Abstract—As data center costs rise and space availability diminishes many organizations are investigating the viability of cloud computing for research use. Yet the majority of research investigators have not readily embraced cloud capability, regardless of the potential cost savings. Through interviews, case studies, and up-to-the-minute blog posts from top experts, it is possible to extract a basic framework of barriers that dampen widespread cloud adoption. Insight gained through examining these barriers can then be used to design an organizational strategic plan to build a cloud-enhanced campus cyberinfrastructure.

Index Terms—cloud; cyberinfrastructure; cirrus; campus; strategy; analysis

I. INTRODUCTION

During the past year, the University of Michigan launched the CIRRUS Project © (Computing and Information Resources for Research as a Utility Service) under the direction of Dan Atkins, Associate Vice-President for Research Cyberinfrastructure. The mission of the project is to build a foundation for a vibrant and sustainable university cyberinfrastructure. As part of the project, the CIRRUS team will evaluate and explore new transformational technology, including emerging cloud computing technologies. This study is the first of a series of investigations to explore issues surrounding cloud adoption on university campuses. Since “cloud” is a trendy and ever-evolving buzzword in today’s IT world, for the purpose of this study “cloud” is defined as shared computational resources that have been abstracted so as to appear to be a utility service to the end user. Within this abstracted layer of computation, general categorical terms such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) are often used to describe the varying degrees of abstraction with which the user interacts with cloud infrastructure. Virtual machines, virtual desktop images, HPC clusters, grids, and externally supplied computational utility services can all potentially be categorized as forms of "clouds." Differentiation of services into sub-categories depends on how close the end user works with the lower levels of system administration and application design. Current campus involvement with these various levels of cloud resources, as well as the state of cloud technology development itself must be evaluated before organizing a course of action for cloud services at UM, or any institution. Therefore, the purpose of this study is to identify existing usage, categorize potential use cases, define barriers for adoption, and ultimately suggest integration methods for universities interested in cloud technology.

II. ASSESSMENT OF CLOUD STATUS: UM CAMPUS AND BEYOND

At the time of this study, cloud utilization statistics for the UM computational environment were largely unknown. In addition, given the segmented nature of the university IT infrastructure, data from any investigation would be by no means 100 percent complete and comprehensive. A more time-sensitive approach to assessment was to focus on specific computing instances utilizing cloud technology at UM, as well identify the barriers that have prevented other users from adopting cloud technology. Case studies were then compiled into user "profiles" and compared with industry trends in an effort to draw conclusions regarding current state and a successful direction for cloud use.

A. UM Internal Clouds: Virtual Machines and High Performance Computing (HPC)

While many define the cloud specifically as “services provided by vendors external to the local IT infrastructure,” it is more accurate to define the term as services provided to users such that the users interact with infrastructure at varying levels of abstraction [4]. For example, the provisioning of virtual services and pay-as-you-go computational allocations follow similar processes in both external and internal IT environments. In both scenarios, the user interacts with a shared resource at an infrastructure level above server hardware. Therefore, to only observe the state of commercial cloud development is to ignore the evolution of shared resources in local IT infrastructures. The most visible examples of shared resource development in local IT infrastructure are in the areas of virtualization technology and HPC efficiency management.

There are several instances of virtualization services in current campus infrastructure. At UM, both Information Technology Services and Medical School Information Services run separate instances of VMWare ESX virtualization technology. With VMWare, IT organizations are capable of deploying enterprise-class virtual servers in many custom configurations. Pre-configured Linux and Windows Server images can be deployed within a matter of minutes for university users. Although UM users are not yet able to launch images instantly on-demand through the VMWare infrastructure, the capability for such a system
exists and could be implemented in the future. Since the end user is never required to configure hardware but is able to configure the operating system, virtual machine hosting can be categorized as version of IaaS service. However, it is important to note that while virtualization is a variation of a cloud service, a mature “cloud” virtualization offering also incorporates automated, on-demand provisioning and may capitalize on large-scale deployments through alternate technologies. For example blogger Gordon Haff, of cnet.com notes, "Google has demonstrated that large-scale distributed infrastructures don't require server virtualization; they architect their infrastructures using other techniques and provide higher-level abstractions and services to users" [6].

Virtualization services are not the only example of shared resources acting in a similar manner to cloud services. Several UM colleges currently offer varying levels of HPC services to users. These HPC clusters can be categorized as a Platform as a Service (PaaS) as the user does not interact directly with the hardware or operating system, but instead use tools provided through pre-configured modules. The newest cost-recovery model for high-performance computing at UM also follows similar cloud pay-per-use models already on the market. Users are able to purchase time on resources, instead of purchasing physical machines. This UM cost-sharing strategy promises to improve efficiency and availability of services to the research community through the brokering of time on HPC internal “cloud resources.”

B. UM and the External Cloud: A Few Brave Souls

Overall, the use of commercial cloud resources across the UM campus is extremely sparse. The common response to the question "Do you use cloud resources for your research?" is "No, but I would be interested to learn more about UM's interaction with cloud vendors and how the (external) cloud could benefit me." Research investigators are interested to learn more about the cloud, but interest diminishes when presented with the Do-It-Yourself administration burden that is a tightly coupled component of the cloud adoption experience. Furthermore, neither campus IT groups or cloud suppliers are adequately equipped to assist every research investigator with every variation of available cloud instance from every cloud vendor. The situation that results is slow time-to-delivery coupled with complex implementation needs, forcing innovation on the cloud platform (and often other types of new technology) to become a lower priority to other research activities.

Research groups that have made use of cloud resources often do so when local resources cannot meet their needs. Data center space is often at a premium on campuses, and many groups have historically found the path of least resistance to obtain computational equipment housing is to construct locally managed "server closets." Yet these Do-It-Yourself server spaces often lack adequate power and cooling facilities. Reliability can quickly become an issue and local groups are forced to look elsewhere for resource solutions. Recently, the UM-based Inter-University Consortium for Political and Social Research (ICPSR) has devised a more innovative approach to the persistent data center space problem. Rather than attempt to negotiate with the various groups on campus already in possession of data center space, the ICPSR has moved some of its operations into Amazon's EC2 cloud. The ICPSR computational need "profile" fits within the constraints of the cloud and simultaneously is able to leverage the advantages of the cloud. ICPSR’s primary goal as a social-research data service is to make data sets available to users through a secured web interface. With database sizes currently ranging in the GB range and with data only required to be transferred into the cloud and not back locally to UM, ICPSR has successfully avoided the most common barriers to entry of cloud computing: security and data transfer.

III. UNCOVERING BARRIERS TO ENTRY

Adoption of HPC and VMWare internal cloud infrastructure has initially been slow but is now growing quickly. The barriers to entry in each of these private environments are primarily operational issues of capacity to scale, adequate support for application transition, and availability to all users regardless of school affiliation. Therefore, it is necessary to focus on private-cloud barriers to entry separately from barriers to entry of publicly available clouds. For the purpose of this study, public cloud barriers to entry will be the primary focus.

As with any IT service, user requirements must be a good fit with the services to be provided in order to optimize the chances for a successful deployment. For cloud services, common concerns that often arise regarding cloud adoptions are security, data transfer speed, reliability, and data curation. To further complicate paths to adoption, the inclusion of time-based resource allocations in federal funding is generally unclear and often not deemed permissible by academic institutions. However, time-based allocation is the primary method of purchase of cloud instances. Lack of system administration or programming knowledge within the noncomputer science, domain-specific research areas also slows cloud adoption progress. Overall, cloud resources are seen as a potentially expensive risk for minimal visible gain.

A. Security and Regulation

While malicious attack prevention has always been a primary concern to IT organizations, audit trail management has become an equally important aspect of the IT security portfolio [9]. For sensitive data, i.e., HIPAA or financial data, audit trails are a requirement for accountability during an audit. Historically, audit trails and compliance crosswalks have often been an afterthought to system design and implementation. However, the abstract nature of using a cloud vendor outside immediate control of campus IT groups forces many regulatory compliance questions to the surface, as expectations of security cannot be taken for granted. Instead, organizations must document security safeguards during the project planning process and then communicate these needs to the external cloud partner. This also means cloud providers must give satisfactory documentation of their policies and procedures for audit documentation in addition to technical security mechanism documentation, before a group may truly start negotiations with them.
From an operational perspective, large organizations like the State of Michigan and NASA, have chosen to categorize their data requirements so as to drive cloud-security decision-making. For example, the State of Michigan MiCloud plans to use external vendors for some services, but still will have a self-managed internal cloud for sensitive data [16]. In the same vein, NASA's cloud project Nebula is categorized as FIPS-199 Low, which makes it suitable for most research, but still unsuitable for computation of classified and sensitive data [3]. Thus the emerging trend is a tiered approach to computation, primarily driven by the security needs of data. This strategy is currently considered best practice, though valid proof in support of the argument to cloud justification based on data security requirements are continuing to emerge [15].

B. Data Transfer

Another common problem that has arisen for cloud adopters has been data management going in and out of the cloud. For large data transfers, even the widest bandwidth connection could still potentially result in hours per transfer. Also, as with any networked service, large data transfers are also subject to network connectivity interruption, which can prolong an already frustrating transfer process. Additionally, at approximately $0.10 per gigabyte on average to transfer data to and from the cloud, the cost of data movement can quickly outweigh any costs savings found through cloud adoption. Therefore, the combination of workflow requirements for data, network bandwidth capacity, and data transfer charges creates a minefield of potential issues that a research investigator is tasked to resolve.

C. Reliability

As is true for all IT organizations, UM IT groups have various levels of service commitments to their users. In a local computational environment, system administrators are able to control, or at least influence, all levels of infrastructure. However, in an external cloud infrastructure, IT groups must place their trust in the vendor's promised delivery of service. Ultimately local systems administrators do not have complete control over guaranteed uptime for services provided. While this scenario may initially appear to be largely prohibitive, empirical data has thus far proven the contrary. The general consensus of cloud adopters at Cloud Camp Detroit 2010, and ICPSR's approximately year-long experience with Amazon EC2 suggests cloud services are reliable enough to be considered for 99.9% uptime quality of service, or roughly 9 hours of downtime per year. It is still unknown if cloud applications are as reliable as 99.999% availability (Google gmail and docs occasionally still become slow or unavailable), but cloud reliability improvement suggests that cloud applications will eventually match or surpass local IT services’ uptime dependability when given a reliable network path.

D. Procurement

As of late, cloud vendors have yet to accommodate brokered billing system services to users. In other words, the only option for payment and allocation of cloud instances thus far is through individual accounts maintained by each researcher or cloud user. As has been found true with bulk hardware purchases, bulk cloud-resource purchases could likely produce cost savings as well as faster time-to-delivery. In the current UM environment, there are limited standard mechanisms for which research faculty may order hardware from a variety of system options at discounted rates, but there is no option to order from cloud vendors.

E. Performance for HPC

While cloud architectures are extremely adept at scaling on demand, most cloud infrastructures are currently not built for fast node-to-node communication. Cloud architecture performs incredibly well with embarrassingly parallel and stochastic modeling, yet any algorithm requiring various tasks to communicate using fast interconnects between nodes renders most cloud infrastructures unsuitable for use [10, 11]. These limitations are expected to diminish as companies rush to provide HPC-friendly cloud offerings, but current cloud configurations are generally not designed for HPC performance needs.

Much like Google, Penguin-on-Demand (an HPC cloud service) solves performance issues by removing virtualization all together. HPC nodes are instead directly built on hardware so as to optimize performance. Currently the Penguin-on-demand services are marketed as a solution to the "bursty" needs of high compute-power, short-term projects. Amazon is also attempting to capitalize on HPC “bursty” needs by offering a new “compute cluster” instance on EC2. To date, the Amazon offering is too new to accurately comment on its impact on HPC’s need to scale.

IV. UNREALIZED BENEFITS

Given seemingly insurmountable barriers preventing cloud adoption, it would appear some might wish to avoid the cloud all together. However, equally powerful pressures of economic viability and workflow efficiency are forcing IT organizations and research investigators alike to re-evaluate their current environments. In this light, cloud computing offers key benefits which make the task of overcoming barriers more attractive. For example:

A. Systems Administration Skills Should Not be a Research Investigator Requirement

The primary task of researchers is to explore and discover in their areas of expertise. It is a benefit to their employers, academic or corporate, that individual researchers devote as much time as possible to this high value-add activity. Very often in the research environment, systems administration tasks become a necessary evil that must be managed. Graduate students, post-docs, or even the researchers themselves are required to devote time to mundane, non-value-add systems administration tasks. The promise of cloud-provisioned systems is to reduce systems administration overhead, as well as increase system reliability through easy-to-use GUI interfaces that are capable of deploying pre-configured machines. An even more attractive outcome of cloud computing is Software as a Service applications like Matlab and SAS, which are ready...
to use with no systems administration responsibility or limitations inherent to desktop-only use. Costs for licensing will also be reduced if the university contracts are able to purchase more licenses in bulk and also make more efficient use of the licenses currently owned. The result will be better-managed licensing, easier access to software, and potential cost savings to the university.

In addition to cost savings, an untapped benefit to cloud computing is the ease at which research collaboration can potentially be organized, documented, and explored. Data that has been relocated to a shared cloud environment will most likely require new management tools and innovative data access techniques, but overall accessibility of research data should improve. The quality of information captured from these data sets also has the potential to improve rapidly through the use of cloud-based development platforms, which are designed to enable developer collaboration. As the cloud matures, it is very possible research methodology will evolve to capitalize on the benefits offered by nimble cloud computing environments.

B. IT Organizations Need Efficiency-Improvement Tools

A cloud-inclusive provisioning strategy will allow IT organizations to provide a higher quality of services to more users. Once IT professionals are given tools and architectures that foster time-saving, user-triggered, automated provisioning, they will have more time to focus on value-add activities. In the long term, IT groups will become more innovative and additional service options will be encouraged to develop [5].

IT organizations harnessing cloud technology will also have opportunities to improve the depth and quality of service provided to users. With time-to-delivery greatly reduced by automated provisioning, administrative costs such as monitoring application ownership should decrease as well. Extra funding and personnel capacity will enable IT organizations to have the option of maintaining better user records through cloud-based Customer Relationship Management applications, automated license management, warranty management, amongst many other value-add systems previously shelved as high overhead projects.

Finally, when an IT organization adopts a regional, national, or global strategy to resource-provisioning services, opportunities arise for collaboration. A prime example a cross-institutional collaborative project is Diagrid. Diagrid is an award-winning computational project that leverages the partnerships and computers of nine university campuses. The project’s primary technological premise is the Condor high-throughput technology, which is able to pool resources and create one massive compute resource [17]. Other opportunities for UM to partner with academic peers and commercial vendors have also arisen. Partnership possibilities include technological research partnerships between UM and IBM, Isilon Systems, and Microsoft (to list a few), but none have been developed beyond initial planning stages.

V. RECOMMENDATIONS

The severity of roadblocks for cloud adoption are largely subject to the nature of the data and/or application. Organizing potential cloud data and applications by traditional IT standards is a familiar approach to a somewhat ambiguous problem. Cloud-vendor service options can then be loosely categorized into the categories of IaaS, PaaS, and SaaS. Through this categorization method, roadblocks will become visible and appropriate fit of cloud offerings to services will materialize.

A. Categorizing Needs and Resources

First, IT organizations must evaluate current services and categorize by need in the following categories: uptime, security, volume of data, accessibility, and service function. Like any new IT service, potential cloud candidates should be evaluated on a case-by-case basis [7]. Figure 1 is a projection of a possible categorization outcome with mission critical needs (uptime) and security as primary factors. The diagram also identifies services that need to be kept local, and others that may be candidates for cloud services, as suggested by cloud infrastructure experts [10]. Currently experts also predict that by 2020, only 10% of applications will stay local [8]. This however is not a target figure as each organization will vary when categorizing services.

![Security-centric tiered approach to cloud justification.](image)

The next logical step is to categorize current cloud providers by known cloud abstraction levels (IaaS, PaaS, SaaS). It is also helpful to categorize existing services within the university into best-fit cloud abstraction levels. By categorizing both internal and external services, it is possible to construct a full picture of available resources at each level of user interaction that may be requested. Figure 2 represents a possible cloud-integrated cyberinfrastructure that also includes local UM services as part of the overall service portfolio.
After categorization, it is now possible to identify services that are easiest to pilot / migrate into a cloud environment. The following profiles in Figure 3 can be used to loosely fit computational need to a cloud vendor’s ability to provide the required level of service.

In addition to new service, it is important to note a common approach to cloud adoption is to migrate older services to the cloud. The rationale for this strategy is that the investment of resources to maintain or improve the current state of older machines (patching, security, general maintenance) is greater than the investment in resources tasked with transitioning the service to cloud platforms.

B. Security

Security concerns are traditionally two-fold: technical security and security policy. Solutions for technical aspects of security for the cloud will inevitably come to fruition as existing security companies race to develop and release products tailored to utility computing [18]. Security research investigators will also continue to craft new methods of security algorithms specific to the cloud [19]. In many cases, services running as PaaS and SaaS will not even require the user to manage security vulnerabilities directly. Therefore the most pertinent issue for IT organizations to address is security policy required by each category of service and/or data the organization plans to support [15]. While some vendors are proactively addressing this issue by pre-certifying cloud services for various regulatory standards [2] (e.g., Rackspace is working with the Life Sciences Information Technology Global Institute to become FDA certified, Google is FISMA certified), IT organizations must ensure that the regulatory policy for each service they provide has been classified so as to easily map onto appropriate cloud-service offerings.

C. Data Transfer

Although time-consuming and tedious, security policy is not the biggest roadblock for cloud adoption. In fact, issues surrounding massive data transfer are much more pressing. There is significant need for experimentation and discovery in the area of data transfer methodology and data sharing techniques. An exploratory program to evaluate and improve infrastructure speed and reliability between cloud vendors and local campus facilities would be an ideal opportunity for any research group interested in expanding the boundaries of shared data. For example, the proposed Open Cloud Initiative, championed by Internet2, is an excellent opportunity for university involvement in standards development for data sharing technology. The Open Cloud Initiative promises to explore the interconnectivity of multiple cloud vendors and encourage a community-based approach to removing data movement as a barrier to entry into cloud utility services.

D. Procurement

A university IT organization has the potential to add value as a broker of cloud services. Through centrally negotiated contracts and standardized deployment mechanisms, IT organizations are in an ideal position to provide lower-cost services, as well as additional specialized user support not currently provided by cloud vendors. Furthermore, pre-screening of cloud vendors for appropriateness of fit and company financial health could easily reduce potential service complications. If IT groups are able to keep pace with more efficient resource delivery methods, the resulting efficiency gain could allow the IT function of manual provisioning to be bypassed. Instead of provisioning resources for the user, IT organizations would give the user the tools needed to provision resources themselves [12]. The IT organization role could then become one of business process managers, and purveyors of the latest technology. Unburdened with the act of provisioning itself [5], IT organizations would have the ability to keep pace with the rapid rate of discovery occurring on campus. However it is important to note that while cloud infrastructure appears to be a good fit for this instance, the cloud hasn't been proven to be economically feasible for all

Figure 2. Proposed Cloud-Integrated CI

Figure 3. Generalized profiles for IaaS, PaaS, and SaaS
scenarios [6]. Therefore, a case-by-case assessment of each service's need in early stages of adoption is recommended. Overall, IT organizations hold tremendous value-add potential in the brokerage of cloud services and support expertise not currently provided in-depth by cloud vendors.

E. Long-Term Development

To remain ahead of the technology curve, academic institutions have found partnerships with other organizations have proved beneficial to their overall mission. Not only do partnerships provide valuable knowledge sharing between organizations and faculty, they also provide faculty and students with unique opportunities to influence the design of tomorrow's technology on a broader scale. Cornell University, Purdue University, Indiana University, University of Wisconsin, and University of Notre Dame are a few in a long list of institutions that actively cultivate partnerships with other universities or commercial entities. Many of these institutions have already launched shared resource projects that could potentially provide instant benefit to UM with very little startup risk. Also, universities are not the only organizations to benefit from partnership and collaboration. Hospitals and health centers also partner with vendors to develop new technologies and associated methods of using technology. For example, Microsoft partners with Seattle-area hospitals and health centers to develop innovative methods of using the Microsoft Azure cloud for health care. In fact, during the course of this investigation, several academic institutions in addition to commercial entities expressed a strong interest in partnerships that could benefit the UM academic mission at various levels.

Another advantageous strategy for campus cyberinfrastructure development is to shift focus from a hardware-only growth outlook to a software-centric strategy. Strategic planning for software is quickly becoming as important to infrastructure planning as hardware planning [13]. As existing barriers to entry into cloud computing are removed, a proliferation of software development, specifically in middleware, will most likely occur [14]. Assuming the software development environment must be nimble and adaptive so as to keep pace with the advancement of research, software infrastructure planning must be equally as innovative and adaptive. This shift in IT strategy will allow the higher education research community to better harness the newest tools, including the latest cloud technology.

VI. CONCLUSION

Regardless of the name (grid, virtualization, clustering, cloud), the practice of sharing resources is here to stay. The evolution of shared services that can be collectively described as "cloud" computing will revolutionize IT practice for academic and research support, yet the cloud is not a panacea for all IT headaches. On the contrary, the challenge of utilizing cloud computing to its utmost potential is to understand user workflow and the data that drives discovery in order to correctly prescribe cloud technology in a beneficial manner. If IT organizations are unable or unwilling to get to know the data and the users, the cloud will inevitably cause more headaches than it cures. In the absence of a unified, organized IT infrastructure, silos of research lab resources will continue, and speed to discovery will not improve. In the case of the cloud, the "build it and they will come" strategy does not apply [1]. Through judicious relationship management and exemplary customer support, shared resources commonly referred to as the cloud have the potential to become a powerful tool in the evolution of campus computational resources.

REFERENCES