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Virtualizing Microsoft® Business Critical Applications on VMware vSphere®

Matt Liebowitz
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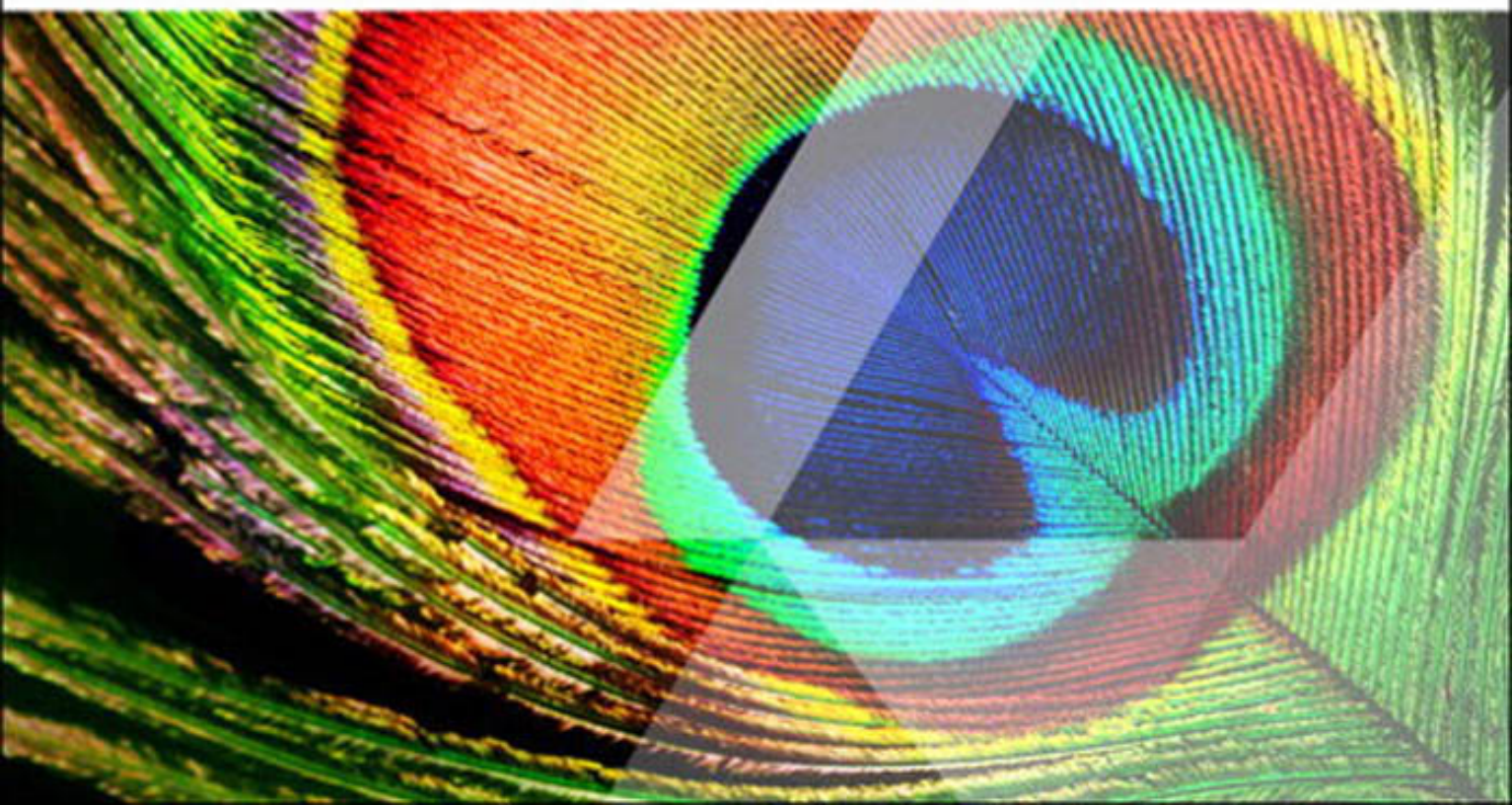
Foreword by **Mark Achtemichuk,** Senior Technical Marketing Architect, Performance Specialist, VMware



Virtualizing Microsoft® Business Critical Applications on VMware vSphere®

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Matt Liebowitz

Alex Fontana

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To Joann, Bean, and Katie Mac—All of this is for you. I love you all very much!
—Matt

To Laura, Joey-boy, Sissy, and Spud—This one's for you guys, but the next one will be just for me, j/k, I love you all very much!
—Alex

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Foreword

It is my privilege to introduce Matt and Alex, two humble and personable authors, with exceptionally brilliant minds when it comes to virtualizing business critical applications, and their new publication, *Virtualizing Microsoft Business Critical Applications on VMware vSphere*.

I've been working passionately with VMware technology for more than a decade, starting when many people were having trouble understanding the value of virtualization, let alone the pending wave that both the GSX and the ESX platforms would unleash on the traditional world of IT. All these efforts afforded me many exciting opportunities and experiences from which I was able to successfully draw to defend an enterprise class virtual infrastructure design and become one of the world's few VMware Certified Design Experts (aka VCDX-050) and actually join the VMware team in 2010. My current challenge, in the role of Performance Specialist within the Technical Marketing team, is to ensure that performance is no longer a barrier, perceived or real, to virtualizing an organization's most critical applications on their journey to the software-defined data center.

Throughout my career, I've met many people but only a small number who truly share my same passion for technology and change. The authors of this book, Alex Fontana and Matt Liebowitz, are two of those people whom I continue to see push the adoption of this business-enabling technology, often against those fearful of change. Their knowledge, experience, approach, and personal respect for every person they work and collaborate with have earned them a reputation as experts in their craft of virtualizing business critical applications.

It is my belief that in order to offer trustworthy guidance on virtualizing business critical applications, one must have experience. Alex and Matt have spent much of their careers architecting, building, operating, and troubleshooting these applications prior to the widespread adoption of virtualization. It is this hands-on, diverse experience, coupled with their in-depth knowledge of VMware vSphere, that makes the advice in this book extremely valuable.

Speaking on behalf of the IT community, we are excited about the future promises of virtualization—not just from a selfish love of technology, but from the realization of true cost savings and the ability to do things more efficiently than ever before. The only way to completely realize this change and its benefits, which is no small challenge, is to ensure that 100% of workloads are virtualized. Only with this continued adoption of virtualization can everyone benefit from a completely software-defined world in which we easily create, operate, and consume IT services. From where I stand, forward momentum always leads to success. Use this book as a resource and I'm confident you will make progress and find success on your own virtual journey.

Mark Achtemichuk

Sr. Technical Marketing Architect, Performance Specialist, VMwareVCDX #50, Performance Geek

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Preface

It's almost hard to imagine an enterprise data center today without virtualization technology. Back when VMware first introduced enterprise class server virtualization with ESX Server in the 2001 time frame, most organizations either had never heard of it or were too skeptical to run anything more than test systems on it. Many people, this author included, were too worried about having "all their eggs in one basket" to see the potential this technology could bring to their data centers.

Fast-forward to today and virtualization has a prominent foothold in the data centers of many enterprises, including nearly all the Fortune 500 companies. It has forever changed the way organizations provision, secure, and manage their infrastructure. IT departments have become more agile, system administrators can manage servers more easily, and IT can enable the business to do more with less.

As virtualization technology has grown and improved, so too has the trust that IT departments and application owners have put in the VMware vSphere platform. Many organizations are now virtualizing their test, development, and production systems with great success. VMware's technologies have enabled them to save money, provide automated workload management, and make disaster recovery easier.

One of the last barriers to 100% virtualization in many organizations, and the driving force behind why we wrote this book, is virtualizing business critical applications. These applications are so important that the business simply cannot function without them, so many organizations have stalled at this point and have kept these servers physical. With this book we aim to help organizations get over that hump and virtualize these applications successfully while meeting the requirements of the business.

Microsoft refreshed many of their key applications between 2012 and 2013, releasing many new versions of their applications along with a new version of Windows Server itself. With each new release of the software, Microsoft improves features and introduces changes that can impact how best to virtualize these applications. With these changes often come new rules for virtualization support, as well as for how to properly license these applications in a virtual machine.

To address these challenges, we decided to write a book to help organizations that want to deploy and virtualize these new applications but are unsure of how to do it properly in their VMware environments. This book is focused on Microsoft business critical applications, including Exchange Server 2013, SQL Server 2012, and SharePoint Server 2013. We hope that our years of experience with these applications as well as with VMware's technologies will help guide you down the path to successfully virtualizing these applications in your organization. In addition, the first few chapters in this book will help you build the business case for virtualizing business critical applications and provide you with

sound strategies to help make you successful. These topics are applicable to all business critical applications, not just those covered in this book.

What to Expect

This book was written with the goal of helping you understand the concepts you'll need to grasp in order to be successful in virtualizing each of the applications we've covered. Along the way, we'll include tips and tricks for how to be successful, information about supported configurations and features, and good (or best) practices for virtualizing these applications on VMware vSphere. For each application, we'll review a basic prototype or proof of concept deployment that can help you familiarize yourself with the new features and functionality before deploying it in production.

The designs described here should not be considered full designs, and you should always understand all of your business, technical, and other requirements before embarking on a project to virtualize these applications. Rather, use the proof of concept deployments as a way to quickly get the application up and running using the methods and supported configurations described within each chapter.

Here's what you'll find covered in each chapter of this book:

- **Chapter 1, "Introduction to Virtualizing Business Critical Applications":** This chapter provides an overview of virtualizing business critical applications in general. Included are the expected benefits that organizations can realize by virtualizing these applications, as well as the risks and objections they are likely to face. The information in this chapter is designed to help you build a business case for your virtualization project.
- **Chapter 2, "Strategies for Success":** This chapter covers the strategies you can use to help make your business critical application virtualization project successful. You learn how to understand the people, process, and technology of a project like this, as well as strategies for capacity planning, licensing, and developing a "virtualization first" policy. The strategies discussed in this chapter are applicable to all business critical applications, not just those covered in this book.
- **Chapter 3, "Overview of VMware vSphere":** This chapter covers the features and technologies included in the VMware vSphere platform. By having a good understanding of these features, you can better plan and design the environment to support your virtualization project.
- **Chapter 4, "Virtualizing Windows Server 2012 Domain Controllers":** This chapter covers virtualizing domain controllers in Windows Server 2012, the latest server operating system from Microsoft. We'll review strategies for sizing virtualized

domain controllers and introduce new virtualization-aware features that are now available in Windows Server 2012 domain controllers.

- **Chapter 5, "Virtualizing Windows Failover Clusters":** This chapter covers how to be successful virtualizing Windows Server 2012 Failover Clusters. Though virtualizing Failover clusters is often feared or hated by administrators, we'll show you how to be successful virtualizing these clusters to support the applications that rely on them.
- **Chapter 6, "Virtualizing Exchange Server 2013":** This chapter covers how to virtualize one of the most popular email platforms in the industry, Microsoft Exchange. The latest version, Exchange Server 2013, introduces a new architecture that changes how organizations plan and size for Exchange deployments. We'll cover how this new architecture impacts your design and how you can successfully deploy a fully virtualized Exchange environment.
- **Chapter 7, "Virtualizing Microsoft SQL Server 2012":** This chapter covers Microsoft SQL Server 2012, one of the most popular database platforms and a staple in most Microsoft-based networks. SQL Server 2012 introduces brand-new availability features that make virtualizing your environment while still maintaining high availability much easier than in previous versions. You learn how to virtualize SQL Server 2012 to take advantage of these new technologies, as well as how to optimize your licensing and potentially save your organization money. Throughout the chapter, we offer tips for how to design your virtualized SQL Server 2012 environment to meet the performance demands of your organization.
- **Chapter 8, "Virtualizing Microsoft SharePoint Server 2013":** This chapter builds on the concepts discussed in Chapter 7 to show how to design and deploy a virtualized SharePoint Server 2013 environment. We'll discuss the new features in SharePoint Server 2013 that make an upgrade compelling, we'll review the sizing and performance requirements for each of the SharePoint Server roles, we'll cover high-availability considerations, and we'll review tips for planning and estimating expected utilization for your environment.

In many cases, the concepts covered in each chapter are applicable not only to the version of the software discussed but to previous versions as well. And high-level concepts in the first three chapters are applicable to virtualizing all business critical applications. Though this book focuses on the latest versions of Microsoft's applications, it is our hope and expectation that you can learn strategies that will help you virtualize other applications as well.

What You Need to Know to Read This Book

You do not have to be a virtualization expert or an application specialist to understand the content of this book. You should have at least a basic understanding of the features of VMware vSphere, because we do not cover basic topics like deploying virtual machines or adjusting virtual machine memory, for example. Understanding the terminology, such as vMotion or virtual machine templates, will help you more easily understand when these topics are discussed as they relate to each application.

Similarly, you should have some level of understanding of the applications covered in the book to get the most value out of them. This book does not go into detail on the overall design considerations of each of the applications, instead focusing mostly on those considerations that are required when the application is run in a virtual machine. You certainly do not need to be an expert in each application, but this basic understanding will help you follow along with the terminology and techniques discussed in each chapter.

Who Is the Target Audience?

We hope that IT professionals across a broad range of technologies and expertise levels will read this book. It was written to help the virtualization architect understand the special needs and configurations that each application requires. It was also written to help the system administrator/virtualization administrator who has to support the infrastructure hosting these virtualized applications. If you're an application owner or architect of one of the applications discussed in this book, you'll find details that can influence your design. Finally, consultants and integrators can find value in this book by learning the necessary details to make their business critical application virtualization projects successful.

In short, we hope that many people within the industry find value on the pages written here. We have been some (or all) of the people to whom we are now writing, so we hope our years of experience will be valuable to you as you embark on your own virtualization initiatives.

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About the Authors

Matt Liebowitz is currently an advisory solution architect at EMC Consulting with a focus on virtualizing business critical applications. He has been working as a consultant and architect for more than 12 years and has been working with VMware's virtualization technology since 2002. Matt has written virtualization articles in several industry publications, has presented on virtualization at conferences and at his local VMware user group, and has been a blogger on the topic since 2009. Matt also worked with VMware to create content for their Virtualizing Business Critical Applications competency for VMware's partners and customers.

Matt is very honored to have been named a VMware vExpert each year since 2010, as well as an EMC Elect in 2013. He also holds numerous industry certifications from VMware and Microsoft. Matt maintains a VMware virtualization-focused blog at http://www.thelowercasew.com, is a frequent contributor to the VMware Technology Network (VMTN), and is active on Twitter at @mattliebowitz.

When Matt is not out trying to save the world through virtualization, he's happily playing with his two young kids, Tyler (3) and Kaitlyn (1), and spending time with his wife, Joann.

Alex Fontana is currently a solutions architect in VMware's Global Center of Excellence. During his eight years at VMware, Alex has focused on the virtualization of business critical Microsoft applications for both VMware IT and external customers. In his current role, Alex helps VMware customers to be successful in virtualizing Microsoft applications by conducting technical workshops and authoring technical documentation and blogs. Alex has been a recurring speaker at VMworld since 2008 and VMware Partner Exchange since 2010, and is a frequent contributor to the VMware Technology Network (VMTN).

When Alex is not busy writing, working with a customer, or trying to break something in the lab, he can be found at the nearest golf course, on a snow-covered mountain, at a San Francisco Giants game, or in the backyard smoking various cuts of meat. Alex lives in the San Francisco bay area with his wife, Laura, and three kids, Joseph, Sissy, and Sergio.

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About the Technical Reviewers

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We Want to Hear from You!

As the reader of this book, *you* are our most important critic and commentator. We value your opinion and want to know what we're doing right, what we could do better, what areas you'd like to see us publish in, and any other words of wisdom you're willing to pass our way.

We welcome your comments. You can email or write us directly to let us know what you did or didn't like about this book--as well as what we can do to make our books better.

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Chapter 1

Introduction to Virtualizing Business Critical Applications

Virtualization has grown over the years from a niche technology for development and testing to a standard technology found in today's data centers. As organizations have become more comfortable with virtualization technology, more and more workloads have become virtualized. If you are reading this book, your organization is likely already traveling down the path of virtualizing servers and reaping the benefits it brings.

Organizations can realize many benefits by virtualizing their servers. They can reduce the power and cooling requirements in their data centers by reducing the number of physical servers required to support their business. By reducing the number of servers required, organizations also save money on the capital costs of servers in addition to the costs of ongoing maintenance and support. Virtualization also facilitates easier disaster recovery by encapsulating virtual machines (VMs) into just a few files, making servers more portable and enabling them to run on dissimilar hardware. We'll discuss these benefits in greater detail later in this chapter.

To achieve these benefits, organizations often seek to virtualize as many servers and applications within their environments as possible. Unfortunately, many organizations reach a level of virtualization where all but their most critical applications have been virtualized.

In this chapter, we explore why organizations should consider virtualizing their business critical applications. We explore the many benefits that organizations can realize by moving these applications into their virtual infrastructure or private clouds. The chapter also reviews some key risks and challenges that organizations can face as they take on a large project like this. Finally, we review common objections and provide counterpoints to each objection to help application owners understand the benefits of virtualization.

By the end of this chapter, you should have a good understanding of why organizations should choose to pursue virtualizing their business critical applications and how to handle common application owner objections. This information should help you build a business case for virtualizing these applications in your own environments.

What Are Business Critical Applications?

Before getting into the benefits, risks, and common objections with virtualizing business critical applications, it is important to understand and define just what makes an application "business critical." Though exact definitions might differ on this subject, most people would agree that the definition of a business critical application includes the following two key elements:

- An application without which an organization is not capable of operating the business
- An application that causes the business to lose significant revenue if it is down or operating slowly

Put into plain terms, a business critical application can be any application that is critical to a business. An application that is not critical to one business might be absolutely critical to another. Simply put, if an application meets the two criteria previously defined, it is likely to be a business critical application to that particular organization.

For example, consider a retail store that runs an application that controls its cash registers. Without this application functioning properly, the cashiers are unable to scan in items or accept payment from customers. That business is unable to operate until that application is back online.

As another example, consider a law firm that relies heavily on the creation of documents for court filings. For a law firm a document management system is a business critical application because it helps lawyers quickly save, categorize, and find documents related to the cases they are working on. Lawyers typically bill their clients by the hour, so if that system is down, the loss of revenue can be easily measured and is often quite high.

The applications covered in this book are business critical to most organizations, but are not meant to reflect the full scope of business critical applications. Though your organization might use some or all of the applications covered in this book, the concepts discussed are relevant to all business critical applications.

Why Virtualize Business Critical Applications?

Now that we've reviewed exactly what makes an application business critical, we will explore why organizations are looking to virtualize these applications. Many organizations have widely adopted virtualization in their environment and have virtualized a significant portion of their infrastructure. The business critical applications are likely to be the applications that remain on physical servers for various reasons. Virtualizing business critical applications can be the next step on an organization's journey to its own private cloud infrastructure.

Although there are many benefits to virtualizing these critical applications, similar to the benefits for virtualizing any application, there are also extra risks and challenges that might make this process difficult. With careful understanding of the risks combined with the benefits an organization can realize, a solid business case can be built for virtualizing business critical applications.

Benefits

The benefits of virtualization that apply to lower-tier or less-critical virtual machines, such as the reduction in cost of servers, power, and cooling, also apply to virtualizing business critical applications. Those benefits, in addition to others that are more specific to business critical applications, are discussed in the upcoming sections.

High Availability

Business critical applications typically require high availability, because downtime to the application can be costly to the business. Some applications have native high-availability features built in, and even those can still achieve better availability when virtualized on the vSphere platform. High availability in this context can be defined as a system or application that is online and available for a high percentage of time, often approaching 100%. Highly available systems often have mechanisms to provide automatic and immediate resiliency to the application when a failure occurs. These systems often operate within the same physical site or location, though newer technologies can provide for high availability of applications across sites.

Both Microsoft Exchange Server and SQL Server serve as good examples of applications that typically require high availability in most organizations. Both applications offer their own native high-availability features, with Exchange utilizing Database Availability Groups and SQL having AlwaysOn Availability Groups (in addition to other high-availability features). These features work at the application level and can offer protection in the event of a server, network, or even storage failure. So does it make sense to virtualize them when they already support their own native high-availability features?

Each of the native high-availability features found in Exchange Server and SQL Server have their own requirements and complexities. For some organizations, these complexities raise the cost of maintaining the environment and are simply not worth it. By virtualizing these applications on vSphere, they can take advantage of vSphere High Availability (HA) to protect their business critical workloads. vSphere HA is used to automatically restart virtual machines if the host on which they are running fails for any reason. The virtual machines are restarted quickly on another host in the cluster, restoring service to the application and end users.

If an Exchange Mailbox server is running on an ESXi host that experiences a failure, that virtual machine will experience a failure and will be restarted on another ESXi host automatically. Organizations get this functionality without having to worry about the complexities of Exchange replication, active and passive database copies, extra storage requirements, and all the other configurations associated with using Database Availability Groups. They might face other challenges using this availability model, such as single points of failure at the operating system and storage level, but for some organizations the availability that vSphere HA provides is enough to meet their availability requirements.

For other organizations with more complex availability requirements, the native high-availability features provided by Exchange or SQL are necessary. To get the best possible availability, those organizations can combine the high-availability features of these applications with vSphere HA to provide better availability than would be easily possible with physical servers.

As an example, consider an organization that has virtualized its Exchange 2013 environment and utilizes Database Availability Groups to maintain three copies of each mailbox database. Let's now say that the motherboard of an ESXi host running an Exchange 2013 Mailbox server virtual machine experiences a failure and the host powers off unexpectedly. In that scenario, the Database Availability Group will quickly detect the failure and activate database copies on a surviving Mailbox server (likely faster than it would take a Mailbox server virtual machine to restart if an organization were relying on vSphere HA alone). vSphere HA will then restart the failed Mailbox server on another ESXi host, restoring the full availability to the Exchange environment quickly and automatically.

Just how quickly could full availability be restored? VMware conducted a test of this exact scenario using the previous version of Exchange, and found that the failed Mailbox VM booted up and resumed replication in approximately three minutes from the time when the first ESXi host experienced a failure. The full details of the test can be found here: http://www.vmware.com/files/pdf/using-vmware-HA-DRS-and-vmotion-with-exchange-2010-dags.pdf. The quick restoration of email service via native high availability in Exchange combined with the ability of vSphere HA to restart virtual machines greatly enhances the availability of the application.

Now consider that same scenario with physical Mailbox servers. After the physical Mailbox server fails, the surviving Mailbox servers would activate the database copies just as they did in the virtual environment, restoring Exchange services quickly and easily. Unfortunately, the physical server that failed would need a hardware replacement. Most enterprise support contracts have a two- to four-hour service-level agreement (SLA) for replacement parts, extending the period during which the Exchange environment is less protected from another failure. When you compare a two- to four-hour restoration time to a three-minute restoration time, you can start to see why many organizations are looking to virtualize their business critical applications in order to enhance availability for their applications. These support contracts are still critical because a failed ESXi host reduces the overall capacity of the infrastructure, but proper design considerations (discussed for each application in each chapter of the book) can help mitigate the risk.

Not all business critical applications have their own native high-availability features. Take multitier applications that utilize middle-tier servers and back-end SQL Server databases as an example. The SQL environment might have its own native high-availability features but the middle-tier servers commonly do not. In that case, you can provide high availability to those applications that do not natively support it themselves. The capability to provide high availability to applications that do not natively support it is a compelling reason to consider business critical application virtualization.

Availability is one of the key reasons why organizations should strongly consider virtualizing their business critical workloads on VMware vSphere. By providing high availability to applications that do not natively support it, or by combining native high-availability features in vSphere with those found in the application, organizations can guarantee higher levels of availability for their applications. Less downtime for applications means more productive end users, a more agile (and relaxed) administrative staff, and a more successful business.

Disaster Recovery

Disaster recovery is another key consideration for business critical applications. As recent history has shown us, hurricanes, earthquakes, and tsunamis are very real things that can have a significant impact on people and businesses. Protecting an organization's most critical applications should be an important factor of any design.

We can define disaster recovery as the process of recovering a server or an application in the event of significant failure or negative situations. Disaster recovery is often a manual process involving the relocation of servers or applications from a failed location to a secondary location that is unaffected by the disaster. Information technology (IT) folks often talk about disaster recovery in terms of major disasters like earthquakes, asteroid impacts, or the zombie apocalypse (you know who you are), but the reality is that the

disaster does not have to be so catastrophic. In reality, a disaster can be a water pipe bursting above your server room, a fire in the building, an extended loss of power, or even the failure of a critical piece of hardware. Organizations need to be prepared to deal with disaster and recover from it in order to keep the business operating.

At its core, virtualization can provide a means of disaster recovery simply by encapsulating virtual machines into individual files that are portable. Copying critical virtual machines to an external hard drive before a hurricane makes landfall is, while certainly not the best, a simplistic example of how virtualization facilitates easier disaster recovery for all applications.

Copying virtual machine disk files to an external hard drive is likely not going to be an acceptable disaster recovery plan for most businesses. Instead, companies will want to consider a more robust solution that can provide disaster recovery in a simpler, more unified way. By virtualizing business critical applications on vSphere, organizations can take advantage of technologies like VMware Site Recovery Manager to help aid in disaster recovery plans. Site Recovery Manager can be used to create recovery plans for critical virtual machines that are used to control which applications are protected, how they are replicated between sites, and in which order they are restarted in the secondary site. In addition, Site Recovery Manger offers the capability to fully test a disaster recovery failover without actually declaring a disaster. The more workloads that are virtualized on vSphere, the more of an organization's servers that can be included in the disaster recovery plan.

Similar to the discussion around high availability, what if an application already includes native functionality that can allow for disaster recovery? Both Exchange Server and SQL Server offer native functionality that can replicate data between sites to provide for disaster recovery. As with before, for many organizations the complexity of maintaining multiple replication technologies for multiple applications means higher cost and higher complexity, which could lead to extended outages and longer recovery times. When all recovery plans are unified to a single tool, Site Recovery Manager, a single team is capable of restoring multiple applications in the event of a disaster. That can significantly reduce complexity and speed recovery, because multiple application teams are not required to execute recovery plans for the individual applications.

NOTE

Not all organizations want to have disaster recovery for all applications managed through a single interface and by a single team. For example, for some organizations it makes more sense for the messaging team to handle Exchange disaster recovery and the database team to handle SQL disaster recovery. Always understand the requirements of your organization before making any decisions around disaster recovery.

The features that provide high availability in Exchange Server and SQL Server are the same features that also provide disaster recovery. By combining those features with Site Recovery Manager, you can still utilize tools like SQL Server 2012 AlwaysOn Availability Groups to maintain high availability within the primary site while using Site Recovery Manager for disaster-recovery purposes. The combination of technology can often provide a "best of both worlds" configuration for an organization.

Many applications do not provide any native means for providing disaster recovery. For those applications, virtualizing them on the vSphere platform and leveraging Site Recovery Manager can once again provide functionality that is simply not possible by running the application on a physical server.

The disaster recovery capabilities of the vSphere platform and Site Recovery Manager present a compelling reason for organizations to virtualize their business critical applications. Even if the application already provides native disaster recovery functionality, businesses can still see additional benefits by virtualizing the application on vSphere.

Scalability

With business critical applications, the ability to create an environment that is scalable to meet the demands of the business is of huge importance. Resource needs of an application can grow for various reasons, including differing business cycles, increases in demand, or normal end-of-month processing. An e-commerce company might see increased spikes in demand during the holiday season, when more orders are placed through their systems than during any other time of the year. Similarly, an accounting firm might experience huge increases in customer demand and activity as the deadline to file taxes approaches. For these and many other similar situations, it is important that an organization's business critical applications are able to scale to meet demand.

If an organization deploys its critical applications on physical servers, scalability becomes much more difficult. Physical servers typically would have to be sized to meet the maximum expected demand despite the fact that this demand might occur only during brief periods every month, every quarter, or even every year. This raises the total cost of the environment and leaves the system largely underutilized for much of the year.

Virtualizing these business critical applications on VMware vSphere can aid in scalability in two key ways. First, vSphere utilizes a technology called Distributed Resource Scheduler (DRS) that can automatically balance workloads among ESXi hosts in a cluster to balance out resource demands. If an ESXi host is becoming overloaded because a SQL Server database is processing many transactions on the same server on which the web server is processing customer requests, causing a large spike in CPU utilization, DRS can automatically perform vMotion migrations to balance out the load on that host and return utilization to normal levels.

The other key scalability benefit that vSphere provides is the ability to add CPU and memory resources to running virtual machines *with no downtime*. The application and the operating system need to support this functionality in order for the new hardware to be recognized. For example, newer versions of Windows Server, starting with Windows Server 2008 R2, Enterprise Edition (and above) natively support it. In the scenario described previously, in which the CPU utilization on a SQL Server virtual machine is growing out of control due to high demand, a vSphere administrator can add CPU resources to the server and run a simple command to make the application aware of its new resources. By providing a way to scale resources on the fly in the event that demand requires it, vSphere administrators possess a powerful scalability tool that provides a huge advantage over deploying business critical applications on physical servers.

CAUTION

Be careful of becoming overzealous and adding too many resources on the fly without properly managing capacity. The hot-add feature should be used only when an application's demand calls for it, when there are sufficient resources available to provide to the virtual machine, and when the application actually supports it. For example, providing CPU resources to a VM when the host does not have spare CPU capacity to provide can actually hurt the performance of not just that virtual machine but other VMs running on the host as well.

In addition, at this time there is no capability to remove CPU or memory resources on the fly without shutting down the VM first. If you've added CPU or memory resources to meet increased demand, be sure to revisit that VM after demand has subsided and remove the resources if they are no longer necessary.

Provisioning

Application owners and developers commonly need new servers to deploy new applications, test application updates, or for a variety of other reasons. Databases in particular are a common request of developers who frequently need new databases or entirely new SQL servers to test their applications. If physical servers are used, these requests can take days or even weeks to complete.

By deploying these business critical resources on the vSphere platform, administrators can deploy new instances much more quickly than if they had to deploy them on physical servers. Administrators can take advantage of vSphere features like templates to create master images of particular applications and then deploy them quickly when needed.

Similarly, the provisioning of new resources to virtual machines is also done quickly and easily. In many cases, resources can be added on the fly without the need to shut down the virtual machine. If a virtual machine needs more space on its virtual hard drive, the drive can be expanded without the need to shut down the virtual machine. In a physical server, adding new local storage to a server typically requires downtime. Other resources, such as virtual network cards, can also be deployed on the fly without any downtime.

CAUTION

The capability to provision new servers quickly and easily can be a bit of a double-edged sword. Though it's easy to deploy new servers, the ease with which new VMs can be deployed can lead to significant virtual machine sprawl. In this scenario, an organization ends up with far more virtual machines than they ever had with physical servers. Virtual machine sprawl can result in higher costs for licensing, management, and monitoring.

Proper life cycle management is very important in virtual infrastructures so that you can make sure that servers are properly patched, protected, and ultimately decommissioned when they are no longer required.

Testing

Administrators or application owners often need to test updates or changes to their applications that are live and running in production. If the application is virtualized, they can simply make a clone of the virtual machine and have an identical copy of the server to use as a test server. Clone operations do not cause any downtime to the virtual machine being cloned and, when properly isolated, enable developers or application owners to perform tests against actual data rather than on development or test servers. This is another example of a capability that is simply not easily possible with physical servers.

Another way virtual machines make testing applications much easier is with snapshots. Virtual machine snapshots provide a way to quickly and easily go back to a point-in-time copy of the virtual machine. This can make testing changes in a virtual machine much simpler, because a change that causes harm can be quickly undone by reverting to a clean state at the time the snapshot was taken. After it is verified that the change does not cause any undue harm, the snapshot can be deleted and the changes are committed to the virtual machine. This functionality would be difficult to duplicate with physical servers.

CAUTION

Always make sure that the application supports the use of snapshots before utilizing them in your environment. Not all software vendors support the use of virtual machine snapshots, and in certain scenarios taking snapshots can actually cause harm. Microsoft does not support the use of snapshots with Exchange Server, for example.

Also note that snapshots are not a replacement for backups in the virtual environment. They should be used for testing purposes and then removed when they are no longer needed. Snapshots that are left to grow can hurt performance and consume unnecessary disk space.

Consolidation

One of the "classic" benefits of virtualization has always been consolidation, or the capability to consolidate multiple physical servers into virtual machines running on fewer physical servers. This can provide an organization with potentially large savings on the cost of the servers, as well as the hard and soft costs for managing and maintaining those servers. There are also cost savings for the power and cooling that would be required to support those physical servers.

Business critical applications can also benefit from consolidation through virtualization. Many of these applications are complex, often broken up into multiple roles within the same application and requiring multiple servers. Or the application could have native clustering or high-availability features that require multiple servers deployed for one application.

Microsoft Exchange Server and SQL Server are both good examples of business critical applications that can benefit from consolidation. In Exchange 2010, the previous version of Exchange, there were five server roles that each served different purposes. If an organization wanted to separate those roles into separate physical servers, it would require a significant investment in hardware to accommodate that requirement. By virtualizing the roles of Exchange, the organization can achieve the same goal of role separation while still consolidating onto fewer physical servers. The new version, Exchange 2013, has reduced the server roles to two, still offering some benefits for consolidation.

SQL Server also has separate components as well as native high-availability features that can require multiple physical servers. By virtualizing SQL Server onto fewer physical servers, organizations can still use dedicated servers for specific components or utilize high-availability features while still reducing the physical footprint. In addition, consolidating SQL Server can have a significant impact on the cost of licensing. This topic is discussed further in Chapter 7, "Virtualizing Microsoft SQL Server 2012."

Consolidation is typically not the main reason why organizations choose to virtualize a business critical application. That said, organizations can still realize the benefits of consolidation even with business critical applications.

Risks, Challenges, and Common Objections of Virtualizing Business Critical Applications

Now that we've reviewed the many benefits that organizations can realize by virtualizing their business critical applications, let's review some of the risks, challenges, and common objections that organizations will face along the way. By understanding both the benefits and the risks, you will be able to understand the full scope of virtualizing these applications and be able to build a better business case. You'll also be more likely to succeed if you go into this with your eyes wide open.

The preceding section might have made it seem as though virtualizing your organization's business critical applications was all rainbows and unicorns and nothing could go wrong, right? The truth is that almost any application can be virtualized on the vSphere platform, but without the proper planning up front and understanding of the risks, it is easy to fail. This section outlines the risks and common objections to virtualizing business critical applications and provides ways to combat these objections with facts, benefits, and counterpoints.

Performance

The biggest concerns that application owners and businesses are likely to express about virtualizing their critical applications are around performance. These are the most common objections you are likely to hear, in one form or another:

- My application will perform more slowly if it is virtualized on vSphere.
- If my application has to share resources with other virtual machines running on the same host, it will perform poorly.
- My application requires too many resources (such as CPU and memory) to virtualize.

It is true that if an application is not properly sized, or a virtual infrastructure is not properly designed, applications can experience decreased performance when they are virtualized. Similarly, if an organization carries over poor practices from the physical world (such as oversizing systems with more CPU and memory resources than they actually need) into the virtual world, performance of the organization's applications can suffer. Without careful planning you could easily fall into the pitfalls of the three listed items.

The best way to avoid performance problems is to treat a business critical application differently from all other applications you might have virtualized thus far. Just because you were successful in virtualizing a front-end web server does not mean you'll have the same success virtualizing the back-end SQL database using the same process. Business critical applications have different requirements than lower-tier applications, so they typically require more planning before virtualizing them. A proper capacity-planning exercise should be performed before the application is virtualized so that you understand exactly what the resource demands will be and you can size the virtual machines, and the environment, properly.

For example, the host on which the business critical applications are running should not have high resource overcommitment or, ideally, any at all. It might be a common practice to overcommit resources on ESXi hosts in your organization to increase consolidation ratios, but that practice can hurt the performance of business critical applications (and might not even be supported by some applications). High consolidation ratios are not typically a goal of virtualizing business critical applications (though it can be an ancillary benefit), so don't try to cram in too many virtual machines per ESXi host.

To address the most common objections, let's go through them one at a time. First, application owners might think that their application will perform more slowly if it is virtualized on vSphere. In fact, VMware has performed numerous performance tests that show that major business critical applications like Microsoft Exchange Server, SQL Server, and others perform as well when virtualized as they do when they are on physical servers. In some cases, the applications actually perform *better* when virtualized than if they are physical, due to the limits of scalability within the application itself. By deploying multiple copies of the same application on the same host, it can often scale better than if a single copy was installed directly onto the physical server. On VMware's Virtualize Business Critical Applications blog (http://blogs.vmware.com/apps), you can find these performance studies and other details that can be great resources for organizations looking to be successful with virtualization initiatives.

TIP

The best way to avoid performance problems is to perform a thorough capacity planning exercise before virtualizing the applications. Simply moving the servers into the virtual infrastructure can often lead to improper sizing and poor performance.

Remember, you can experience performance problems if a server is undersized or if it's oversized. Capacity planning can help you understand the actual utilization of the application so that it can be sized accordingly. We discuss capacity planning in much greater detail in Chapter 2, "Strategies for Success."

Next, a common concern is that performance will suffer if a business critical application needs to share resources with other less important virtual machines on the same ESXi host. This can happen without the proper planning up front or if the goals of the virtualization effort are misaligned, but with a proper design this should be an unlikely scenario. The vSphere platform provides numerous technologies that can be implemented to help control access to resources so that this does not occur. For example, vSphere offers the capability to provide resource reservations for particular VMs, where they reserve a specific amount of resources ahead of other virtual machines. This guarantees access to those resources and can be especially useful if other workloads run on the same host, or if a host experiences a failure and more workloads are running on an ESXi host than originally intended. In addition, features such as Storage I/O Control and Network I/O Control can help control the "noisy neighbor" scenario in which another virtual machine is consuming too many disk or network resources. These tools are especially important as organizations move their most critical applications into their own private clouds.

While there have been major improvements to the vSphere platform over the years, there have also been significant advances in the world of storage and networking. These advances make virtualizing business critical applications easier than it was in the past. Storage performance has vastly improved in recent years, with storage arrays that offer automatic tiering systems to move highly accessed data to the fastest disks available. The introduction of solid-state drives into enterprise-class arrays has also greatly improved storage performance, making it possible to meet the performance needs of even the most demanding applications. On the networking side, 10Gb Ethernet has become more prevalent in today's data centers, which greatly increases the bandwidth that applications have available to them.

Finally, some application owners think that their applications simply have system requirements that are too high to be satisfied by the vSphere platform. As the vSphere platform has improved over the years, so too has the scalability of the platform itself. As of vSphere 5.1, a virtual machine can now be configured with 64 vCPUs and 1TB of RAM, and can achieve up to one million I/O operations per second. This should satisfy the needs of even the largest business critical applications. Often the maximum recommended system configuration for a business critical application is far below the capabilities of modern server hardware, so without virtualization there would be large amounts of wasted resources.

In Table 1.1, you can see what approximately 95% of applications actually require in terms of resources, and what the vSphere platform is capable of supporting. VMware gathered these 95% statistics from the thousands of customers who have uploaded data to their Capacity Planner tool (which we'll discuss in more detail in the next chapter). It is clear that nearly any application can be virtualized on the vSphere platform.

Table 1.1 Resource Scalability of the vSphere Platform

	95% of Apps Require	ESX 1	ESX 2	VMware Inf. 3.0/3.5	VMware vSphere 4	VMware vSphere 5.1
CPU	1 to 2 CPUs	1 VCPUs	2 VCPUs	4 VCPUs	8 VCPUs	64 VCPUs
Memory	<4GB at peak	2GB per VM	3.6GB per VM	16/64GB per VM	256GB per VM	1,000GB per VM
Network	<2.4Mbps	<.5Gbps	.9Gbps	9Gbps	30Gbps	>36Gbps
IOPS	<10,000	<5,000	7,000	100,000	300,000	1,000,000 per VM

Supportability

Another common objection that organizations might raise about virtualizing business critical applications is the supportability of these applications on a virtual platform. Once again, this is actually a valid risk in that if it is not implemented properly, the software vendor might very well not support the application. Now that virtualization has become much more prevalent, many software vendors have clarified their support statements for applications running in a virtual environment.

It can be easy to ignore vendor-specific support statements and simply deploy the application on vSphere as if it were being deployed on a physical server. By not paying close attention to the vendor's support requirements, you run the risk of virtualizing the business critical application in a fashion that is not supported by the vendor.

Microsoft, for instance, has specific support statements for applications like Exchange Server and SQL Server that dictate the requirements for running them in a virtual environment. For example, only specific versions of SQL Server are supported in a virtual environment, and if you plan on clustering your SQL servers, only specific versions of Windows are supported as well. Similarly, Microsoft supports only a two-to-one overallocation of physical CPUs to virtual CPUs (that is, assigning only a maximum of double the number of virtual CPUs than there are physical CPUs in the server) for Exchange Server. Many organizations are used to much higher consolidation ratios and might inadvertently run Exchange in an unsupported fashion.

There are other virtualization-specific support requirements that might be overlooked that can lead to an unsupported configuration. Software vendors might not support the use of virtual machine snapshots for their applications, yet snapshots are a common practice in many organizations. Snapshots are typically not supported on applications where databases are in use (such as Exchange Server or SQL Server), because there can be issues when

reverting those virtual machines to previous versions of the snapshot. In that scenario not only could your organization be in an unsupported configuration, but you could actually cause problems for the applications you are trying to protect.

By paying careful attention to vendor support statements for running their application in a virtual machine, you can avoid many of these risks. Most businesses cannot survive extended outages without their critical applications running, so maintaining proper support is incredibly important. Always follow the individual vendor's specific guidance around how to run their application properly in a virtual machine.

TIP

Much as with capacity planning, make sure you understand the supportability requirements of applications before embarking on a project to virtualize them. Obtaining vendor support has become easier in recent years as virtualization has gained in popularity and independent software vendors recognize that their customers are using the technology. That said, you should always review all support requirements first and make sure you deploy supported configurations.

In some cases, vendors that have restrictions around virtualizing their applications can be persuaded to create custom support statements on a per-customer basis. If your software vendor does not support virtualization, you should inquire about a custom support statement, especially if you are a large customer with a significant number of purchased licenses.

Management

Application teams and administrators of business critical applications are used to having a physical server that they own and can operate as they see fit. If they need to access the console of the server, they can use remote tools like HP Integrated Lights Out (iLO) (or similar) or network-based keyboard, video, and mouse (KVM) systems. There is typically nothing sitting in between the administrators who manage the server/application and the application itself.

When an application is virtualized, however, the vSphere platform now sits in between the administrator and the server or application. Although the administrator can use common remote desktop tools to access the server, he loses the ability to do things like access the console, walk up to the server and insert a CD/DVD, or press the power button to reset the server if it is hung. For these reasons application owners might resist the move to a virtual infrastructure for fear of losing "control" of the application.

The loss of the ability to manage the application is a valid concern for application owners, and one that vSphere and business critical application architects need to take into consideration. Luckily, VMware vCenter includes a granular role-based access control system that is fully integrated with Microsoft Active Directory. Administrators can grant granular access rights for specific virtual machines to the application owners, restoring their ability to manage the application the way they did in the past.

Not providing this access is a great way to alienate the application owner and make other application owners more hesitant to move their applications into the virtual infrastructure. A thorough understanding of the application owner's requirements should uncover this need and it should be included in your design.

Reliability

Right behind performance, questioning the reliability of the vSphere platform is typically one of the most common objections from application owners when virtualizing their applications. After all, the business depends on these applications, so reliability is important to make sure that they remain online and operational.

Just as with performance, if your environment is not properly designed or implemented, there is a very real risk of reduced reliability when virtualizing these applications. For example, if your environment relies heavily on overcommitting memory on your ESXi hosts, the reliability of your application can suffer during peak utilization periods. The same can be said if the vSphere environment as a whole is not properly maintained, secured, or monitored. After all, the virtualized application is only as good as the platform on which it runs.

The vSphere platform has proven year after year that it can provide the reliability that business critical applications require. The ESXi hypervisor was introduced without a general-purpose operating system like the previous version, ESX, reducing the attack surface of the platform and also reducing the frequency with which it needs to be patched. The ESXi hypervisor also utilizes hardware drivers that are optimized for virtualization rather than generic vendor-supplied drivers that other hypervisors rely on. By limiting the hardware drivers to only those that are tested and optimized, the likelihood of a system failure is reduced.

Despite the smaller ESXi hypervisor, patches are still required. VMware has a tool called vCenter Update Manager that can be used to streamline the installation of patches on ESXi hosts. vCenter Update Manager can scan hosts and determine whether they are compliant with the latest patches and, if not, indicate which are missing and facilitate the installation of these patches. Maintaining a regular patching schedule for ESXi hosts is

important to make sure your organization remains compliant with the latest security and functionality updates.

When patches are required or hardware maintenance must be performed, features like VMware vMotion enable the live migration of workloads between ESXi hosts without any downtime to the application. This can increase the uptime of these applications while still enabling administrators to maintain the servers and keep them up to date. Should there be an issue with an ESXi host patch, the system supports the ability to roll back to the previous state to quickly and easily restore functionality.

Finally, the maturity of the ESX/ESXi platform shows that it is trusted and reliable. VMware has won numerous awards over the years from many in the technology industry, including prestigious titles such as Best Virtualization Solution (Cloud Computing World Forum, 2012) and Best Virtualization Platform (InfoWorld, 2012). These awards show that the industry trusts the vSphere platform with the most critical virtualized workloads.

Customers have trusted the ESX/ESXi platform for over 10 years, and VMware has continued to improve the features, functionality, and reliability of the platform. In fact, VMware states that 100% of the Fortune 100 and 98% of the Fortune 500 use VMware products. That is a testament to the reliability of VMware's products and the trust that even the largest organizations place in them.

Security Risks

Another very common objection against virtualizing business critical applications involves concerns about security. If an application is critical to the business, security of that application is crucial, so it is easy to see why it can be a common objection to virtualization.

Back in the early days of the ESX platform, virtualization was new and many folks did not understand how the basic concepts actually worked. VMware worked hard to educate their customers by discussing concepts like "encapsulation" and "isolation" of virtual machines. Though VMware does not need to describe these somewhat basic concepts anymore, it can be helpful to revisit them to reinforce why vSphere is a secure platform for business critical applications. Virtual machines are completely encapsulated into a small set of files rather than the thousands of individual files that typically make up an operating system and application installation. These files are not typically shared between virtual machines, so the data within the files remains secure without risk of another virtual machine accessing them (with the one exception being certain virtualized Windows clustering configurations in which a disk is shared between cluster nodes). Similarly, a virtual machine is isolated from all other virtual machines so that the operation of one does not affect the other. An application or operating system crash in one virtual machine has no impact on another due to this isolation.

Because virtual machines are made up of a small set of files, controlling access to these files becomes very important. By default, ESXi does not allow remote connections using tools like secure shell (SSH), and that configuration should not be changed unless you are troubleshooting a problem. ESXi can also be integrated with Active Directory for authentication, enabling you to closely audit who is connecting to hosts for auditing and compliance. By adhering to these good security practices, you can help mitigate the risk of the console of an ESXi host becoming compromised.

If a single virtual machine is compromised via a security vulnerability (in the operating system, for example), other virtual machines are not automatically exposed. That means that if a hacker gains access to a single virtual machine on an ESXi host, the individual does not automatically have access to all virtual machines running on the host. The isolation of virtual machines inherently provides security benefits similar to if the servers were physical.

VMware continuously improves the ESXi platform and releases security patches to address any vulnerabilities that are discovered. Due to the smaller size of the ESXi code base, there are far fewer security updates than with other platforms like Microsoft Windows or even previous versions of VMware ESX. If administrators remain vigilant about patching ESXi hosts with security updates when they are released, they can greatly reduce the risk of an entire host becoming compromised.

Taking a step beyond the basic concepts, VMware also offers a full suite of security products to help augment or improve the security of virtualized environments. The vCloud Networking and Security suite of products (formally released as individual products under the vShield suite) can provide a robust set of security features, including (but not limited to) these:

- Perimeter security services including firewall, Network Address Translation (NAT) services, and Virtual Private Networking (VPN) connectivity
- Application-level firewall that maintains security as virtual machines migrate between hosts
- Virtual appliance that allows for the offloading of antivirus operations from the virtual machine to the hypervisor
- VXLAN, a technology that, very simply stated, creates a logical layer-2 network that can span physical boundaries for a very scalable virtualized networking solution

VMware also provides vCenter Configuration Manager, an application that monitors and reports on configuration changes and compliance. By constantly monitoring and reporting on any change that happens both in the virtual infrastructure and within the virtual machines, administrators can maintain compliance as well as be able to pinpoint when

changes (authorized or otherwise) were made in their environments. Change control and compliance with regulatory mandates are crucial for many business critical applications, and vCenter Configuration Manager can help put application owners at ease with the knowledge that their applications are protected and compliant.

In addition to the features found in vSphere and other VMware tools, standard security practices that are used in physical servers can be carried forward to virtual machines as well. This includes things like role-based access control for access to virtual machines, security software run inside the virtual machine, or other common requirements that application owners might have to secure their servers.

By combining the native security features of vSphere with the security, compliance, and auditing features of vCloud Networking and Security, application owners should feel confident that their applications will be protected and secure when virtualized.

TIP

Security concerns can quickly derail a virtualization project when business critical applications are involved. Involve the security team up front during the planning and design process so that there are no surprises later.

Complacency

It's the classic "if it ain't broke, don't fix it" argument: Why should an application owner who currently has his applications on physical servers make the decision to move that application to the vSphere platform? This is a common objection and one that can derail a project if not properly addressed.

Application owners are used to running their applications on physical servers and might not understand the benefits of moving to a virtual infrastructure. They also might not be experiencing problems with their application, especially if it is running on modern hardware and is well managed. Additionally, application owners can have concerns about the effort involved in moving their application to a virtual platform and might not feel that the benefits are worth the risk or time investment.

These and other reasons are commonly why application owners become complacent and unmotivated to move their applications to the virtual infrastructure. Typically, the best way to combat complacency is to understand the issues and pain points that the application owners are currently dealing with. Are they using complicated clustering solutions to maintain high availability? Can they provide high availability at all for their application? Do they have a disaster recovery strategy for their application?

By understanding the issues application owners face on a daily basis, you can better frame the conversation and showcase the benefits of virtualizing their application. If an application has no native capability to provide high availability, for example, showing that vSphere provides this capability to all virtual machines might make them rethink their decision to remain physical.

Even if application owners are happy with the current application performance and availability features, highlighting the features of vSphere that are not easily possible on physical servers can help tip the scales in favor of virtualization. For example, showing that vSphere has the capability to add resources on the fly without downtime or deploy new servers quickly to meet demand can help application owners see the benefits. Including the application in a disaster recovery solution that already protects many other applications and can easily be tested without incurring downtime is likely to be another key selling point. Also, the capability to easily test patches and updates and then roll back quickly if there is a problem is another major benefit that is not easily possible with physical servers.

Finally, private clouds can be disruptive forces in organizations, so it is important to explain all the benefits they provide. If an organization is moving toward a private cloud model, complacent application owners might find themselves on the outside looking in if they do not adapt to this new paradigm.

TIP

When it comes to virtualizing business critical applications, cost savings is not typically the main benefit or business driver. When speaking to application owners who are complacent, highlighting cost savings is not likely to be a big enough driver to convince them to move their applications to vSphere. Instead, focus on the challenges they face in managing and maintaining their application and on how moving the application to vSphere can help them in their day-to-day operations. By showing them how they can provide better service to end users and be more agile in responding to changing demand, you can help shift the attitude away from complacency toward agreement.

Summary

Business critical applications are often the engines that run the business, allowing businesses to bring in revenue and operate on a daily basis. Without these applications running, the business can be severely impacted and have its capability to bring in revenue significantly reduced or removed completely. Clearly, making sure that these applications remain operational and perform as expected is crucial to keeping businesses successful.

By virtualizing business critical applications, organizations can enhance the availability of their applications by leveraging the availability features found in VMware vSphere. They can also combine the native high-availability features found within their applications along with the features of vSphere to provide better availability than would be possible with physical servers. After the applications are virtualized, they can take advantage of applications like VMware Site Recovery Manager to provide an easier disaster recovery process that is also difficult to duplicate with physical servers.

The scalability of the vSphere platform enables it to virtualize even the most demanding applications, with support for up to 64 virtual CPUs and 1TB of RAM per virtual machine. As resource demands change, vSphere provides the capability to quickly deploy new servers or even add CPU or memory resources to virtual machines on the fly and without any downtime. Using these features can replace the potentially several-week process of procuring new physical servers, racking them in your data center, and installing an operating system and application.

As with all disruptive changes in technology, there will be some who cannot see the benefits and will voice objections to virtualizing business critical applications. They might have concerns about the performance of their applications, support from software vendors, or the security of a multitenant virtual environment. Application owners also might have simply become complacent over the years and might not want to introduce any change. By understanding their objections and providing feedback on the many benefits of virtualizing their applications, you can convince the application teams of the value of virtualizing their applications.

Taking the time to understand the benefits along with the common objections you might face is crucial for success in virtualizing business critical applications. After you are armed with this information, you can build a strong business case for your virtualization initiatives. Having the buy-in of the application owners, as well as the security team, system administrators, and management, will be key to your success.

In the next chapter, we'll cover strategies you can use on your business critical application virtualization projects. These strategies are designed to be generic enough to use for multiple applications, even those not covered in this book.

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