A Systems Approach to E-Government Cloud Sustainability

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***Abstract*—The purpose of this study is to explore the use of public cloud computing by the US Federal Government leveraging dynamic systems modeling and system thinking methods. A historical analysis of public cloud hyperscale service provider growth and Federal Government cloud consumption is conducted as a baseline to highlight significant milestones over the past fifteen years. A stakeholder interest map is established to determine the endogenous and exogenous elements of our study, and a novel dynamic model is developed to capture the feedback loops, stocks, and flows, as well as multi-dimensional relationships between the variables presented. To prevent large and potentially harmful oscillations, cloud diversity principles such as interoperability and security are presented which promote both balance and sustainability in the system. The primary hypothesis is that self-reinforcing feedback loops which represent the consumption of public cloud services will be constrained by goal-seeking loops which represent Federal Information Technology (IT) budget limitations and macroeconomic fluctuations. To conclude, areas such as model enhancement through greater quantitative analysis as well as recommendations for further research on this topic are proposed.**

Keywords-E-Government; E-Governance; Public Cloud; System Dynamics; Systems Thinking.

I. Introduction

The US federal IT budget for the fiscal year 2022 is approximately 92.4 billion dollars [1]. Over ten percent of that amount is projected to be utilized towards the consumption of public cloud services by government agencies. This double-digit percentage has increased exponentially over the past five years and appears to accelerate as new use cases are discovered and demand increases. The shift from privately run government data centers to cloud-hosted infrastructure has accelerated over the past decade as security and resiliency of these platforms and services have finally met stringent government compliance requirements [2][3]. With digital transformation initiatives now in progress from multiple areas of government, a new problem is forming and related to increasing spend on these premium cloud services.

With a seemingly endless supply of computing resources available public cloud vendors such as Amazon, Microsoft, and Google have capitalized on the shift from on-premises maintained compute, network, and storage systems to offsite third-party operated platforms. With business agility comes some trade-offs, primarily associated with less control and visibility around the complete spend of managing and maintaining these environments. Cloud vendors are intent on increasing Annual Recurring Revenue (ARR), boosting their share price and overall profitability. While this incentive leads sales teams to position large transformational deals, the customer (in our case, the federal government) must make careful selections and ensure the proper controls are in place to prevent sprawl in the resources provided [4][5][6][7].

In a previously published research paper titled "Preventing E-Government Tragedy Of The Clouds Using System Thinking Methods", we developed a cloud service ontology, used a systemigram to highlight system connections, and proposed a novel cloud efficiency model [8]. In this study, we focus on the multi-dimensional nature of an E-government system leveraging public cloud infrastructure to define causal relationships to understand multi-loop behavior. In Section 2a, a timeline is developed to highlight significant milestones in both E-government use of the public cloud and the beginnings and dynamic growth of the big three hyperscalers, Amazon Web Services, Microsoft Azure, and Google Cloud Platform. In Section 2b, we explore our system's endogenous and exogenous agents with a stakeholder interest map. Section 2c presents a causal loop diagram to display the variables in our system and show the relationship, polarity, and behavior of this multi-loop structure. Section 2d introduces cloud diversity principles, a road map for E-government entities to leverage public cloud resources more efficiently and effectively. We touch upon portability, security, and interoperability of the system to ensure we are creating a future state architecture that is sustainable and resilient. In Section 3, we conclude with our hypothesis, constraints, and ideas for further research to enhance the body of knowledge around this topic.

A. *Definitions*

E-government is defined as the delivery of government services via information and communication technology (ICT) efficiently to both businesses and citizens [9][10]. E-Government refers to the delivery of government services via Information and Communication Technology (ICT) efficiently to Citizens (G2C), Businesses (G2B), Government Employees (G2E), and other Government Entities (G2G). It also infers the use of digital technologies such as computer systems and mobile platforms. Cloud computing, as defined by the National Institute of Standards and Technology (NIST), is "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction"[1]. Hyperscalers are cloud service providers; as their name denotes, they have the ability to rapidly scale compute resources from geographically dispersed data centers. Hyperscalers focused on for this study will be Amazon Web Services (AWS), Microsoft Azure, and Google Cloud Platform (GCP) as those are the largest based on current market share and customer base, and adoption. Cloud service models are categorized as public, private, and hybrid. Public refers to a third-party managed service, and private is typically owned and operated by the organization requiring the services, hybrid refers to an entitiy that uses infrastructure and services which traverse both public and private. Some of the prominent cloud service offerings are AWS Elastic Compute Cloud (EC2), Azure Active Directory (AAD), and Google's Big Data Service (BDS) [11][12].

B. *Problem Statement*

The rate of US Federal IT spending on public cloud services has been growing exponentially over the past ten years. Over 10% of the US Federal Government's IT budget is now used for public cloud services which are consumed in a "utility" model [13][14]. Unlike

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capital expenses for on-premises data center hardware and software, the cost of public cloud services is difficult to quantify and predict. Macroeconomic volatility presents an enhanced socioeconomic risk. A strategy is therefore proposed to ensure diversification through governance.

The research goal is to use systems thinking and systems dynamics methods to establish boundaries of the system under analysis, examine the causal relationships of system elements and propose a cloud sustainability model that is based on principles, not process [15][16][17]. The motivation of this study is to contribute to the body of knowledge towards a significant and timely problem that is beginning to present itself in E-Government and may have far-reaching economic consequences if not adequately addressed.

C. Research Questions

The following are research questions we aspire to answer in this study:

1) What are the endogenous and exogenous boundaries for modeling E-Government consumption of public cloud computing resources?
2) Using a causal structure, how do you model the Federal US Government IT consumption of Public Cloud Services?
3) How can you represent the life cycle of Public Cloud services in a dynamic model?
4) Are there factors that may limit the long-term growth of Cloud service utilization in E-Government?

II. Approach & Methods

The foundational method employed for this study was a systematic literature review. The inclusion and exclusion criteria involved selecting conference papers and scholarly journal papers via major academic search engines such as IEEE Xplore, Academic Search Premiere, and Scopus. The time frame selected was from 2006 to the present as the modern concept of cloud computing is relatively new and was formed alongside the Hyperscaler organizations such as AWS, Microsoft, and Google.

Systems thinking methods are used to identify the primary stakeholders and their endogenous and exogenous boundaries. Causal loop diagrams provide an overview of reinforcing and balancing elements in our analysis. Stock and flow dynamic diagrams are also represented to quantify the accumulation and drainage of elements such as budget amounts. Valves provide us with the rate of inflows and, in our model, connect to the causal loops. By employing a multi-disciplinary approach, the data collected can be observed from multiple angles leading to a more thorough analysis and conceptual understanding of the research.

A. Timeline

In Figure 1, green markers represent the launch dates of Amazon Web Services in 2006, Google Cloud Platform in 2008, and Microsoft Azure in 2010. The pillars in blue represent significant milestones in the public cloud, such as the modern cloud computing concept introduction by then-Google CEO Eric Schmidt. This is followed by AWS's significant expansion in Europe and Asia, which is now gaining global traction for its public cloud services. In 2016 the Gartner magic quadrant was released for infrastructure as a service, with only three companies in the Leadership quadrants showing how far behind the others have fallen.

Events in orange denote the milestones of government public cloud adoption. Changes, such as creating a Federal cloud computing PMO in 2009 and passing the Modernizing Government Technology (MGT) act, allow government agencies to begin to invest in public cloud services. Markers in dark grey show dynamic year-over-year double-digit hyperscaler revenue growth, hitting 81% in 2015. In 2021, the Federal IT budget allocation for the public cloud topped ten billion and exceeded 10% of the total funding. The final red

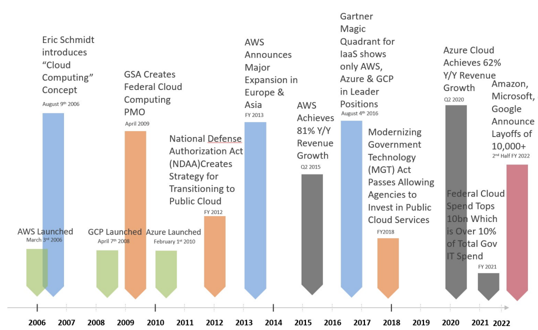

Fig. 1. Timeline.

marker shows the recent downward trend in all three hyperscaler organizations leading to extensive tech industry layoffs.

B. Boundary

In an effort to define the endogenous and exogenous elements, key system stakeholders and orient our study, Figure 2 presents a stakeholder interest map.

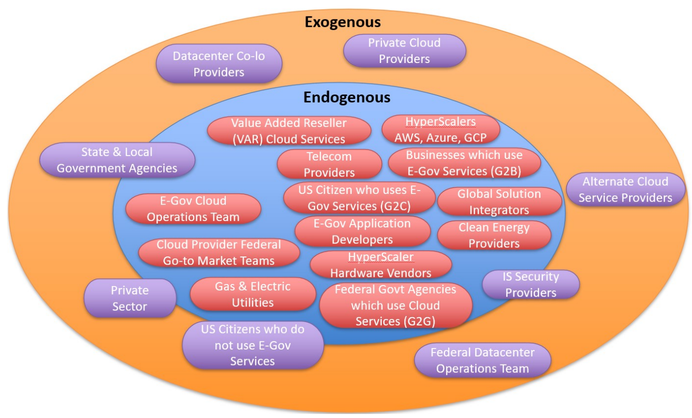

Fig. 2. Stakeholder Interest Map.

Internal to this study are what we consider E-Government primary consumers: citizens, businesses, government employees, and alternate government agencies. Also endogenous in this model are the public cloud operations and customer success teams which partner with value-added resellers to provide professional services and support based on requirement [18]. Utility providers and clean energy partners deliver services that power, cool, and regulate the large tier-four data centers. Exogenous stakeholders include alternate (non-big-three) cloud service providers, Federal data center operations teams, and co-location providers.

Multiple stakeholders straddle endogenous and exogenous boundaries, such as information system security providers, as they serve both the public and private sectors. Also, US citizens who do not use E-Government services still contribute to taxes that fund budgets, so they cannot be entirely removed from the endogenous stakeholder list.

C. Causal Loop

A causal structure model is presented in Figure 3 and focuses on E-Government service development [13][19]. The first stock represents an accumulation of services that are currently in development. The valve following into this stock is the rate of new projects. Out of the E-government services development stock flows a link with a positive

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polarity to the expected service rejection rate, which is expected based on evaluations of solutions. Connected to service rejection are the approvals, which have negative incoming polarity and a positive one towards the expected increase in operational efficiency. New services typically enhance effectiveness and lead to the next variable, customer satisfaction rate, with a positive incoming polarity. Next is the expected business value of new services, which completes the chain and creates a clockwise balancing loop due to the single negative polarity.

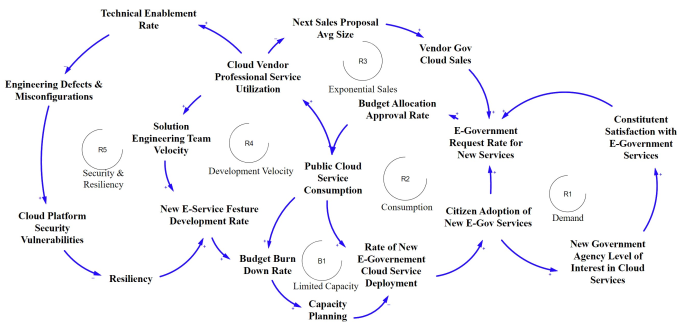

Fig. 3. Causal Loop.

Out of the E-government services, the stock also flows a positive connection to the service development rate valve, which has a negative development delay relationship because any delay can significantly impact our flow. On the model's right side, we have a stock representing E-Government services in production. Out of that stock, there is a positive relationship to the service rejection rate, reducing the IT budget stock down the line. There is a delay in the IT budget in two directions; the arrow on the left is the budgeted IT costs and has a positive polarity towards the expected approvals variable. Flowing in the opposite direction of the IT budget stock is another delay towards the desired new capabilities of the individual government agencies. There is a positive relationship between these new desired capabilities and the demand for new services, which has a negative relationship with the service rejection rate, creating another counter-clockwise balancing loop. The service rejection rate connects to the expected service rejection rate with positive polarity, making our final complete loop another clockwise balancing loop.

Completing the model is a negative polarity from the average life of services to the service decommission rate valve. This value connects to the opposite flow of the rate of new project charters denoting that as services are retired, new services are being formed in their place. The final variables which affect our model are E-Government growth positively connected to the demand for additional resources, and this increased demand having a positive polarity towards the demand for new services.

D. Cloud Diversity Principles

Cloud diversity principles, shown in Figure 4, provide a strategic way that E-Government entities can evaluate the public cloud solutions and make determinations based on principles over process. Principles were selected based on their level of importance and impact as it relates to cloud operating paradigms. These areas were consistently referenced in the literature and related cloud computing case studies hence their inclusion in the framework. A thorough understanding of vendor cost models, including resource consumption, falls under the economical principle. This involves understanding per unit costs, terms of service, and the value chain of public cloud adoption. It is critical to understand how pricing is established to ensure the predictability of spend for budgetary purposes. Interoperability of services and platforms ensures that systems that are already established have a level of integration to the public cloud service, this prevents silos and greater efficiency of operational resources.

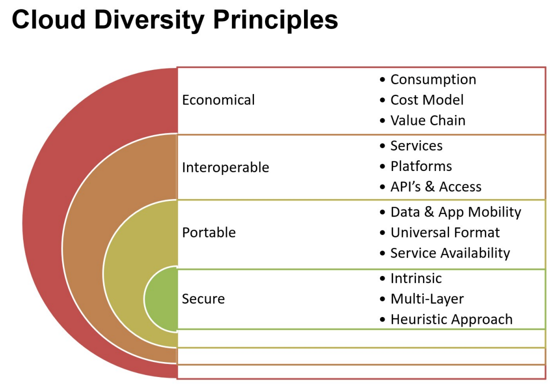

Fig. 4. Cloud Diversity Principles.

The ability to migrate data and workloads to disparate services is a key tenant of the portability principle. Preventing vendor lock-in scenarios and "sticky" service solutions is paramount to ensuring the most cost-effective landing zones can be utilized and open universal formats are adopted. The final principle is security which should be intrinsic to the architecture and follow defense-in-depth tenets. Defense-in-depth refers to the use of multiple security mechanisms such as firewalls, endpoint agents, or intrusion prevention and detection systems deployed in layers on the target system. Heuristics have become increasingly important as the types of cybersecurity threats have grown, the system should have an early detection mechanism and understand anomalous behavior with automated remediation processes.

III. Conclusion & Future Work

E-Government will continue to grow due to the exponential demand for digital services. The next generations will expect government services to be easily accessible via mobile platforms with fast access to data and relevant content. For this reason, public cloud services and their respective capabilities will be necessary to build future iterations of innovative applications and public sector cloud-hosted services. We first set our boundary via a systemigram in Figure 1 and showed the interconnections of these endogenous components. Next, we explored our first causal relationship diagram in Figure 2, which highlighted the multi-dimensional loops and balancing behavior as a result of the stock, flows, and variable linkages. In Figure 3, we leveraged the aging chain and logically segmented the system by the maturity of services through the system. We can model the effect of time on and quantify the rates at which E-Government services get evaluated, moved into a production environment, and finally move towards decommissioning, and replacement [20][21].

Research questions related to the boundary, causal structure, as well as service life-cycle have been addressed via our models. Factors that may limit the long-term growth of cloud services in E-Government should be addressed with a more quantitative model; therefore, any results have a low degree of accuracy; this also holds true for the question around the quantitative significance of factors related to development velocity, budgetary constraints as well as service retirement rates [10]. While we have leveraged multiple models to test our hypotheses, the ones we employed are more basic in nature. This is due to the time allotted for the study as well as research experience with these dynamic tools. To further this research, a greater dive with more profound expertise on the subject would be required to build out the quantitative models that accurately depict this E-Government service adoption and budgeting life-cycle. The data collection process for this research was rudimentary and would yield more accurate results if additional rigor and time were allocated. A literature review with greater depth and acceptance criteria could also bolster the quality of our overall study. Some additional areas of research which could be complementary to this study would be focused on the E-Government application development process, associated toolchains, and possibly enablement methods to understand if more significant outcomes can be achieved through the build-out of a new government innovation lab. This would involve the government operating like a start-up and attracting top-tier technical talent, typically captured by big tech companies. This would be a significant shift based on how government IT operations have traditionally operated but not impossible; it would take a shift in mindset and policy, which is not impossible.

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