Exploring the Sustainability Life Cycle of Enterprise Computers in Higher Education

Martin Wagner[1], Charles Feldhaus[1], Pat Fox[1], Feng Li[1], Kim Milford[2],
Julie Little-Wiles[1], Stephen Hundley[1]
[1]Purdue School of Engineering and Technology, Indiana University Purdue University Indianapolis, Indianapolis, IN - USA
[2]Indiana University, Bloomington, IN - USA

Abstract--**Enterprise computing services play a critical role in universities enabling faculty, students, and staff to complete meaningful work and further goals of the institution. These services require physical server computers with processors, disk space, and memory. Physical servers take up data center space and consume power; they are designed for performance with little detail paid to ecological design. In an effort to reduce hardware and maintenance costs, a trend to virtualize these servers exists, which would also free up physical space and save energy. This exploratory case study explored the current sustainable computing trends at a large university in the Midwest as well as whether practices of virtualizing enterprise server computers were economically, socially, and ecologically sustainable. Finally, this study investigated how these practices were planned, monitored, and evaluated.**

Findings indicate virtualizing enterprise servers in the Intelligent Infrastructure is economically, socially, and environmentally sustainability. Recommendations for university leadership were developed as a result of data gathering and analysis from participant interviews, correspondence, observations and artifacts. Maximizing utility and outreach were the two dominant related themes present in the data sources.

I. INTRODUCTION

Total energy consumption for data center servers and their cooling units in 2005 was projected at 1.2% of the total United States (U.S.) energy consumption and is doubling every 5 years [25]. Climate change presents very serious global risks, and it demands an urgent global response. According to Stern [21] collective action is critical in responding to the threat of global climate change. Research is necessary to analyze the importance of sustainable enterprise computing practices in higher education and the importance of transformative technical leadership with a pro-active focus on sustainable practices. Forrest, Kaplan, and Kindler [4] suggest that organizations can double the energy efficiency of their data centers through more disciplined management, reducing both costs and greenhouse gas emissions. This project examined opportunities to enhance sustainability practices throughout the lifecycle of enterprise server computers at a large university in the Midwest. This university will be defined as *the university* in this document.

Little is known about server computers once they have been ordered through purchasing. The university has an asset tracking system for items that are greater than $5,000.00, however many enterprise server computers do not exceed this cost. The school or department that ordered the server is responsible for the equipment once it is in possession. This includes the disposal of the equipment once it has reached its useful life. Daoud [2] illustrates this problem and believes tasks such as procurement are generally separated from disposal practices with different managers with different skill sets handling each task and rarely communicating with one another. Often requirements of the inevitable removal of the equipment at the end of useful life are not taken into account.

Enterprise server computers are used to perform amazing analysis from molecular dynamics modeling to client change forecasting. Interestingly enough, the very tool used to predict our planet's future is also causing considerable amounts of the damage. These machines are composed of plastics, heavy metals, and other toxic components that need very intentional disposal or recycling. Server computers contain arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver. The toxicity characteristic leaching procedure (TCLP) extracts of the vast majority of the printed wire boards (PWB) ranged from 150 to 500 mg/L, which are 30-100 times the regulatory level of 5 mg/L for classifying a waste as hazardous [23].

There are some advances to make server computers less toxic. Fujitsu and Sony are reducing landfill waste by incorporating biodegradable plastic in their electronics [12]. Proper disposal of the equipment is a significant part of the sustainable process. Disposing computer electronics in landfills is cost-ineffective and is environmentally dangerous. Extending the useful life or the donating/selling of equipment will still fill-up in landfills and consume large amounts of power and energy [12].

The data centers that house the servers create a very large carbon footprint. The IBM Blue Gene/L requires twenty megawatts to operate, which is approximately equal to the power consumption of 22,000 US households [10]. There are limited energy resources and a continuous demand for more computational power makes energy efficiency important in enterprise computing [25]. Reduction of energy consumption is critical for sustainability.

There are many ways to improve the sustainability of enterprise computing in higher education, however many of the ideas are new, untried and developed within the last five years. These ideas have not been brought together in a comprehensive analysis of a complete life cycle of enterprising servers. There is a cost, physical space, and energy savings associated with both co-location and virtualization, however, these factors have not been measured. A barrier to encouraging sustainability in the computer industry is the lack of accurate information on materials [12]. Specifically, the metrics associated with migrating from a physical server to a virtualized server will enable information technology leaders to make informed decisions about where they will house their servers. Maximizing energy efficiencies though the intelligent infrastructure may be a positive step in the process, however, in addition to quantitative analysis, there is a need to gather perceptions and viewpoints from technical leaders and managers using qualitative approaches as we examine the life cycle of enterprise servers.

II. LITERATURE REVIEW

Many authors define sustainability as a collection of three contributing qualifications, ecological, economical, and social [22, 5, 12, 25]. This three-prong definition of sustainability is applied to enterprise computing in many areas of the literature. The general definition that includes measurement, efficient resource management, and leadership are recurring sustainability themes in the literature. Within each theme are trends that align with the three-prong definition of sustainability. The purpose of reviewing the literature is to explore these themes in detail and identify gaps or areas that need to be further explored, and to determine if there is a dearth of qualitative research on the subject of sustainability and perceptions of technical leaders.

A. Sustainability

Sustainability can take on many meanings depending on the context. In most corporate initiatives, sustainability has been conceptualized as something to do with eco-efficiency. Reducing or preventing pollution, and resource conservation has been the focus. Although noble and important, this environmental emphasis is just one aspect of sustainability [5]. Hart, Milstein, and Caggiano [8] believe that some see sustainability as a one-dimensional nuisance, involving regulations, added cost, and liability. However, they define the sustainable enterprise as one that contributes to development by delivering the triple bottom line, economic, social, and environmental benefits. Products, services, and infrastructure must meet the needs of the present with out compromising the ability of future generations to meet their necessities [8]. Sustainability is both a goal and a process according to research by Parrish [17]. Gladwin [5] believes sustainability represents a paradigm shift. This shift is being applied in computer technology, specifically enterprise computing. Maximizing economic profit by manufacturing, selling or using computer systems may not be achieved by polluting the environment or discriminating other social groups or following generations [16].

B. Measurement

One of the major themes in the literature is the lack of information about recyclability and the overall environmental impact resulting from computer equipment use and disposal. Accurate information is essential when making wise suitability decisions. Currently, there is not an easy way for consumers to make informed decisions about the computer equipment they purchase. A production facts label can be applied to computer equipment to guide consumers about the energy efficiency and makeup of toxins and heavy metals [12]. Yet, often the amounts of toxic materials found in a computer are 30-100 times the level when classifying equipment as hazardous waste [23]. The production facts label has yet to be applied universally on server computers, leaving the decision maker without vital information.

Energy consumption is coming from the university data centers at significant levels, which can impact a university's EF score. There are also visualization techniques used to help consumers make informed decisions about products by their impact to the environment. This is a more dynamic and engaging approach to inform people about the impact of the decisions they make [11]. The Environmental Protection Agency (EPA) has proposed that data centers use energy meters. This is a step for designing operating-efficiency standards [4].

C. Efficient Resource Management

The top 500 ranking of supercomputers according to the LINPACK benchmark are listed on top500.org. The LINPACK measures how fast a computer solves a system of linear equations. An alternative to the top 500 is the green500.org site, which lists supercomputers ranked by the computational power per watt of energy consumed. The design constraints for supercomputer deployments are performance and power consumption [3].

There are many methods for addressing sustainable enterprise computing. Virtualization is key a technology to address sustainable IT challenges [6]. Migrating existing server computers to virtualized environments will reduce the total number of computers required to provide the same level of service. The hardware used for virtualization is 20% more power efficient [4].

Other common sustainable computing practices are power management, improving cooling technology, recycling, electronic waste disposal, and optimization of IT infrastructure [7]. Virtualization is a key component of cloud computing. As cloud computing grows, so does the need to make virtualization more power efficient. Scheduling systems that are both power-aware and thermal-aware are needed to maximize energy savings both from physical servers and the cooling systems used [25]. Optimizing existing data centers for energy efficient is seen as more sustainable than building new centers [4]. Literature from the most recent few years has focused specifically on efficient resource utilization. The topics addressed have not been included in my review due to their narrow scope in process scheduling and thermal aware design.

D. Technical Leadership and Management

Sustainable computing often takes a transformative leadership approach. Leaders will need to inspire others to participate in their vision, cultivate a culture that guides and supports sustainable behavior, and create learning opportunities centered around sustainability [5]. Leading effective change requires an examination of the entire computer process from purchasing, to energy efficiency, to use, and disposal. Purchasing enterprise-computing hardware is typically separated from disposal practices, with different managers with different skill sets handling each task and rarely communicating with one another [2]. Rarely is there oversight by leadership through each step of a computer's life cycle. There is not a single group involved with disposal or the energy efficiency of the computers. Purchasing, facilities, system administration, resale, and any group that manages the computer do not work to a common sustainable goal nor do they have the ability to influences one another.

Sustainable IT needs to come from the top down. This can be accomplished by developing a sustainable IT strategy. Researchers have produced a comprehensive initiative with clear sustainability goals related to products and services called Design for Environment (DfE) and Design for Recycling (DfR). Both DfE and DfR involve the integration of the IT organization's sustainability initiatives with the enterprise-level model and throughout the corporate ecosystem [7]. The design should provide a balance between environmental excellence and business competitiveness [9]. According to Potocan and Muelj [18] holistic thinking, decision-making, and actions should be profitable and socially responsible.

There are trends emerging from themes in the general definition, measurement, efficient resource management, and leadership of sustainability related to enterprise computing. The current trend is to establish a working definition of sustainability. Much of the research is focused on one, two, or all three prongs of suitability. There seems to be a gap in the research on social sustainability as it relates to enterprise computing. As defined, a practice that is ecological and economical, but not socially sustainable is not entirely sustainable. A practice must be accepted and used by people, otherwise the practice will not continue.

Impact must be measured if it is to be improved. People cannot make efficient resources management decisions without collection and scope of data. Power consumption, computational efficiency, and raw computer materials data must be collected, organized, and scoped. The ability to make decisions based on sustainable data comes from leadership. Leadership is essential for suitability but often leaders are not responsible for developing the suitability vision according to Potocan and Muelj [18]. This reality must change and leaders must be accountable for communicating the vision and earning buy-in from the organization. The organization needs to be set up to empower the initiative and incorporate the vision into the culture. These trends tie into the relationship of enterprise computing and the three prongs of sustainability.

III. PURPOSE

The purpose of this qualitative case study was to explore which higher education enterprise computing practices were considered environmentally, economically, and socially sustainable from the perspective of technical leaders currently charged with these practices. A case study was chosen to capture the complexity of sustainability with a single case of enterprise computing virtualization in higher education [20]. The linear and iterative case study process created flexibility for the researcher to explore the areas of sustainability and technical leadership/management [24]. The practices of virtualizing enterprise server computers were analyzed for their ecological, economical, and social applications of sustainability. The practices were examined with regard to technical planning, monitoring, and evaluation by leadership/management.

IV. METHODOLOGY

The researcher is an IT Project Manager at the university, which is the research site location. The gatekeepers are university information technology directors and managers that had insight into trending enterprise computing sustainability practices. The research consisted of interviews with key personnel, documentation of the life cycle process, and observation of current practices. This strategy provided a basic understanding of how an enterprise server was ordered, used, and recycled.

A. Research Questions

- Primary: What are the current sustainable computing trends in higher education?
- Sub-Questions: How are the practices of virtualizing enterprise server computers economically, socially, and ecologically sustainable? How are the practices planned, monitored, and evaluated? What are the perceptions of technical leaders regarding these practices?

B. Data Collection Procedures

The first principal of case study data collection is using multiple sources of evidence and a good case study leverages many sources of evidence [24]. The six sources used were documentation, archival records, interviews, direct observation, participant observation, and physical artifacts.

Documentation is plentiful on the Intelligent Infrastructure. Yin [24] suggests focusing on the materials that directly relate and are pertinent. The documentation of the process included public documentation and email correspondence. Archival records provided an historical perspective on computational power as it relates to cost and power consumption and an understanding of the progression of virtualization technology and it's importance.

Principle uses of case study were to obtain the description and interpretations of others and interviews are a common form of data collection in case study research [1, 20, 24]. IT

Directors and Managers were chosen as the samples for this study to provide a unique perspective. This is a convenience sample as participants were easily accessible and willing to participate in the study [1]. Demographics were not collected, as they were not relevant to this study. All participants names were changes to aliases.

Creswell [1] suggests having an interview protocol before entering the field. The interviews were conducted face-to-face using structured interview questions. The interviewees were sent questions ahead of time and follow up questions were documented, tape-recorded and transcribed. The interviewees were asked three basic questions.

1. What are the barriers to sustainable enterprise computing practices?
2. How do you overcome these barriers?
3. What else?

These basic interview questions addressed barriers in all areas of enterprise computing. Discipline specific questions, however, were asked in addition to the questions listed. These questions were tailored to the participant's functional area. An interview with out pre-determined questions allowed the participants to talk openly about the topic while allowing the information to emerge freely [1].

The direct observational protocol included descriptive and reflective notes [1]. The role of the researcher was known during the field observation. Viewing the management (direct) and planning (participant) of the Intelligent Infrastructure provided additional evidence to the case. The participant observational protocol was identical to the direct observation. The researcher looked for any output on the workstation that indicated power consumption, efficient resource management, and utilization. This observation was interactive and not a behind the curtain view. The researcher asked the participants to demonstrate any software for tasks related to planning, monitoring, and measuring.

Physical artifacts in this case study were the enterprise computer hardware. Viewing the artifacts in their natural setting broadened the understanding of their use [24]. The researcher was looking at the installation of enterprise servers in the data centers and outside the main data centers. Not all enterprise computers at the university were in the two main data centers. The researcher was looking at the similarities and differences between installations.

The transcriptions were coded for themes, which included economic, social, and environmental sustainability. The literature review identified these three themes and the makeup of sustainability. These themes showed the current sustainable practices and opportunities for others as the outcome of this study. The analysis process was adapted from Cresswell's six steps of data analysis [1]. This analysis is appropriate for the evidence that was collected and is displayed in Table 1.

TABLE 1: DATA ANALYSIS

Creswell's Steps to Analyze Data	As Applied to Project
Conduct interviews with key personal	Conduct interview face to face
Document each step a server computer takes in its lifecycle	Ask questions related to lifecycle of equipment
Examine each step in lifecycle	Understand process in detail
Apply codes to interviews for themes	Economic, social, and environmental themes
Interrelate themes	Relate themes to each step in lifecycle
Interpret themes	Address purpose of research

C. Reporting and Verification

The identified themes are presented in tables, graphs, and figures. Qualitative studies need validation to their findings [1]. The researcher has spent many years in the setting of the research. In addition, the reliability procedure in Table 2 for this case study followed these steps as adapted from Cresswell [1].

TABLE 2: VERIFICATION PROCEDURE

Procedure	Effect on Reliability
Transcriptions checked for mistakes	Mistakes corrected
Data constantly compared with coded themes independent of analyzing for new themes	No definition drifting, documentation of new themes
The themes come from the triangulation of evidence from the sources in the literature review	Strong justification of themes
Member checking used to determine the accuracy of the findings	Follow up interviews
The setting of the research is documented	Future validation
An auditor who is not familiar with the researcher or the project reviewed the entire project	Objective assessment
Researcher bias description	Reflectivity
Presentation of discrepant or negative information that does not align with sustainability	Real life representation

D. Codes

The codes were formed from the data collected and the literature review. No previous assumptions or theories were developed about the data prior to collection. The initial set of codes was generated from common themes in the literature review. The interview transcriptions were read all at once in detail. HyperRESEARCH was used to highlight and code selections of text. The software was also used to create a code database. The reason for defining each code was developed and stated as well as the connection to the research design. These codes accurately reflect the meaning of the retrieved words and phrases [24]. The codes and meaning as related to the theoretical framework are listed in Table 3.

TABLE 3: CODES AND MEANING AS RELATED TO THEORETICAL FRAMEWORK

Code	Meaning as related to research
Economic	• Related to cost, money, and budget • Core member of sustainability
Efficient Resource Management	• Related to planning, monitoring, and measuring • Necessary to achieve sustainability as identified by literature
Environment	• Related to recycling, proper disposal of items, and reduction of impact • Core member of sustainability
Leadership	• Related to managers, directors, and people with authority position • Necessary to achieve sustainability as identified by literature
Social	• Related to usability, enabling mission via IT • Core member of sustainability

E. Pattern Matching

In each step of the life cycle of enterprise computers at the university, the researcher identified the predetermined patterns. In this descriptive case study, pattern matching was still relevant as long as the pattern was defined prior to data collection [24]. Specifically, the researcher was looking for patterns in leadership decisions that caused economic, environmental, or social sustainability of enterprise computing at the university.

F. Logic Models

Applying a logic model as an analytic tool was appropriate for examining the chain of events of the enterprise computer over the span of time in which the hardware was utilized. The IT policies in place caused or triggered certain events in the life cycles of enterprise computers. This process can help a group; in this case the university, define more clearly its vision and goals of sustainable enterprise computing. Because of sequential stages, logic models deserve to be distinguished as a separate analytic technique from pattern matching [24].

G. Organizational-level Logic Model

Creation of organizational-level logic models involves tracing the life cycle events of an enterprise server computer over time while paying particular attention to the chronological sequence of events exposed the current sustainable computing trends related to the practice of virtualizing enterprise computers [24]. In this study, the order was when the server hardware was ordered in purchasing, utilized by the IT services, and retired and sent to surplus for redistribution.

H. Summary and Quality Assurance

Pattern matching, logic modeling, and organization-level logic modeling were the analytic techniques chosen for this case study. All evidence that was made available was included for analysis in this case study. All interpretations were based on evidence and did not leave loose ends. No rival interpretations surfaced during the duration of this research. Any rival interpretations that could surface would have to be explored and investigated in a future study. The sustainability of enterprise computing in higher education is the most significant aspect of this study. No detours were made during the study. The researcher's prior knowledge of higher education computing has added value to this study due to the familiarity of current trends.

V. RESULTS

Analytic generalization, according to Yin, is when a previously developed theory is used as a template against which to compare the empirical results of the case study [24].

Naturalistic generalization is what Stake argues as an empirically grounded generalization [20].

For purposes of this descriptive case study, a linear-analytic structure was chosen to report the findings. This standard approach is often the reporting style for descriptive case studies [24]. The enterprise computer life cycle has many stages of life at the university from ordering to disposal. These stages are presented in a chronological structure. The lifecycle of an enterprise server at the university starts at purchasing. The server is then utilized in production enterprise services as a part of the intelligent infrastructure. Finally it reaches the end of its life though surplus.

A. Purchasing

Enterprise computers are ordered through the Purchasing Department in the Office of Procurement Services. The department is governed by policy, which concerns all university financial operations. Purchasing is defined as a process, which includes consultation with user departments, selection of vendors, solicitation of quotations, awarding of orders, and recording of audit trail [19].

Purchasing has a sustainable purchasing section on their web site that includes specific projects that are related to environmentally sustainable computing practices such as print services, paper selection, toner cartridges, and soy ink. The Office of Procurement Services also recommends buying products with labels and certifications, some of which are related to enterprise computing hardware. The list includes

Cradle-to-Cradle (C2C) certification, Electronic Product Environmental Assessment Tool (EPEAT), Energy Star, and the Green Seal [19]. Economic sustainability is a focus in purchasing. There are many policies and practices in places to reduce the total cost of enterprise server hardware. These practices would not be considered sustainable if the policies and practices in place were not meeting the financial needs of the university.

Departments and schools within the university work with staff members at Procurement services for the purchase of enterprise server hardware. After the purchase is made and the hardware has been issued to the department, purchasing does maintain communication with the unit. Purchasing does not have the responsibility of tracking capital assets. All of the responsibility for proper utilization and removal of hardware is solely up to the departmental Local Support Provider (LSP). UITS offers colocation services for departments who wish to host their own physical computer equipment in the university Data Centers at the downtown campus and the south campus. Departments can lease physical space in the Data Centers for their servers as a transition strategy to standard options provided by UITS that improve efficiency and reduce environmental impact (Midwestern University Server Co-Location Agreement, 2013). These services include virtualization and consolidation. When a server order arrives at purchasing, community partnerships staff members are contacted by purchasing for a possible intervention. Community Partnerships can contact departments who may not know about colocation and virtualization services offered by UITS. The cost to build the University Data Center was $32.7 million in 2009. The University wants to fully utilize this space. Consolidating, co-locating, and virtualizing server computers will move the initiative to accomplish this utilization goal.

At the time of the data collection, the university did not have a policy in place for utilization of its data centers. There are different reporting lines and budgets in place that make enforcing sustainable practices a challenge.

Once the servers are ordered, purchasing receives confirmation that items are delivered. The department making the order is typically never heard from again regarding that particular order. Most hardware that has been utilized and at the end of its lifecycle is sent to University Surplus, however purchasing does not follow up on this. This is not purchasing's role. The Local Support Provider for the unit is responsible for the proper disposal and adhering to University policy. According to UITS purchasing, they do not decide what people buy. They do not have the authority. Purchasing only has the authority in regard to where they have to buy from or whether or not it needs to be competitively bid.

B. Utilization

The Storage and Virtualization (SAV) group supports infrastructure services for server virtualization, the storage area network, and data backup and recovery products. The virtualization service is called Intelligent Infrastructure (II). II is a suite of services provided by the UITS Enterprise Infrastructure Division. II is offered not only to university departments, schools, and affiliates, but also state government and other institutions of higher learning. According to D. West (interview, 2012), other universities leverages the data center in the downtown campus. The University Data Center is divided into areas called pods.

There are many benefits to using II over traditional server hardware, however for purposes of this research, only sustainability related benefits are described. Ecologically, the virtual systems perform like physical systems without utilizing additional physical space. Additionally, the cooling and power maintenance of the systems are efficiently housed in the university data centers. Units utilizing II only pay for the resources they use, making this service more economically sustainable. Flexibility, scalability, deployment time, and high availability contribute to II's social sustainability.

The setup of the university Data Center is well matched for sustainability. High availability is established through redundancy. The server hardware needs constant power; any interruption will interrupt availably and cause outages. The power for the enterprise hardware is delivered to the building and can be accessed in the high voltage storage room. The power is delivered though redundant high power lines to each server cabinet. There are many systems in place in the event of a power disruption [13].

The current systems are the backup batteries stored in the battery pod; the flywheels in the uninterruptable power supply pod, and the generators are stored in the generator pod. The data center can run on these engines as long as they have fuel. Just as important as ensuring the servers have power; the climate of the data center is critical. The hardware will not operate if the data center is not within an acceptable temperature range. The enterprise server hardware produces quite a bit of heat and there are many systems in place to ensure these servers run efficiently. The enterprise servers also need a reliable network for social sustainability. A service is not available if it cannot be reached from the internet.

The virtual machines are monitored using administrative software. The Hypervisor software is what makes the virtualization possible. Hypervisor essentially abstracts the hardware layer, so a virtual machine can act as if it is running on a bare metal server. It is responsible for delivering the actual IO (input output) operations, whether it be disk IO, network IO, compute cycles, or memory cycles. VMware ® vCenter Server™ is used for the primary administrative functions of the virtual machines. This software breaks down the management into datacenters, clusters, hosts, and virtual machines. The hardware is on a three-year renewable cycle. At the end of each cycle, the storage and virtualization team can submit a request for proposals. The systems are evaluated on performance, ease of use, and scalability. The request for proposals does include power consumption. University Storage & Virtualization is effectively reducing the footprint of enterprise computing every three years [13, 14].

The old hardware is put up for a bid process. University schools, departments, and the general public can be purchased. This process extends the life of the hardware. About 20% of the original cost of hardware is recovered.

C. The University Surplus

The university has specific policies related to the disposal and redistribution of university property and the sale of computing equipment. "When an item no longer is wanted by a department, the campus purchasing department or the appropriate property designee of the campus, will attempt to redistribute the item within the university, based on equitable criteria and utilizing the appropriate mechanisms." [13, 14, 15].

When a department or school has university owned server hardware that it no longer needs, the item is transitioned to one of the many services offered by University Surplus. The services they offer include pickup and delivery, data destruction, retail store, online auction, resource redistribution, reimbursement, and recycling. The server equipment is often in bulk due to the three year purchasing cycle.

University Surplus handles all types of computing equipment. The UITS Student Technology Centers send their old desktop to surplus for resale. According to P. George (interview, 2013) even though the responsibility to wipe the storage media is with the owner of the equipment, University Surplus will check before the equipment is set for redistribution. When the warehouse begins to reach capacity, P. George (interview, 2013) will hold a public auction that is facilitated though an auction company. He said some of the buyers would resell the equipment to companies while others will take the bulk equipment overseas and resell them. The life of this equipment is typically extended long after it reaches the end of its useful life at the university [14, 15].

The equipment is tracked by purchasing using the Capital Asset Management System. University Surplus uses the same tags to follow where a particular piece of equipment is located. Assets are tracked via a barcode sticker placed physically on the item. According to P. George (interview, 2013), this tracking system is not different, but enhanced. The assets are inventoried into a surplus database that is separate from the purchasing database. This enables University Surplus to know where a particular piece of equipment is located.

When a piece of equipment that comes in that cannot be resold, it is not thrown away. "We had a server that caught on fire, we are not going to sell that, but it will go to e-waste. The university has a contract with a company that will dispose of that item properly" (P. George, interview, 2013). This particular server was still located in the University Surplus warehouse where it was awaiting removal by the e-waste contacted company. The university received pennies on the dollar for this equipment.

Based on data collection and analysis, Table 4 provides a summary of university purchasing, utilization and surplus planning, monitoring and evaluation.

D. Barriers to Sustainability

As described in the methodology section of this manuscript, subjects from the university Purchasing, Storage and Virtualization, and Surplus were asked about the barriers to sustainability. Those barriers, summarized below, were significant and related to the literature review and theoretical framework of this study.

E. Purchasing

Purchasing "green" was a barrier according to D. Granger (interview, 2012), and Purchasing did not have the needed authority to overcome the barriers. "We can't say you have to buy a green product. We can suggest that we put environmentally sustainable language in the request for proposal asking for vendors to respond to specific questions, but ultimately it is up to the purchaser at UITS or the department to whether or not they want to buy the more sustainable product." The other barrier was financial according to D. Granger. "Cost is another big issues form purchasing standpoint. We need to be responsible with the taxpayer dollars. So we are responsible for enforcing that lowest cost is where we make our purchase. When you are talking about the dollars in the department's pocket, they have a budget, this is how much money they have, and it is going to cost them more than what they have budgeted to get a more environmentally sustainable product, then they are going to go with the less expensive. So cost and budget is huge issue."

How did D. Granger overcome these barriers? "It really is just advising and trying to communicate with people. Make people more aware of these issues and try to gear them in that direction. Look for opportuneness where they can work sustainability into the contracts where you can." The RFP process also had some opportunities. "It is more communication and doing what we can piece by piece but until there is some kind of directive, that comes down, that

TABLE 4: UNIVERSITY PURCHASING, UTILIZATION AND SURPLUS PLANNING, MONITORING AND EVALUATION

	Planning	Monitoring & Evaluation
Purchasing	Planned though established contracts and partnerships with vendors	All purchases over $5,000 are monitored and evaluated by Procurement services.
Utilization	The planning for virtual machine growth is administered using software called VMTurbo	Monitored using VMware ® vCenter Server™
Surplus	Items are auctioned in bulk dictated by space	Capital Asset Management System & Surplus Database.

says we need to buy green products, all we can do is look for opportunities." She added "I feel there is less opportunity in the big infrastructure type purchases for environmentally sound products vs looking at computers with energy star ratings and thing of that nature.

G. Hill (interview, 2012) listed barriers related to Enterprise Managed Print Services (EPMS), non-standard PC hardware models, central purchasing, and document workflow/digitization. "EMPS is a barrier because you limit the number of devices that people can print to and you change the way they print. Like getting up from your desk to pick up a print job. Some people/dept. hate change. They do not want to give up their local printer." G. Hill also mentioned the purchasing card, "With personal consumer convenience having reached new levels of simplicity, many members of the campus community circumvent centralized purchasing by, for example, increasing their use of p-cards to make purchases. This makes it increasingly difficult to: meet transparency requirements that a public institution has regarding its use of funds; ensure that we are taking advantage of our tax-exempt status; and, assess the extent to which we are advancing our green purchasing objectives." The lack of awareness of print services was also a barrier. "Reductions in the use of paper throughout a variety of university processes with tools such as OnBase and with Enterprise MPS services. However, there is concern that many departments do not know about the current availability of OnBase or that the university is currently working on an Enterprise MPS project. There may be possible push back from departments because of the change in document workflow and departments not able to purchase local printers." These barriers have yet to be overcome.

F. Storage and Virtualization

D. West (interview, 2012) believed it took time to continue to review opportunities to leverage green computing. "Continually reviewing alternatives takes time, effort and funding commitments." He overcame these barriers by allocating additional time into projects to perform the needed analysis. He added "Significant amount of improvement has taken place over the past few years, green computing was an afterthought a few short years ago…not so today."

G. Surplus

P. George (interview, 2013) believed that the primary barriers to sustainable enterprise computing practices at the university were communication, support, and management. "Specifically relating to Surplus however, the only barrier I may address is dissemination of information (for departments in need of hardware)." He overcame these barriers "through direct and indirect communication via online publication, verbal exchange, and other forms of correspondence. Hopefully I will have the option to incorporate more instruction in the near future." P. George (interview, 2013) added that sustainable enterprise computing practices at the university should be presented on a regular basis to raise awareness.

H. Related Common Themes

As a result of analyzing the data sources, primarily from transcriptions, policies, and archive data, related common themes were found. The coded data in Table 5 were consistent with the themes identified in the literature review and the theoretical framework. Efficient resource management was the most common theme present in the interview transcriptions, which focused on maximizing utility from the enterprise equipment. This theme was present in purchasing, storage and virtualization, and surplus. Outreach and communication as related to social sustainability was a common theme in purchasing, storage and virtualization, and surplus as well.

I. Efficient Resource Management by Maximizing Utility

The three components of sustainability were applied to maximizing utility in their own individual way. In terms of economic sustainability, maximizing utility was extracting the most value from money spent on enterprise computing equipment. According to R. Hibbert (interview, 2012) "Cost savings, consolidation, talking about sustainability. Virtualization is a big part of that." Consolidating of enterprise computing equipment decreased the cost of operations. A department might opt out of virtualization because they wanted to maximize their utility on a server they purchased. "The reason why a department or school may not migrate to intelligent infrastructure in the beginning, they may have just purchased new server hardware. It has to lifecycle." The school or department will consider migration after the hardware has been life cycled. R. Hibbert contacted the customers to see where they were in their cycle in an effort to maximize the utility of the University Data Center.

The purchasing of enterprise computing equipment was very focused on cost savings. There were a lot of contracts that were purposefully negotiated in an effort to reduce cost and maximize the utility from the equipment purchased. Orders that come though purchasing were sometimes denied when purchased off contract. According to G. Hill (interview, 2012) "purchasing will make recommendations, and can deny it, if that item is off contract". Orders that came in over $5,000 were tracked specifically in the Capital Asset Management System (CAMS). This was also done in an effort to carefully watch the equipment and see that the investment was meeting the intended function.

The equipment that was tacked via CAMS will end up at surplus. According to P. George (interview, 2013), "when we do get a server over here [surplus], a local support provider (LSP) has already demanded or wiped the system accruing to policy. If that is the case, and they filled out our form, we have a form per item, then I will check it to make sure, everything looks good, and then I put it out for redistribution." This service extracts even more utility out of a piece of server equipment. The department turning in the server gets “pennies on the dollar” according to P. George (interview, 2013). The department or school purchasing the hardware extracts tremendous utility from a three-year-old server.

In terms of social sustainability, maximizing utility was delivering high availability for all services delivered from the enterprise computing equipment. According to R. Hibbert (interview, 2012) University Community Partnerships had the marketing and outreach role. They say “come here, we have this data center space.” When the schools or departments were ready, “we will actually have a sit down session so they have an idea of what the co-location offering is and what the virtualization offering is and get from point a to point b.” The discussion always favors virtualization, however co-location was always an option. This was more favorable to schools and departments who might not be ready to migrate to the intelligent infrastructure. Another aspect was the reliability from backup services offered in the data center. “We have the ability to protect the data by replication from our Tivoli storage manager environment or backup infrastructure. By migrating to the intelligent infrastructure, they automatically get included into that off site data protection scheme that provides that off site campus owned data center where the data is protected. It significantly changes what their data protection standpoint and disaster preparedness standpoint” (D. West, interview, 2013).

The ability to virtualize a server computer is not new, but it is gaining ground in social sustainability. “It is no longer a fad. Virtualization is here and in order for vendors to continue selling their product they have to be prepared to support a workload in a virtualized space” (D. West, interview, 2013).

In terms of environmental sustainability, maximizing utility is increasing computational power while decreasing the ecological footprint in terms of power consumption and electronic waste. According to D. Granger (interview, 2013) “We can suggest that we put environmentally sustainable language in the request for proposal asking for vendors to respond to specific questions.” This language would detail the power efficient requirements of the enterprise equipment. Purchasing can only do so much as requested by the departments. UITS will need to request green computing options. “I believe we need to continue to review opportunities to leverage green computing” (D. West, interview, 2013).

E-waste was greatly reduced when the life of the equipment is extended. The redistribution process will bring additional life to enterprise computing equipment. The non-functioning equipment is turned over to a partnered e-waste service. According to P. George (interview, 2013), “We don't throw them away, if by some odd chance, we have a server that caught on fire, we are not going to sell that, but it will go to e-waste.”

Together, sustainability is demonstrated through this theme of maximizing utility. Purchasing wants to buy enterprise-computing equipment with the most value in addition to being good stewards of university capital. UITS demands the most computational power in a decreasing power and space footprint. Surplus wants to extend the life of all equipment and reduce the amount of e-waste.

J. Communication and Outreach

The social theme encapsulates communication and outreach related to sustainability. There are many sustainable related services available at the university that need more outreach and communication. According to D. Granger (interview, 2013) “I think one of the short comings in the purchasing area is the need to be more educated on what’s available in different product lines as far as what is environmentally friendly.” The vendors do not publish a lot of the information related to sustainability. This was consistent with the literature review. D. Granger has looked for this information. She added “I just have not seen as many energy type ratings out there, haven't seen the information, that says that if you buy a large storage system, its got these environmentally factors, I have not seen that come forward from the vendors. And maybe that is something that we need to go to the vendors and get more information.”

According to P. George (interview, 2013), regular communication about sustainable computing “would evolve into substantial positive results.” Sharing this information about sustainability was important to raise awareness. This theme was present in purchasing as well. According to G. Hill (interview, 2013) “Providing cost savings/service efficiencies data to department Deans, IT Professionals, Business Administrators, and Fiscal Officers” was a way to overcome sustainability barriers. G. Hill added, “UITS and Department IT Professionals need to work with the contracted vendors to educate departments on optimizing document workflow and recommend the departments use the enterprise software tools such as OnBase.”

By and large, outreach and communication was an important factor that contributed to social sustainability. Whether it was energy efficiency information from vendors or awareness of sustainable services offered by the university, knowing about sustainability was a consistent theme present in the data. The data in Table 3 represent the code frequency from the transcriptions. The two most reoccurring codes from the transcriptions were Efficient Resource Management and Social. These data guided the related common themes.

TABLE 5: TRANSCRIPTION CODE FREQUENCY

Code	Total	Min	Max	Mean	Standard Deviation
Economic	46	3	19	9.2	6.648
Efficient Resource Management	73	0	27	14.6	10.621
Environment	25	0	7	5	2.915
Leadership	32	0	18	6.4	7.232
Social	51	4	21	10.2	6.979

K. Conclusions

The life cycle of enterprise computing equipment at the university was a model for sustainable practices according to the findings of this study. Indeed, the connection to the themes from the literature review and the theoretical framework for this research was striking. Specifically, the practice of virtualizing enterprise server computers was economically sustainable. Over 2,000 virtual severs were installed on less than 90 physical server computers. There was economic savings on equipment, human resources, power, space, and cooling. The economic savings increased every three years due to Moore's Law. Additional computing power was available for less money in a smaller amount of physical space. The practice of virtualizing enterprise server computers was also socially sustainable. The high availability of the virtual machines, their ease of use, the reliability, and backup/recovery features made the practice of virtualizing socially sustainable. There were many redundant measures in place at the university Data Center to ensure high availability. The batteries, flywheels, and generators kept the power up to the machines at very high levels. This cannot be achieved affordably outside the data center. The practice of virtualizing enterprise server computers was also environmentally sustainable. There was considerably less waste when virtualizing a server. The reduction of waste was not just with the physical equipment, but also the cabling. There were less network and power cables.

The sustainability practices were planned, monitored, and evaluated through the coordination between UITS, the university, Central Purchasing, and University Surplus. Each team was responsible for planning sustainable practice in their respective area. The Sustainable Computing Working Group provided leadership for planning, monitoring, and evaluating sustainable practices at the university. There are members from purchasing and UITS. The group included associate vice president level leadership, managers, staff members, and students.

VI. DISCUSSION AND FUTURE RESEARCH

Sustainability from enterprise server computing came mostly from squeezing the most utility out of the equipment. This was true from economic, social, and environmental perspectives and not surprising considering the literature that exists on each of these subjects. Economically, the university wanted to be good stewards with available capital for computing needs. The trend of virtualizing server computers accomplished this by providing more services for less money. Socially, there were many advantages to a virtual server. Certainly the ability to spin up a new server in minutes was an asset and the ability for administrators to add RAM and hard disk space in minutes virtually was a positive. The Data Center's high availability power and network additionally add to maximizing the utility from this service. Environmentally, the power savings were not from idle cycle systematic machine shut down, it is from maximizing the utility from all the servers.

The results were consistent with the literature themes of sustainability, measurement, and efficient resource management. Leadership themes were consistent with regards to actions required. Creating change with regards to purchasing, for example, would require leadership moving the change forward in addition to policy change. Cyber Risk Mitigation policy exercised an authoritarian style of leadership. Policy is in place to safeguard private data and must be followed. A similar policy could be created to safeguard the environment by sustainable enterprise computing practices. This would require action from leadership to draft, approve, and create a new policy with sustainable language.

As is often the case in qualitative research, many questions are revealed. Based on the results of this case study additional research should be considered in the areas of leadership themes including organizational change, organizational climate and culture in a technical environment and leadership ethics. Specifically, survey research geared toward technology leaders in large (20,000 employees or more) organizations would be useful to the field of sustainability. Additionally, comparison research between sustainability practices in private vs. public sector businesses would break new ground in the area of sustainability life cycle of enterprise computers. While higher education does indeed account for a large portion of enterprise computers, private sector organizations account for a much larger portion than non-profits. Finally, studies on the rapid change in the area of sustainability life cycle of enterprise computers should be designed, developed and implemented. Data are clear that knowledge in this field is increasing exponentially. Trends of even 2 years ago, are past practices today. Research on future trends could help illuminate this issue and inform policy makers and technological leaders as they attempt to make high quality decisions for future generations.

.

REFERENCES

[1] Creswell, J. W. *Research design: Qualitative, quantitative, and mixed methods approaches*. Thousand Oaks, CA: Sage Publications, Incorporated, 2013.

[2] Daoud, D. Beyond Power: IT's Roadmap to Sustainable Computing. *IDC White Paper, IDC, New York, NY, October,* 2008.

[3] Feng, W., Ching, A., & Hsu, C. "Green supercomputing in a desktop box." *Paper presented at the 3rd IEEE Workshop on High-Performance, Power-Aware Computing (in conjunction with the 21st International Parallel & Distributed Processing Symposium*), Long Beach, California, 2007.

[4] Forrest, W., Kaplan, J. M., & Kindler, N. "Data centers: How to cut carbon emissions and costs." *McKinsey Quarterly* (November), 2008.

[5] Gladwin, T.N., Krause, T., and Kennelly, J.J. "Beyond eco-efficiency: Towards socially sustainable business." *Sustainable Development*, vol. 3(1), pp. 35-43, 1995.

[6] Grush, M. "Expanding HPC and research computing--The sustainable way." *Campus Technology*, vol. 23(1), pp. 32-34, 2009.

[7] Harmon, R. R., & Auseklis, N. "Sustainable IT services: Assessing the impact of green computing practices. In *Papers presented at PICMET'09* [CD-ROM]. Eds,: D.F. Kocaoglu, et al. *Portland, OR* (pp.

1707-1717). August 2009.
[8] Hart, S., Milstein, M. "Creating sustainable value." *Academy of Management Executive,* vol. 17(2), pp. 56-69, 2003.
[9] Kerr, I. R. "Leadership strategies for sustainable SME operation." *Business Strategy and the Environment*, vol. 15(1), pp. 30-39, 2006.
[10] Laszewski, G., Wang, L., Younge, A. J., & He, X. "Power-Aware scheduling of virtual machines in DVFS-enabled clusters." *Paper presented at the IEEE International Conference on Cluster Computing,* New Orleans, LA, 2009.
[11] Ljungblad, S. "Everyday visualization to support a sustainable development." *Paper presented at the 9th International Conference on Ubiquitous Computing,* Innsbruck, Austria, Sept. 16-19, 2007.
[12] McCullar, N., Blackmore, B., Goh, A., King, G., Kowalski, N., & Rau, M. "Bridging the information gap: material tracking and consumer labels to encourage sustainable computing*." Paper presented at the IEEE International Symposium on Information Theory*. Chicago, IL, June 27-July 2, 2004.
[13] Midwestern University, "UITS data center operations & production services." *University Data Center Facts and Figures*, 2013.
[14] Midwestern University News Room "$32.7 million university data center to be unveiled; anchor for growing technology park." *University Data Center Facts and Figures, 2013*.
[15] Midwestern University "Public safety and institutional assurance; securely removing data." *University Data Center Facts and Figures, 2013*. 2013.
[16] Mocigemba, D. "Sustainable computing." *International Journal of Ethics, Science and Technology Assessment,* vol. 4(3), pp.163-184, 2006.
[17] Parrish, B. D. "Designing the sustainable enterprise." *Futures,* vol. 39(7), pp. 846-860, 2007.
[18] Potocan, V., & Mulej, M. "Ethics of a sustainable enterprise—and the need for it." *Systemic Practice and Action Research*, vol. 20(2), pp. 127-140, 2007.
[19] Skiles, S. University Procurement Services - Purchasing Authority, 2009.
[20] Stake, R. E. *The art of case study research*. Thousand Oaks, CA: Sage Publications, Incorporated, 1995.
[21] Stern, N. *Stern review on the economics of climate change*. Cambridge, United Kingdom: Cambridge University Press, 2006.
[22] University of Maryland Campus Sustainability. "About Sustainability at Maryland." Retrieved 5/30/13 from http://www.sustainability.umd.edu/content/about/what_is_sustainability.php.
[23] Yadong, L., Richardson, J. B., Walker, A. K., & Yaun, P. "TCLP heavy metal leaching of personal computer components," *American Society of Civil Engineers,* vol. 132, pp. 14-23, 2006.
[24] Yin, R. K. *Case study research: Design and methods* (Vol. 5). Thousand Oaks, CA: Sage Publications, Incorporated, 2008.
[25] Young, A., von Laszewski, G., Wang, L., Lopez-Alarcon, S., Caruthers, W. "Efficient Resource Management for Cloud Computing Environments." *Proceedings of the IEEE International Green Computing Conference (IGCC).* Chicago, IL, June 15-18, 2010.