AC 2011-1882: INCORPORATING VIRTUAL LAB AUTOMATION SYSTEMS IN IT EDUCATION

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Incorporating Virtual Lab Automation Systems in IT Education

1. Introduction

Online education has witnessed tremendous growth in recent years. Advances in technologies have made it possible to deliver not only lectures, but also hands-on labs remotely. Traditionally, online courses were heavily weighted towards lecture and paper assessments; this was justified due to lab hardware cost, lab availability, and inability to objectively measure student lab performance. While cost remains a factor in any course with a lab component, implementing new technologies such as virtualization and cloud computing has mitigated and in some cases completely removed ancillary lab issues. Different virtual lab approaches, centralized or decentralized, have been tested or implemented in many educational institutions[1,2,3,4]. Previous studies usually focused on a single system, for example, how VirtualBox was used in a particular course. In the Information and Computer Technology program at East Carolina University, we have deployed multiple virtual lab systems and approaches over the past 5 years. The focal point of this paper will be two centralized virtual lab automation systems and our experience using those systems.

Virtualization allows multiple guest operating systems to run concurrently on a physical computer. This technology has facilitated the development of cloud computing which allocates information technology services and applications dynamically and on-demand to end users. Virtualization and cloud computing have been rapidly adopted in information technology (IT) education because they provide cost-effective ways of delivering complex, hands-on learning experiences. The benefits of virtual labs include, but are not limited to, high availability, easy access, low hardware and maintenance costs, and fast content deployment.

With the rapid development of cloud computing, it is likely more IT labs will be hosted in the "cloud" in the near future. Although the resources provided by a cloud may be located at different locations, the clients usually access it through a central, remote server. A centralized approach makes it possible to deploy complicated virtual labs which require high-end equipment and resources. The virtual machines in the cloud are often hosted on a virtualization infrastructure such as VMware vSphere and managed by a virtualization management tool such as VMware vCenter. Although vCenter is effective in managing virtual machines and virtual datacenters, it does not directly provide a user-friendly provisioning (allocation) system for individual virtual lab users.

Virtual Lab Automation (VLA) systems facilitate the need by automating IT labs using underlying virtualization technology. Some notable VLA systems include Virtual Computing Lab (VCL), VMware vCenter Lab Manager (VLM), formerly known as VMware Lab Manager, and VMLogix LabManager (recently acquired by Citrix), among others. Virtual Computing Lab (VCL)[5] is a free, open source, virtual lab automation system originally developed at North Carolina State University and released under the Apache license in 2008. Figure 1 depicts a simplified VCL infrastructure. The user makes a reservation for a virtual environment through the VCL web site. The scheduler will check whether the virtual environment (VE) is already available to the user. If not, the scheduler will instruct the management node to retrieve the VE

image from the application image library, load it on a virtual machine or a physical server and make it available to the end user. The user may access the virtual environment using different protocols, including RDP, SSH, and VNC. After the reservation ends, the virtual machine or physical server will be released and made available to host virtual environments for other users. A VCL server can be installed on a Linux virtual machine or physical computer and can provision (allocate) not only virtual machines but also physical computers.

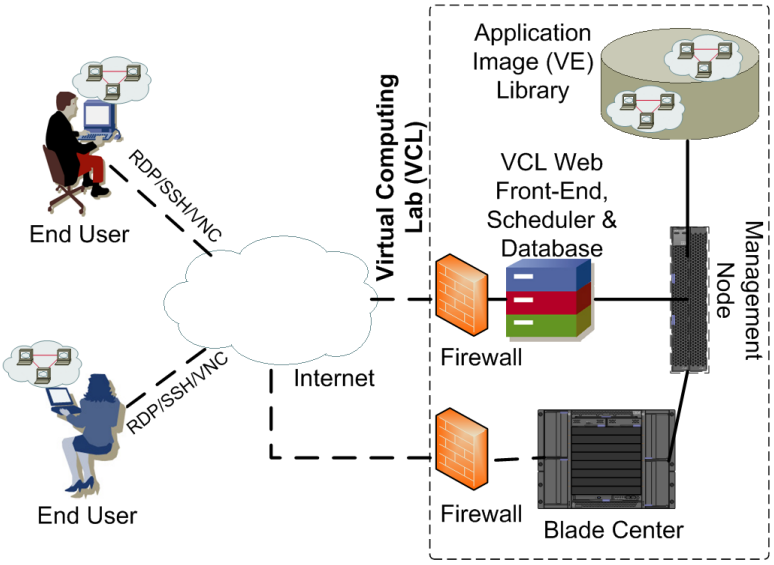

Figure 1. Virtual Computing Lab[6]

VMware vCenter Lab Manager (VLM) is a commercial product by VMware Inc. Educational institutions may obtain free licenses through the VMware Academic Program. The backend of VLM is a group of VMware ESX/ESXi servers, controlled by a VMware Virtual Center or vCenter . VLM can only be used to provision VMware virtual machines and configurations. It provides user-friendly interfaces for instructors/administrators to manage users, roles, workspaces and configurations and allows users to access the virtual machine consoles remotely. As shown in Figure 2, the users and the administrators can access the VLM server remotely through a web browser (Internet Explorer or Mozilla Firefox). VLM offers some powerful features not yet available on other VLA systems such as fencing[7].

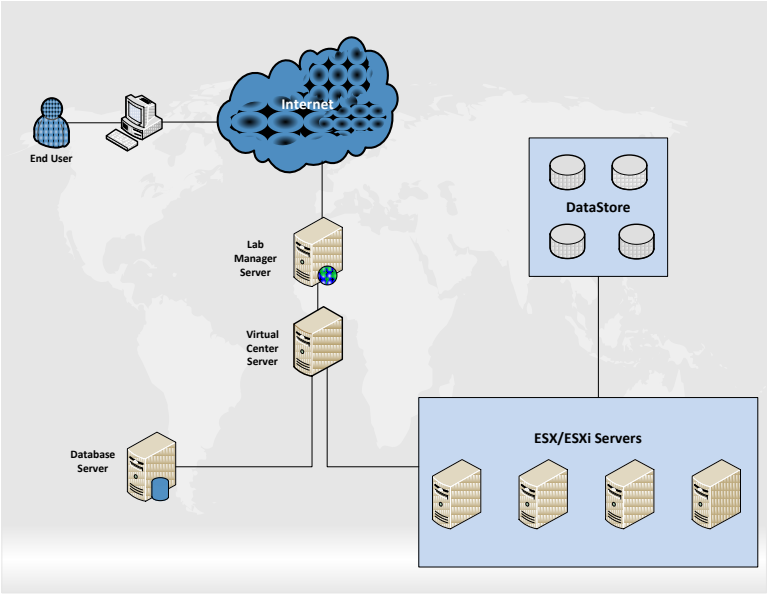

Figure 2. VMware vCenter Lab Manager

2. Integrating Virtual Lab Automation Systems

2.1 Background

With increasing enrollment in distance education, the high demand for remote labs significantly impacted our already limited resources. In 2006, we began incorporating virtualization technology in IT labs in order to find cost-effective ways of delivering remote hands-on exercises. In the first three years, a decentralized virtual lab approach was implemented: the students installed prebuilt virtual machines on their personal computers to complete hands-on labs. Various virtualization software packages were used in successive years and were focused on hosted hypervisors which depended on a host operating system to run the virtualization software, beginning with VMware Player and VMware Server, followed by VMware Workstation and Sun xVM VirtualBox (now renamed as Oracle VM VirtualBox). The student feedback was positive and the student performance was consistent[4].

The decentralized virtual lab approach was cost-effective; however, it did not scale well for labs requiring multiple virtual machines. For example, a virtualized datacenter lab environment was composed of five virtual machines, using approximately 8 GB RAM. Not all students' personal computers were powerful enough to run so many virtual machines efficiently. From 2008, we started experimenting with new centralized virtual lab automation systems, specifically Virtual Computing Lab (VCL) which was used in several projects that year. The next year VMware (vCenter) Lab Manager (VLM), another virtual lab automation package, was made available in selected courses.

Our VCL infrastructure was supported by 84 IBM HS21 blade servers, each with two Intel dual-core Xeon processors and 12 GB memory. 1 TB Network-attached storage (NAS) was available for students to save their work. In contrast, the VLM system was supported by a total of six LS22

blade servers with each blade consisting of two six-core AMD processors and 20 GB memory. A total of 750 GB of NAS was provided for student storage and ISOs. VLM utilized VMware ESXi 4 hypervisor for its virtualization layer. In one instance, a host was running 74 VMs concurrently, utilizing about 12% CPU and 90% memory without significant degradation of performance.

2.2 Using VLM in ICTN 4200/1

ICTN 4200/1 (Intrusion Detection Technologies) was offered to both face-to-face (F2F) and distance education (DE) students in the fall semesters. The lab section of this course was offered online. There were no on-campus labs.

A decentralized virtual lab approach was used in this course from fall 2006 till fall 2009[4]. In 2006, students installed VMware Player or VMware Server to run a single pre-built virtual machine on their personal computers to perform the hands-on labs. In fall 2007, VMware Player and VMware Server were replaced by VMware Workstation and a second pre-built virtual machine was added so students could do more advanced labs. In fall 2008 and fall 2009, VMware Workstation was replaced by VirtualBox, which was more lightweight, suitable for low-end personal computers. However, labs in some courses required three or more virtual machines. Most students did not have personal computers powerful enough to run these virtual machines simultaneously. It was also difficult for the instructor to monitor the labs and to help students troubleshoot problems in a decentralized environment.

In fall 2010, VMware vCenter Lab Manager (VLM) was made available to students in ICTN 4200/1. Each student was assigned a configuration with three virtual machines: the first VM as the defender, the second as the attacker and the third as the client workstation, as shown in Figure 5. The configuration could be expanded and more VMs could be added easily. The students were assigned 12 required labs and a number of optional, bonus projects. The topics included: Internet Footprinting; File System Integrity Check; Host-based Intrusion System; Packet Analysis Tools; Network Traffic Analysis; Network Intrusion Detection System; Basic Analysis and Security Engine (BASE); Traffic Monitoring with IPAudit; Bro Intrusion Detection System; Malware Detection and Removal; and Incident Handling and Forensics.

The students accessed the VLM server using a web browser (Internet Explorer or Mozilla Firefox) and then logged in to the client workstation (a Windows XP VM). From there, they could access the other two Linux virtual machines through SSH. They could also access the consoles of the virtual machines. After the students finished certain tasks, the changes they made were automatically saved, enabling students to come back later to continue the lab. With VLM, the administrator/instructor was able to monitor the lab operations of every student and provide assistance via a web browser remotely.

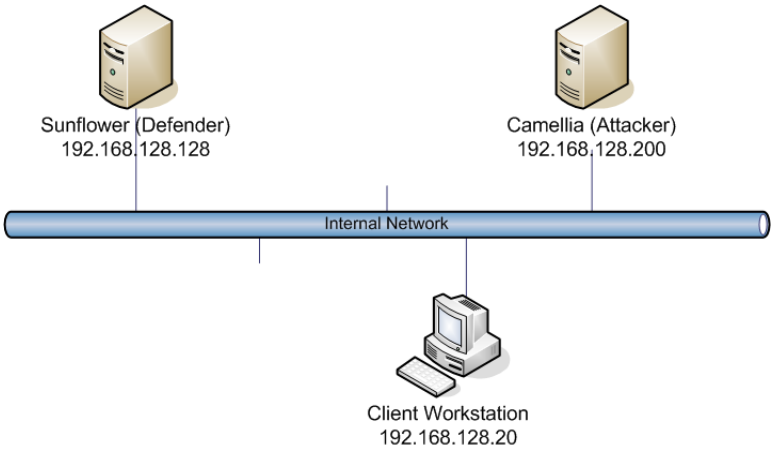

Figure 5. The virtual environment on VLM in ICTN 4200/1

2.3 Using VCL and VLM in ICTN 3900/1

ICTN 3900/1 (Web Service Management) was offered to both F2F and DE students in the fall semesters. For F2F students, a lab section was offered in an on-campus computer lab twice a week. Both F2F students and DE students logged in remotely to VLM or VCL and used the same virtual environments to complete the lab exercises.

The labs in ICTN 3900/1 were redesigned in fall 2010, including File Server and File Services; Network Installation of Windows Server; Setting up DNS Services; Installing and Configuring Web Servers; Web Programming Environment; Providing E-mail Services; Extending the Web Environment; Securing the Web Environment; Web Hosting Management Tool and Container-based Virtual Datacenter. The students were assigned 11 required labs and 5 optional, bonus projects. ICTN 3900/1 was the only course in which both VCL and VLM were used in the same semester. VCL was used in 2 required labs and two bonus labs. VLM was used in the remaining labs.

Figure 4 shows the VCL virtual environment (image) we created. It contained nine Windows and Linux based virtual machines. The ProxMox VE virtual machine was used to host Linux virtual private servers, on which students installed web servers, DNS servers and web hosting management systems. The Openfiler VM and the FreeNAS VM were used for data storage exercises. VMware Server 1.x was installed inside a CentOS 5.5 Linux VM so students could perform labs on operating system installation.

After logging in to the client workstation using a RDP client, users could access other servers on the private virtual network through SSH, RDP or through their web interfaces.

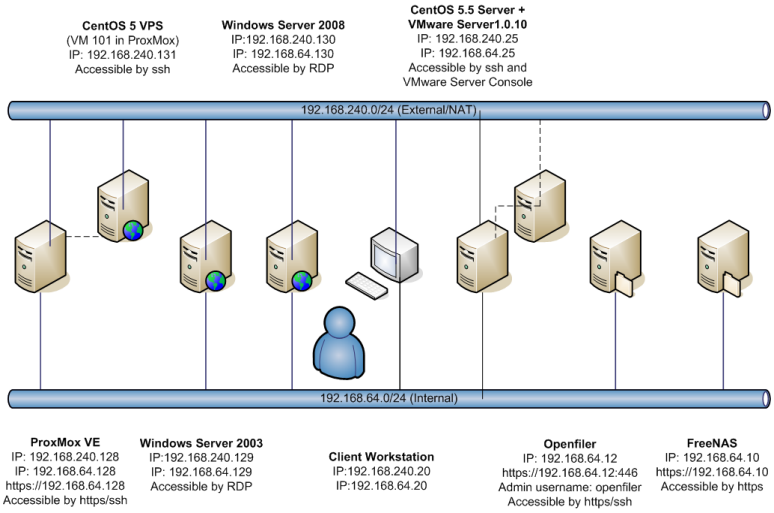

Figure 4. The virtual environment on VCL in ICTN 3900/1

The custom virtual environment for VLM is shown in Figure 5. The ProxMox VE VM was used to host Linux-based virtual private servers. Windows-based web services were to be installed by students on Windows Servers. The client workstation was used to access the Linux servers through SSH and Windows servers through RDP.

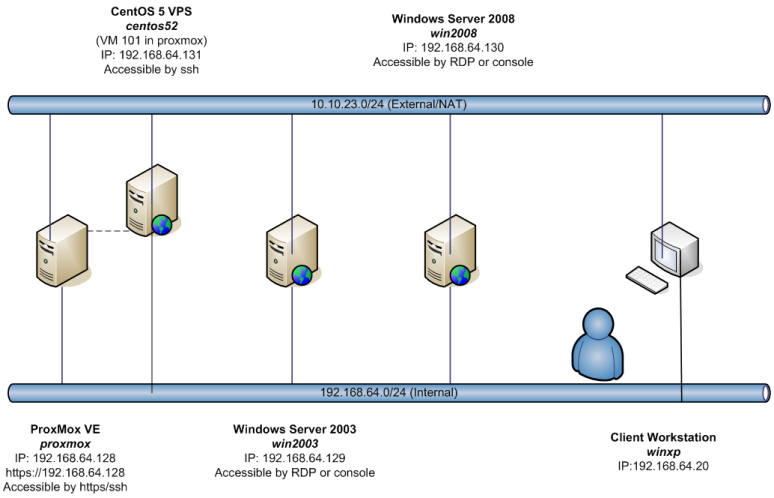

Figure 5. The virtual environment on VLM in ICTN 3900/1

2.4 Using VCL in ICTN 4505

Virtualization Technologies was offered as a special topics course (ICTN 4505) in spring 2010. The text book and the lab manual provided by VMware IT Academy Program were used. The hands-on labs included: Configuring ESX; Installing VMware vCenter Server; Using VMware vCenter Server; Standard and Distributed Switches; Designing a Network Configuration; iSCSI Datastore; VMFS Datastores; NFS Datastore; Creating a Virtual Machine; Using Templates and Clones; VMware vCenter Converter; Modifying a Virtual Machine; Managing Virtual Machines;

Access Control; Monitoring Virtual Machine Performance; Using Alarms; Resource Pools; Migrating Virtual Machines; VMware Distributed Resource Scheduler Clusters; Using VMware High Availability; VMware Data Recovery; VMware vCenter Update Manager; and Installing ESX (VDC and DVD).

In a physical lab environment, the hands-on exercises would require costly hardware to run. The minimum server requirement for a single student was: two 64-bit processors, 4GB or more RAM, three Ethernet NICs (100MB or 1 GB), 120 GB local storage accessible through the SCSI controller. For a typical section of 24 students, a minimal of 12 dedicated student servers were required, in addition to an infrastructure server, a data storage server and gigabit Ethernet switches, cabling and optionally 24 student workstations. It would be very expensive to set up and maintain a physical lab for this class.

Instead, we created a custom virtual datacenter environment consisting of five virtual machines, hosting two VMware ESX4 servers, a vCenter VM and an Openfiler iSCSI/NFS VM and a client workstation respectively. The virtual datacenter was created as a VCL image for students to reserve. More details about this virtual environment were published elsewhere[6].

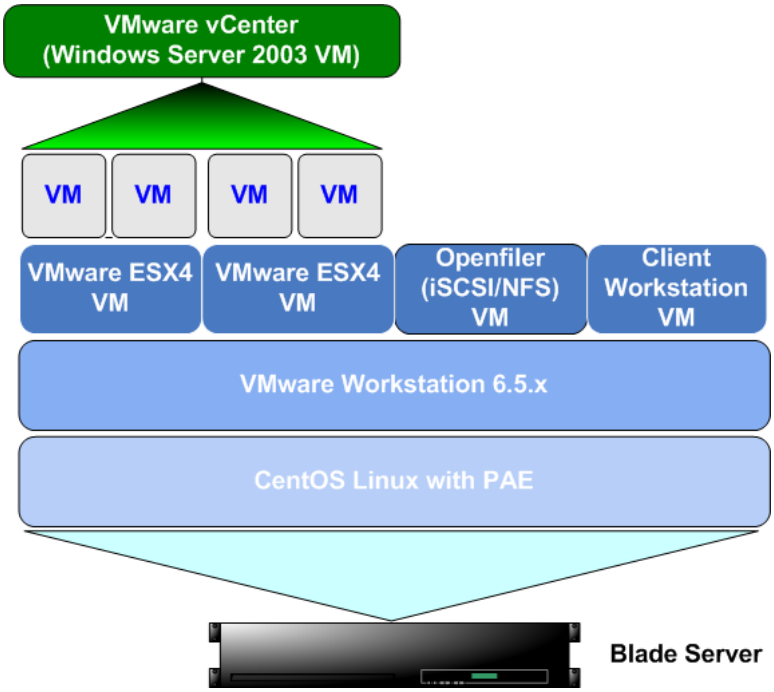

Figure 6. The vSphere virtual datacenter on VCL in ICTN 4505[6]

3. Evaluation and Discussion

3.1 Usability and Availability

An anonymous, optional, lab survey was conducted online at the end of the semester in fall 2010. In ICTN 3900/1, 15 out of 30 students responded to the survey. In ICTN 4200/1, 26 out of 46

students responded. A similar survey had been administered in the past three fall semesters in ICTN 4200/1, in which the decentralized virtual lab approach was used[4]. No lab survey was conducted in ICTN 4505 in spring 2010.

In ICTN 3900/1, 11 required weekly labs and 5 optional bonus labs were assigned. VMware Lab Manager (VLM) was used in 9 required labs and 3 bonus labs while Virtual Computing Lab (VCL) was used in 2 required labs and 2 bonus labs. Students were asked to rate the usability (VLM/VCL was easy to use) and availability (I had access to VLM/VCL when I needed) of each system. The feedback in Table 1 shows that while most students were positive about the usability and availability of both VCL and VLM, VLM received better ratings. The comments from students showed that they preferred VLM because it offered persistent storage and was more user-friendly.

Table 1. Feedback on Usability and Availability of VCL and VLM (ICTN 3900/1, Fall 2010)

	VCL Usability	**VCL Availability**	**VLM Usability**	**VLM Availability**
Strongly Agree	40.0%	40%	73.3%	73.3%
Agree	33.3%	40%	26.7%	20%
Neutral	13.3%	13.3%	0%	6.7%
Disagree	6.67%	0%	0%	0%
Strongly Disagree	0%	0%	0%	0%
Not Applicable	6.67%	6.67%	0%	0%

In fall 2009, Virtual Computing Lab (VCL) was used in 2 bonus labs (4 bonus sections) while decentralized virtual machines were used in 12 required labs and 1 bonus lab in ICTN 4200/1. In fall 2010, VMware Lab Manager (VLM) was used in 12 required weekly labs and 2 bonus labs while VCL was used in only one bonus lab. So we asked students for opinions on VLM only in 2010. As shown in Table 2, most students were positive about both virtual lab automation systems while VLM was more favored, especially in usability.

Table 2. Feedback on Usability and Availability of VCL (ICTN 4200/1, Fall 2009 and Fall 2010)

	VCL Usability (Fall 2009)	**VCL Availability (Fall 2009)**	**VLM Usability (Fall 2010)**	**VLM Availability (Fall 2010)**
Strongly Agree	44.0%	64%	76.9%	61.5%
Agree	32.0%	32%	11.5%	34.6%
Neutral	16.0%	4%	7.7%	3.8%
Disagree	8.0%	0%	0%	
Strongly Disagree	0%	0%	3.8%	0%

3.2 Decentralized Approach or Centralized Approach?

Students were asked about their preference on how the hands-on labs should be conducted. It is notable that results in Table 3 show more students preferred the centralized remote lab approach while the results in Table 4 show a majority of students preferred the decentralized approach.

The results demonstrate that students were comfortable with the technologies they used in their courses. In fall 2010 (Table 3), they preferred VLM and/or VCL. The likely reason is that they used VLM and VCL and therefore were familiar with them while decentralized virtual machines were not used in the two courses. In fall 2008 and fall 2009, students preferred the decentralized approach because they used virtual machines on their own computers to do most labs and were less familiar with centralized virtual lab approach.

The data shows that virtual labs, decentralized or centralized, were preferred to physical labs. We believe that the instructors have the flexibility to select the virtual lab approach, depending on the needs of the particular course. For example, if the labs will only require a single virtual machine, the decentralized approach with VirtualBox should work well in most cases. If a virtual environment requires five virtual machines and 8 GB RAM, the centralized approach, powered by a virtual lab automation system will be appropriate.

Table 3. Responses to the question "Which of the following is your preferred method for conducting hands-on labs?"

	ICTN 3900/01 (Fall 2010)	ICTN 4200/01 (Fall 2010)
Perform the labs on physical machines in face-to-face computer labs.	20.0%	3.8%
Set up a virtual lab environment and perform the labs on my personal computer without using a remote, central server.	13.3%	11.5%
Perform the labs in a centralized remote lab (e.g. Virtual Computing Lab or VMware Lab Manager)	66.7%	84.6%

Table 4. Responses to the question "The hands-on labs can be performed in various ways. Which way do you prefer as a student?"

	ICTN 4200/01 (Fall 2008)	ICTN 4200/01 (Fall 2009)
Perform the labs on physical machines in a computer lab.	2.2%	4.0%
Perform the labs using VirtualBox on my personal computer	67.4%	52.0%
Perform the labs using VMware on my personal computer	21.7%	28.0%
Perform the labs in a centralized remote lab (e.g. VCL) through Remote Desktop or VNC	6.5%	16.0%
Unanswered	2.2%	0%

3.3 Usage Analysis

The centralized approach, supported by virtual lab automation systems, provides useful statistical data that are difficult to obtain in a decentralized virtual lab environment.

Figure 7 shows the numbers of reservations by day of the week for three courses using VCL and/or VLM. Figure 8 shows the numbers of reservations by hour of the day. The data for ICTN 4505 were collected during a period of 29 days between February 4 and March 4 in 2010. The data for ICTN 4200/1 were collected from September 16 through December 16 in 2010. The data for ICTN 3900/1 were collected from October 1 through December 15 in 2010. Since the

numbers of students were different in each class, the comparison of total reservation numbers would not be meaningful between courses. However, the data still provides useful information about student learning.

Figure 7 shows that the number of reservations peaked out on Wednesdays, the due date of the lab projects for ICTN 3900/1 and ICTN 4200/1. For ICTN 3900/1, the number of reservations is also relatively high on Mondays because F2F lectures and labs were scheduled on Mondays and Wednesdays. There are no F2F labs in ICTN 4200/1. We can learn from the figure that fewer students worked on labs during Fridays and Saturdays and many students started working on labs on Sundays.

Figure 8 demonstrates that outside the classroom, students tended to work on labs between 7 pm and 9 pm. There is a peak between 9 am and 10 am for ICTN 3900/1 because the F2F lectures and labs started at 9 am on Mondays and Wednesdays.

The usage statics can help us identify what resources are used, when students are using the resources and allow us to allocate resources more efficiently, especially in a large environment.

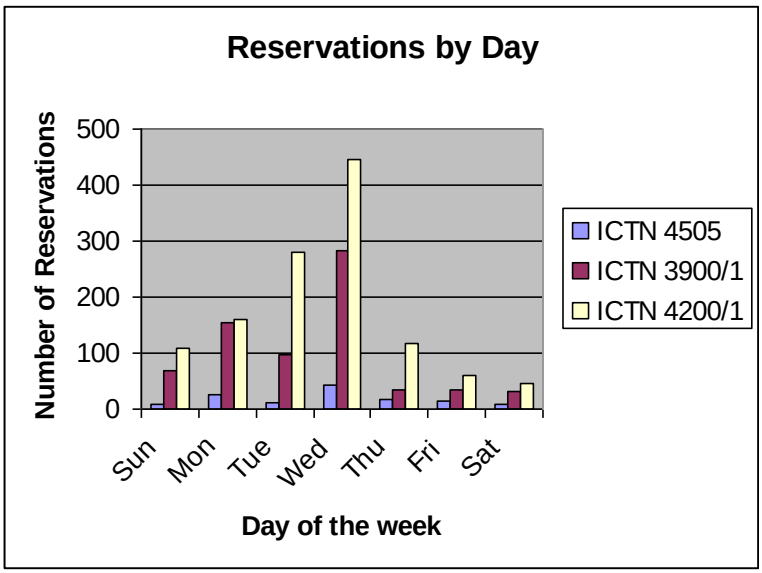

Figure 7. Reservation by Day

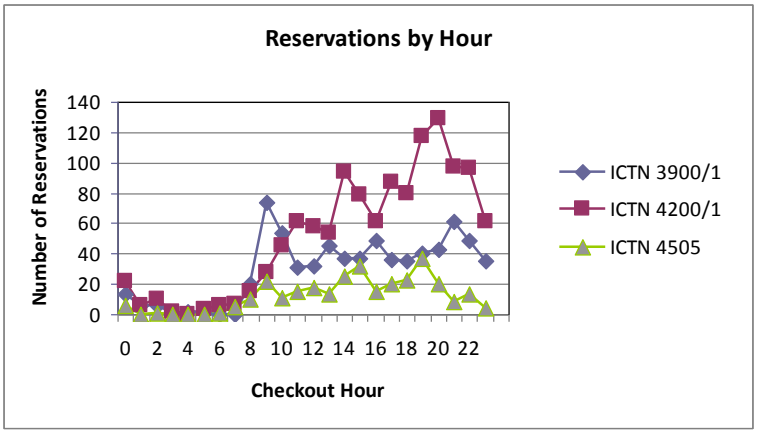

Figure 8. Reservation by Hour

4 Conclusion

Centralized Virtual Lab Automation (VLA) systems allow users to access remote labs more easily, without the need to install virtual machines on their local computers. The VLA systems can support virtual labs requiring multiple virtual machines and other resources. It is easier for the instructor to monitor the lab activities and for students to seek help or to collaborate in a centralized environment. Furthermore, the collection and analysis of usage data to aid effective resource allocation is made easier within a centralized setting. Our experiences with Virtual Computing Lab (VCL) and VMware Lab Manager (VLM) show they are both flexible in supporting hands-on IT labs in a variety of areas. VLM is easier to manage and more user-friendly and efficient because it only provisions virtual machines. VCL is open source and has the ability to provision both virtual machines and physical computers. The decision on virtual lab approach or virtual lab automation system to use depends on the needs of the course and the available resources.

Cloud computing can be implemented in many different forms. Virtual lab automation systems such as Virtual Computing Lab and VMware Lab Manager provide cost-effective ways of delivering hands-on learning experiences in a centralized manner. The centralized approach is especially useful in online labs which require high-end resources, support a large number of users, and provide rapidly changing contents. It helps create a digital learning environment for students to study from any place and at any time.

Acknowledgment

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