBM WebSphere Hybrid Edition with Red Hat OpenShift can lower server
costs and improve response time

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IT organizations frequently seek to lower cost and to create higher efficiencies. Virtual machine deployment of applications has improved efficiency over native server deployment, and moving to containers can bring even more value.

IBM tests show that transaction workloads on x86 can be delivered at over four times the throughput and in half the response time using a Red Hat® OpenShift® environment versus a classically deployed virtual machine environment.[1] In this paper we examine resource requirements for virtual machines and containers, and the impact of these technologies in real data center environments.

The case for containers
Several factors contribute to underutilization of resources in an x86 server infrastructure when using virtual machines. Containers, in place of virtual machines, can address those challenges.

<u>"One-size-fits-all" servers</u>
To facilitate server deployment, many IT organizations use just a few "t-shirt" size x86 server configurations to support all their workloads. The benefit of this approach is that it simplifies the procurement process and makes server deployment and maintenance easier. All servers conform to a limited variety of profiles, so staff can more efficiently patch, repair and replace hardware as needed. The downside is that not all customer applications perform the same. Due to individual workload characteristics, some require more CPU or I/O resources while others may be more memory intensive.

<u>x86 CPU utilization levels</u>
Most applications on x86 servers run at very low CPU average utilizations. Measurements of 7,485 virtual machines from IT Economics assessments of four large enterprise customer environments found that the majority of workloads peak at less than a single 2 GHz x86 core[2], resulting in underused CPU driving the need for additional servers to satisfy workload requirements.

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[1] IBM tests were performed to replicate conditions in observed customer environments for transaction workloads running in virtual machines versus Red Hat OpenShift containers on x86 servers. Workloads were run to simulate a variance in CPU demand with a peak-to-average ratio of 7 to 1 on 16-core Cascade Lake x86 servers configured with 128 GB memory as well as a separate server for Control Plane functionality. Software included RHEL, x86 hypervisor, OpenShift containers, and an OLTP application driven by JMeter. The OCP environment required 15,536 MHz to deliver a total of 2,676 TPS collectively over 33 containers with a per-container average of 81 TPS and a response time of 3 milliseconds and a CPU consumption of 5.81 MHz per TPS. Using identical workloads 8 VMs required 3,911 MHz to deliver a total of 627 TPS with a per VM average of 78 TPS and a response time of 6.4 milliseconds and CPU consumption of 6.24 MHz per TPS.

[2] Utilization samples were taken from 7,485 virtual machines running on 15,558 x86 cores in four large enterprise accounts to measure actual consumed MHz. Sample period durations varied from five minutes to 30 minutes. Time-series values were normalized to a five minute duration using a standard normal distribution. Average utilization was calculated as the average of all of the time-series samples for each virtual machine and the peak utilization was defined as the 95th percentile highest value measured. 63% of virtual machines measured had a peak/average ratio greater than 7 to 1 and 30% of virtual machines had a peak/average ratio greater than 13 to 1. For additional information on x86 workload analysis contact the IBM IT Economics team, IT.Economics@us.ibm.com.

Workload variance

Not only do workloads have low peak CPU utilization, they also have highly variable CPU peak-to-average ratios. Measurements from the same 7,485 virtual machines referenced above found that while some of the measured applications show extreme variability with 13-to-1 or greater peak-to-average ratios, on average the measured applications showed a 7-to-1 or greater peak-to-average ratio.[2] For example, the peak CPU utilization might be 91% but the average CPU utilization is only 7%.

For an application with a peak-to-average ratio of 7 to 1 the best possible CPU utilization would be 1/7 or just less than 15%. We say best possible because that would assume that the peak is 100% of the available capacity of the machine. Many users run their servers more conservatively to peak at less than 50% of the available capacity of the machine. Peaking at half the available capacity is sometimes due to systems limitations, but more often to provide for high-availability failover and disaster recovery.

Linux workloads

Linux® brings openness, flexibility and savings, and thus continues to be a strategic operating system for the IT industry. Linux was originally designed to 'own' the server as a UNIX® OS. In particular when it comes to memory, the Linux operating system attempts to effectively use all the memory available to it. The result is that it locks up memory resources that could be made available to other virtual machines when it is not needed, for example during virtual machine idle periods.

Hypervisor impacts

Common rules of thumb used to manage hypervisor performance also contribute to low utilization. Three rules in particular tend to limit utilization: CPU overcommit ratios, hypervisor host limits, and memory overcommit limits. Conventional capacity planning suggests using no more than 4:1 for virtual to real CPU overcommit. The second rule, hypervisor host limits, is to allocate no more than one virtual machine per real CPU on the host. The third rule, for memory overcommit, is that no more than 75% to 80% real memory should be used by virtual machines. The purpose of the memory overcommit rule is to leave sufficient margin for the movement of virtual machines among hosts.

All of these factors cause applications running in virtual machines to exhaust host memory resources before effectively using available host CPU resources resulting in low average CPU utilization at the real server level.

Red Hat OpenShift containers[3], on the other hand, can share memory resources and instead of being memory limited, are more likely to be CPU limited. This is a positive outcome since it means that applications running in this environment can effectively use all of the CPU resources available in the server resulting in high average CPU utilization. The ability to freely use CPU resource decreases the number of wasted cores and servers, resulting in reduced infrastructure, fewer software licenses, and fewer management resources.

Comparing containers to virtual machines

In order to determine the actual benefits of containers versus virtual machines we compared a client simulated banking application transaction suite running IBM WebSphere® Hybrid Edition in an x86 virtualized environment using Red Hat OpenShift containers versus virtual machines.

x86 configuration

[3] https://www.openshift.com/products/container-platform

Both hypervisor hosts were compared against the resources available on a 2.1 GHz Cascade Lake x86 server with 16 cores and 128 GB of memory. JMeter drove workload for both client simulated banking transaction processing solutions on x86. The backend database was hosted on an IBM z15™ for both environments (see figure 1).

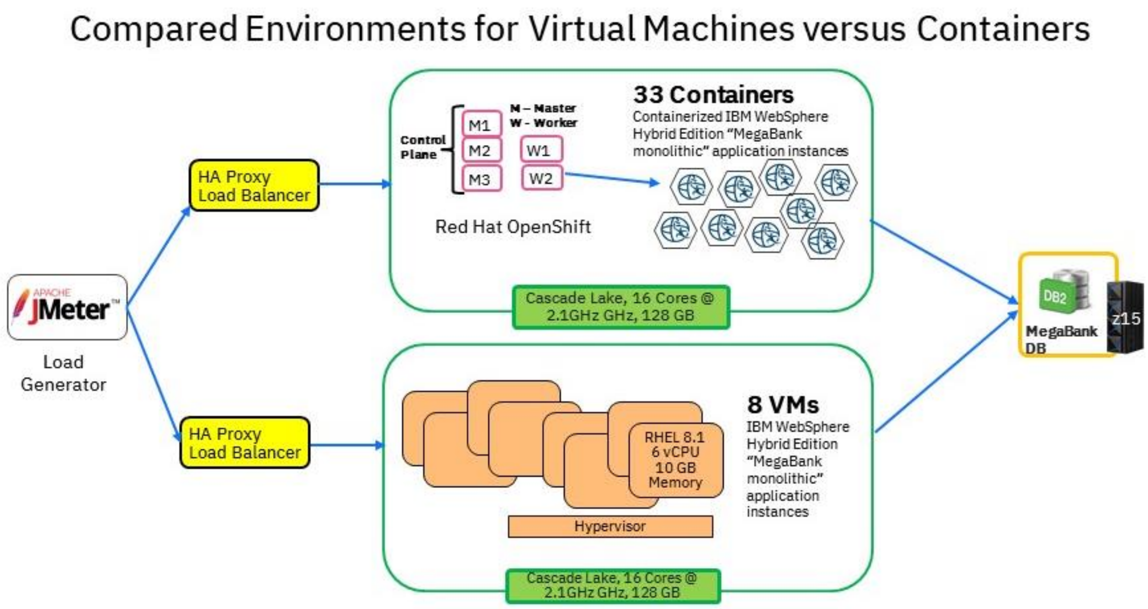


Figure 1: Overview of test environment with JMeter driving client simulated banking solution on x86 with backend database on IBM z15

For the hypervisor environment we made the following assumptions based on the three CPU overcommit ratio, hypervisor host limit, and memory overcommit limit rules observed in client environments.

- CPU Overcommit Ratio (OCR) of 4 virtual CPUs to 1 real CPU
- Hypervisor limit of 1 virtual machine per real CPU
- 1-for-1 virtual memory allocation to real memory AND 20% of memory is left free to facilitate the virtual machine movement

Application activity
The application load for the banking suite was designed to reflect the CPU variance of workload distribution activity observed in datacenters. The workloads were run to simulate a variance in CPU demand with a peak-to-average ratio (7 to 1).

- Average utilization of 488 MHz on a 2 vCPU server (11% utilization) and a 7-to-1 peak-to-average ratio

Although JMeter drove the same workloads to the virtual machines and container environments, testing found that CPU utilization with the virtual machines was significantly lower than with the containers due memory constraints in the VM environment. Without available memory, additional workloads (virtual machines) to improve CPU utilization could not be run within the existing configuration.

Conversely, testing found that in the container environment all of the resources were shared, freeing up memory for more productive use. With additional memory more application instances could be hosted, driving more CPU resource and resulting in more effective use of all resources within the existing configuration.

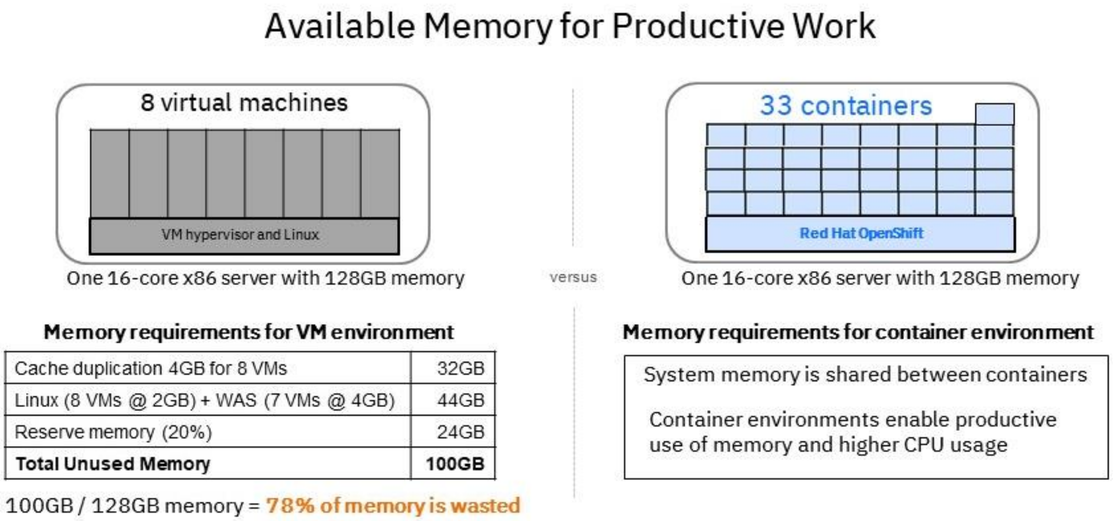


Figure 2: Comparison of available memory for productive work in virtual machines versus containers

The Red Hat OpenShift container environment required 15,536 MHz to deliver a total of 2,676 TPS collectively over 33 containers with a per-container average of 81 TPS and a response time of 3 milliseconds and a CPU consumption of 5.81 MHz per TPS. The same workloads in eight VMs required 3,911 MHz to deliver a total of 627 TPS with a per VM average of 78 TPS and a response time of 6.4 milliseconds and CPU consumption of 6.24 MHz per TPS.

Observations

Even with the virtual machines and containers driving nearly identical workloads, the same x86 environment ran more containers than virtual machines enabling greater throughput.[1] An added benefit was that the container environment also saw a reduction in response time by ½ as a result of lower network latency.[1] Having over 4x more containers than virtual machines drives an increase of throughput by the same 4x factor.

Financial impact

The improved utilization and throughput reduces the amount of CPU and servers required to deliver the same workload, which translates into significantly lower infrastructure costs. To evaluate the financial impact, we examined annual infrastructure costs to run the same amount of workload throughput, that is, 33 containers versus 32 virtual machines. The cost model found that transaction workloads running on x86 can provide a 75% reduction in annual server maintenance, administration and facilities costs using a Red Hat OpenShift container environment versus a virtual machine environment.[4]

[4] Annual server maintenance, administration and facilities costs include hardware maintenance, server labor, networking, floor space and energy costs for x86 servers running transaction workloads in virtual machines versus Red Hat OpenShift containers. Both virtual machine and container environments were run to simulate a variance in CPU demand with a peak-to-average ratio of 7 to 1 driving a total of 2,676 TPS over 33 containers and eight virtual machines. The Red Hat OpenShift environment was comprised of one 16-core

Transactions Per Second (TPS) Workload Results

x86 Red Hat OpenShift containers

TPS per container	Response time per transaction	MHz per TPS	Total System TPS
81 TPS	3 ms	5.81 MHz	2,676 TPS

x86 virtual machines

TPS per VM	Response time per transaction	MHz per TPS	Total System TPS
78 TPS	6.4 ms	6.24 MHz	627 TPS

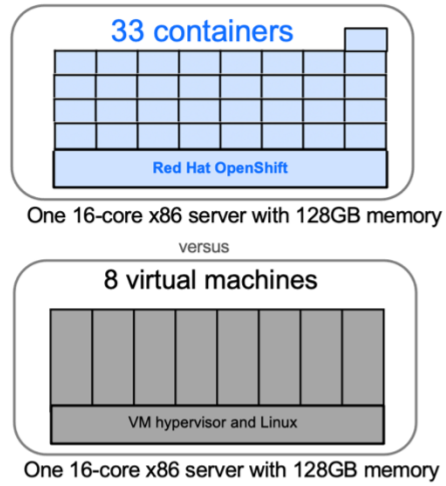


Figure 3: Results from transactions per second (TPS) for workloads in virtual machine and container environments

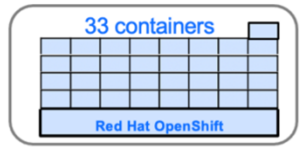
Cascade Lake x86 server running 33 containers. The virtual machine environment was comprised of four 16-core Cascade Lake x86 servers. The results were obtained under laboratory conditions, not in an actual customer environment. IBM's internal workload studies are not benchmark applications. Infrastructure costs are based on client data from IT Economics assessments. x86 hardware pricing is based on IBM analysis of U.S. prices as of June 2020 from IDC. For more information contact IT.Economics@us.ibm.com.

Comparison of Annual Infrastructure Costs

Annual infrastructure cost of 33 x86 Red Hat OpenShift containers

HW Maintenance	$	1,050.00
Labor	$	2,558.00
Space	$	136.00
Power	$	812.48
Networking	$	7,800.00
Total Annual Cost	$	12,356.48

75% Reduction In Annual Infrastructure Costs

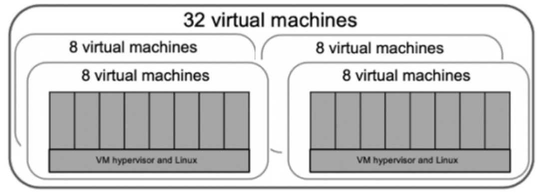


One 16-core x86 server with 128GB memory

versus

Annual infrastructure cost of 32 x86 virtual machines

HW Maintenance	$	4,200.00
Labor	$	10,232.00
Space	$	544.00
Power	$	3,249.92
Networking	$	31,200.00
Total Annual Cost	$	49,425.92



Four 16-core x86 servers with 128GB memory

Figure 4: Comparison of annual infrastructure costs for 33 containers versus 32 virtual machines

Remove wasted resource

Containers can have a significant impact on the efficiency of your IT infrastructure. With access to shared resources within a given environment, containers can leverage more memory and CPU, avoiding memory constraints that can result in low CPU utilization. More effective use of server resources means decreased system requirements, fewer servers, less upkeep and lower infrastructure costs.

Assess the benefits of a container strategy for your organization

For the many reasons explored in this paper, containers offer a variety of efficiency and cost-savings benefits when compared to traditional VM-based application deployments.

If your organization is heading to the cloud, or simply evaluating how to optimize on-prem resources, consider using containers for your workloads. Contact the IBM IT Economics team at IT.Economics@us.ibm.com for more information on Red Hat OpenShift containers. Ask for a no-charge hybrid cloud assessment to determine the most effective infrastructure for your data and cloud based solutions.

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