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What If...?

Measuring Impacts of Policy Decisions on Technical Resources

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Imagine that as part of his “state of the university” address, your president announces that beginning in fall 2008, all incoming students will be required to take at least one course online every semester until they graduate. Although your information technology (IT) organization is well aligned with current campus needs, you are concerned about the impact of this new initiative on your personnel, hardware, and networking resources. You have a meeting tomorrow with the provost and chief business officer to discuss next year’s budget. You know they will want to discuss the fiscal implications of this new policy.

How do you build a model that includes the variety of factors you know will influence your ability to support this new policy direction?

Higher education is undergoing a significant but unacknowledged change. Administrators want to respond to increasing societal demands for distance education. Faculty are hybridizing their courses, identifying ways to exploit the capabilities of technology for their teaching strategies (Howell, Williams, & Lindsay, 2003). Students (and faculty) expect technology on campus to perform like it does in the marketplace—24 x 7 availability, on-demand support and service, customized interface, and “zero tolerance for delays” (Frand, 2000, p. 16). Students and faculty expect a seamless and secure experience. Small “pilot” instructional technology projects started by enterprising early-adopter faculty for use in improving learning in their own classes have steadily transformed into full-scale campus or system-wide learning management enterprise systems.

Systems theory and the disciplines of system dynamics or systems thinking are methods for viewing interrelationships rather than specific outcomes, for viewing wholes rather than parts, and for seeing patterns of change and learning rather than viewing snapshots (Senge, 1990). Systems dynamics allows for a better understanding of dynamic behavior of a complex system and the relationship of its component parts. Specifically, systems dynamics allows the practitioner the ability to test for and study the impact of small changes or shifts of a particular system.

For the CIO responsible for managing resources for large installations of interconnected ERP systems, “system dynamics [is able] to capture the small-changes-cause-large-effects nature of systems. By separately modeling hundreds of interacting variables within a system, it is possible to witness emergent behavior of the whole system” (Shaffer, 2005, p. 8–9). Techniques and tools, such as mental models and feedback loops, allow the practitioner to construct the relationships within a system and view their interrelatedness.

This research bulletin discusses how systems dynamics is being applied to higher education administration. It offers a case study for modeling growth in usage of a learning management system (LMS). This model was used to identify the current capacity of the system-wide LMS at the University System of Georgia (USG) and forecast the impact of rapidly increasing faculty and student demands on the system. The LMS Capacity Planning Model offered administrators an overview of the entire operating environment, including hardware, application, database, network, and personnel, and it enabled them to evaluate the impact of policy decisions and operational rules over time on technical capabilities and resources.

Highlights of System Dynamics and Higher Education

System dynamics modeling can organize descriptive information about a system, retain the richness of the real processes, build on the experiential knowledge of managers, and reveal a variety of dynamic behaviors that follow from different choices of policies. Since the 1920s, researchers have used systems dynamics to study and explain interrelationships in such diverse disciplines as biology, engineering, manufacturing, economics, and political systems. In the early 1970s, educators began to incorporate systems dynamic theories in K–12 classrooms as a way of engaging students in thinking about their world and making teaching more learner-centric (Forrester, 1992).

For the past three decades, “systems theory,” “system dynamics,” and similar terms can frequently be found in the literature of education, describing everything from group interactions to service learning to instructional design. Sterman (1994) provides an introduction to the use of systems theory in education. Recently, theorists have tried to apply systems theory to better understand distance and distributed education. Many of these articles offer simple descriptions of distance education, offering techniques for managing change, rather that a framework for more complex investigations. Saba and Shearer (1994) attempt to fill in some of the more complex details of the distance education process by looking beyond the programmatic view of education, to the impact on stakeholders. Frick (1995) demonstrates the use of SIGGS, a complex modeling approach integrating Set, Information, Graph, and General Systems theories to drive systems theories development in educational contexts.

USG LMS Capacity Model

Early in 2006, GeorgiaVIEW,USG’s system-wide LMS, was experiencing phenomenal growth. Not only were more faculty from more institutions using online materials for more of their courses, they were using more tools more often. In a single month in fall 2005, 102,000 unique visitors performed over 51 million actions, more than double the activity from the previous year.

At the same time, system-level decision makers were considering a proposal to require all incoming students to take at least one course online prior to graduation. Realizing that such a policy could seriously impact the performance and stability of the LMS, the Office of Information and Instructional Technology needed a way to test different scenarios on the impact of user demand and activity on the distributed learning system in order to plan for additional hardware, personnel, and network bandwidth.

After examining the types and frequency of data they were already collecting on performance of the LMS and on usage, GeorgiaVIEW project directors quickly realized that traditional risk and regression models might not suit their needs. Data was inconsistent, collected for a wide variety of time frames, and, in some cases, missing.

System dynamics modeling seemed to offer a way to use the collected data without too much transformation and to test a wide variety of scenarios.

USG IT leadership approved a proof-of-concept LMS Capacity Planning Model in which systems dynamics scholarship and techniques were used to model the interconnected relationships and transactions of the distributive learning environment from users to technical infrastructure, from actions to storage demands, and from users to bandwidth demands over the course of two semesters. Various questions were tested during the course of building, testing, and releasing the model, including:

- Are there specific times during the semester when capacity is stressed?
- What phenomena, relationships, or transactions precede stressed capacity, and what phenomena, relationships, or transactions follow this stress?
- Can certain user activities be associated with demand peaks?
- When does peak activity stress bandwidth and storage capacity?

Researchers used a system dynamics modeling application called STELLA to design and refine the model. This software offered a way to visualize and communicate complex systems and ideas dynamically.

Building a System Dynamics Model

Generally, there are five steps to building a systems dynamics model. The following paragraphs describe the process generally and some of the specifics of the USG LMS Capacity Planning Model.

Step 1: Define the Model

As with any research, a clear understanding of the parameters of the system, its key components, and the questions to be asked are essential in developing a workable model.

Identify the system. Systems are defined as a set (group) of dynamic and complex interdependent parts, where information flows or feedback mechanisms “try to pull the system into balance or equilibrium” (Meadows, Randers, & Meadows, 2004, p. 143). One example of a system is the Earth’s ecosystem, where the component parts are its natural resources and its human population. Another example is America’s higher education system, where the component parts are faculty, students, curriculum, degrees conferred, administrators, classrooms, and so on. Some systems may even have subsystems governed by different rules, norms, and relationships of their component parts, such as private colleges and universities versus public colleges and universities.

For the first version of the LMS Capacity Planning Model, IT managers wanted to look specifically at the course management and delivery system and its interrelated parts (the network and application database). In terms of systems dynamics theory, the system is the USG’s overarching IT system, called the Integrated Learning Environment (ILE), and the component parts modeled in the first version of the model are the course management system, network services, and common database. Figure 1 represents the overall ILE system and the actual component parts used in the first version of the LMS Capacity Planning Model. Ideally and ultimately, every component represented in the ILE honeycomb graphic should be included in the model.

Figure 1. USG Integrated Learning Environment Component Parts: Course Management System, Network, and Common Database

Identify the component parts, their variables, and their relationships within the system. Understanding the relationships of component parts in systems dynamics is essential when building a model. A cause-and-effect relationship between component parts can be either beneficial or detrimental and will generate exponential growth or exponential decline of components. This type of a relationship creates a self-reinforcing change. A goal-seeking relationship seeks equilibrium or balance of the system and is a second relationship type (Meadows, Randers, & Meadows, 2004).

In the ecosystem example, the component part "human population" is marked by two types of relationships or events: births and deaths. Births exponentially grow the population, and deaths reverse the population boom to pull the ecosystem into equilibrium. For the higher education example, the component part "degrees conferred" is dependent upon the cause-and-effect relationship of matriculated students per year and the goal-seeking relationship of drop-outs per year.

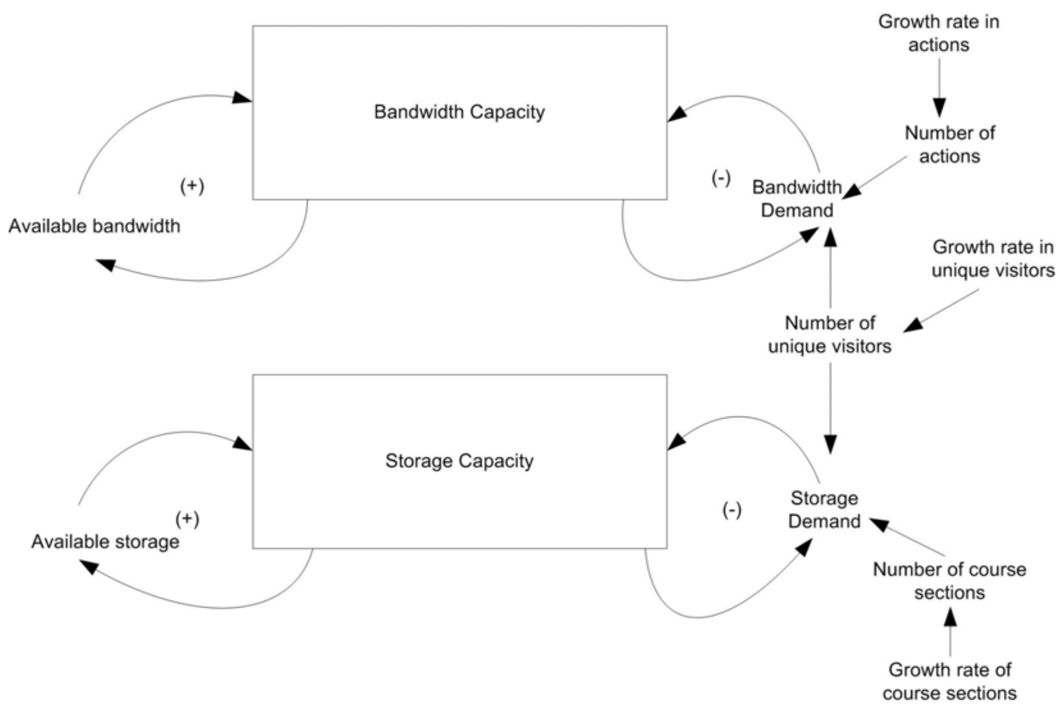
For the LMS Capacity Planning Model, two components were chosen: bandwidth capacity and storage capacity. Both are defined by the relationship of supply and demand. Variables affecting bandwidth demand are actions and unique visitors. Variables affecting storage demand are course sections and unique visitors.

Create the mental model with feedback loops. A mental model is the graphical relationship of all component parts, variables, and their relationships within the system. Mental models "determine not only how we make sense of the world, but how we take action" (Senge, 1990, p. 73). Mental models can be simple generalizations, such as "online students will always log in after hours," or complex theories such as explaining how students and faculty interact in the LMS.

A feedback loop is a key tool that makes the application of systems dynamics unique. When used by the practitioner, this feedback mechanism allows for simulation of positive or negative causal relationships and ultimately measures learning and changes within a complex interconnected system (Senge, 1990). Feedback mechanisms and information flows allow for learning to take place, and they enable the systems theorist to predict what would happen if certain conditions or learning exist. There is usually some sort of exponential growth or exponential loss that occurs within a feedback loop. Cause-and-effect relationships are positive feedback loops, and goal-seeking relationships are negative feedback loops.

Figure 2 illustrates the USG model with feedback loops. Growth in the number of courses offered, unique visitors, and actions impact both bandwidth capacity and storage capacity. Growth may result in the need for additional purchases of hardware or software. Slowness as a result of overburdened capacity may impact growth in users and the number of actions performed.

Figure 2. USG LMS Capacity Planning Mental Model with Feedback Loops



Identify the scenarios, simulations, and or hypotheses to run and test. Scenarios and simulations include hypothetical or real-life events and phenomena for the purpose of testing relationships, assumptions, and hypotheses of the model. Scenarios and simulations can highlight systemic deficiencies or surpluses and can even create opportunities for system change and learning.

The LMS Capacity Planning Model was designed to address scenarios and simulations such as:

- What if all students from 35 institutions logged into the LMS simultaneously?
- What if all English composition courses (all sections) were available online?
- What if X% of all core curriculum courses were available online?

For the LMS Capacity Planning Model the following hypotheses were tested:

- High rates of user actions and power users (those who use the most bandwidth and storage) drive network traffic, thus increasing the stress on storage.
- If we can predict peak capacity bandwidth and storage demands, system administrators can plan procurement, budgets, and staff resources accordingly.

Step 2: Identify the Data Sources

Perhaps the most elusive of all steps is identifying the data and finding its sources because collection systems may not have been designed to collect real-time or desired data. However, unlike most statistical and predictive packages, systems dynamics enables modeling for uncertainty. For example, if data are not readily available to build the first version of the model, using a three- or five-point Likert scale (see "Collect, normalize, and scale data" below) could represent 1 = low, 2 = medium, 3 = high. Using a Likert scale will not yield a more granular prediction if real data were used. Regardless, an IT manager can use this absence of data as an opportunity to request more finite data-extraction capabilities within the enterprise.

The USG LMS Capacity Planning Model used the following collected metrics:

- Network (PeachNet) system statistics
- Curriculum inventory reports
- Course management (WebCT Vista) statistics
- Database (Oracle) I/O rates

Collect, normalize, and scale data. Normalizing data is important to ensure that the scenarios and predictions are within a reasonable range and that relationships are represented in the same base unit. For example, if one were trying to predict when the Amazon rain forest will ultimately be depleted based on current human consumption of lumber, one would use a measure such as *for every x-square-foot house built worldwide, x-square-feet of forest is lost*. Mixing meters and yards or inches and centimeters would not be standard. Scaling data allows for measuring uncertainty, the strength of a relationship, or even the attitudes of a particular population or sample.

Spending time understanding where data are derived, normalizing for consistency, and scaling for uncertainty or measuring strength of relationships will yield a more powerful model and further articulate the system's dynamics.

Step 3: Understand the Model's Constraints and Assumptions

Systems dynamics looks at causal relationships and their effects on the entire system. Precise forecasting and point-in-time predictions are outside the scope of systems dynamics. The model can be used to predict trends and view how a small change in one or more variables can affect the system as a whole. The model is far less functional when it is based on incomplete knowledge of the entire enterprise operations, incorrect relationships, incomplete data, or false assumptions.

The constraints of the USG LMS Capacity Planning Model were:

- Human capacity demands were not modeled in the initial version because of issues with data retrieval, coding, and synthesizing variables. Data were not consistently collected on the actions of systems administrators and operational staff prior to the development of the model.
- Actions and course-section variables are only available by semester, not by day or month, as are many other variables including network traffic loads. Therefore, when running simulations, these variables appeared rather static.
- Nine peak dates were used to create a baseline model: 8/29/2005, 9/28/2005, 10/3/2005, 11/14/2005, 12/05/2005, 12/06/2005, 01/17/2006, 02/01/2006, and 03/01/2006. High bandwidth demand was originally hypothesized to drive high storage demands or consumption patterns; thus network statistics and I/O rates were reported simultaneously.

Step 4: Test the Model

Step 4 occurs within the systems dynamics software package when the practitioner loads large-scale data into the model. The final step is testing assumptions, running scenarios, and making predictions.

Step 5: Analyze the Results

The practitioner of systems dynamics takes results of simulations and scenarios and presents findings to IT mangers and key decision makers within the enterprise. Typically, discussions of assumptions, data, scenarios, and predictions ensue, and the desired result is a marked change or greater understanding of the system or enterprise.

The USG LMS Capacity Planning Model was a proof of concept, built on a baseline of eight months of existing real-world data. Simulations, therefore, predicted when storage and bandwidth demands fell below or rose above expected demands during a given calendar year. While this model only included data from portions of fall 2005 and spring

2006 data, respectively, cyclical semester trends can already be detected from peaks and valleys within the data and simulations. The initial hypothesis that network user traffic drives storage demands was incorrect. While storage consumption patterns were relatively high during the nine peak days of network traffic, they were not the peak days during the month's worth of activity logs. Later iterations of the model may build on peak days within a given week and perhaps model 24 hours' worth of activity for peak days.

An interesting trend outside of the nine days' worth of data was that peak storage days do indeed cluster near peak network activity, and at times they track earlier than a flurry of network activity. This may suggest that super users consume more storage per visit than normal users.

Furthermore, the notion of super users versus regular users can be tested with this baseline data. For future research, the type of course (fully online, hybrid, or component) can also yield insight into the notion that the more component-rich a course is, the more storage and bandwidth it demands. Understanding the cycles of super-user and regular-user behavior with respect to the type of action within component-rich or component-poor courses will help administrators strategically plan for resource depletion and glut and manage accordingly.

In summary, systems dynamics looks at causal relationships and their effects on the entire system. The model can be used to predict trends and view how a small change in one or more variables affects the system as a whole. This type of case study can provide empirical evidence, baseline metrics, or benchmark data.

What It Means for Higher Education

Information and instructional technologies are becoming more integrated. With integration comes complexity. In the past, CIOs may have been able to isolate the workings of individual applications or systems, and growth might only impact the services supported by the network or an administrative system. Today, applications are dependent on shared databases, middleware, and networks. Growth or change in one application can impact the performance and stability of others. Planning for these interdependencies is imperative.

Systems dynamics is one tool for strategic planning and scenario planning. Often, institutions must implement special operational procedures to address the requirements of distributed learning, especially regarding system performance (can the infrastructure support all online students at peak demand?), scalability (as the number of online courses and students expands, can the infrastructure accommodate this load without undergoing degraded performance?), and availability (is the online course server accessible at all times when students may need to access their courses?).

"What-if" scenarios can scope out causal chains of particular policy directives (what if all freshmen were to take English composition I online?) or IT management decisions (what if we were to purchase a new server farm?).

Systems dynamics is not a crystal ball; its models cannot make point-in-time precise predictions, but it can be used to view causal links and changes within the learning or adaptive organization.

What do CIOs need to know when applying systems dynamics to their planning?

- Supply and demand dynamics of distributed education
- Causal relationships among storage, bandwidth, application, and human resource capacity; supply and demand within the context of the academic enterprise system
- What data reside in the academic enterprise system and their quality; the ease of data extraction; how to manage and analyze data; and how to create meaningful causal feedback loops between the data processes and the system
- Standardized data collection and reporting, especially across multiple ERPs

Key Questions to Ask

- Are there complex, interconnected relationships on my campus where systems dynamics can help with capacity planning?
- Are there projects or initiatives that share enterprise applications and resources across departments where systems dynamics can help develop a cognitive framework to simulate innovation or track change and learning within the organization?
- Where are untapped data resources?
- How will data be used?
- How will the simulations and results help with learning within the organization?

Where to Learn More

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