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Architecting for Scale and Resilience Standardizing Cloud Infrastructure in Financial Services

Sandeep Sarngadharan
Software Architect, SPRI Partners LLC, USA.

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Abstract: *Establishing a public cloud infrastructure for financial services can present a variety of difficulties relating to security, compliance, and operational consistency. This case study highlights how the enterprise-wide migration of a large private equity firm to the Microsoft Azure cloud resulted in significant architectural fragmentation and operational risk due to manual deployments being performed in a decentralized fashion. As the lead cloud architect, I designed and developed a unified enterprise landing zone architecture that would provide standardized infrastructure patterns for all users, automate the deployment of those patterns using Infrastructure as Code (IaC) technologies, and build resilience into the architecture by implementing failover mechanisms for mission-critical applications. The approach used to implement this solution was to leverage the principles described in Microsoft's Cloud Adoption Framework (CAF) and built enterprise-scale architecture using the Bicep and Terraform automation technologies to create a consistent, repeatable, secure and compliant way to deploy the infrastructure pattern. After rollout, we removed manual configuration errors, reduced the time required to set up an environment from weeks to minutes, achieved 99.99% uptime for Tier-1 applications through multi-region failover patterns, and established a governed cloud foundation that would support the firm's strategic efforts for analytics and AI. This case study showcases how adopting architectural standardization and automation can create a common, scalable, enterprise-grade platform for the entire organization while simultaneously satisfying the necessary security and resiliency requirements of the financial services industry.*

Key Word: *Azure Landing Zones, Infrastructure as Code, Cloud Migration, High Availability, Disaster Recovery, Zero Trust Security, Private Equity, Bicep, Terraform, Enterprise Architecture.*

I.INTRODUCTION

The financial sector has increasingly utilized public cloud computing for agility, flexibility, and speed of innovation. Due to regulations, migrating to the cloud is challenging for many businesses, especially private equity firms that need to protect their sensitive investment data; therefore, careful planning regarding security, compliance, and operational governance is critical throughout the entire migration process. When cloud deployments donot have an enterprise-wide architectural strategy, they tend to be multiple fragmented implementations that create large amounts of technical and operational risk [5].

As senior Cloud Architect for one of the largest private equity firms globally, I discuss the cloud migration process that I oversaw while leading the cloud architecture for the migration to Microsoft Azure. The first step of the cloud migration process involved the cloud being decentralized; multiple application teams were individually provisioning and deploying Azure resources to the Azure portal utilizing their own standards, processes, and security models. As a result of the decentralized cloud approach, there was inconsistency in how to configure and use the cloud across the organization (including cloud networks, storage accounts, key vaults, databases, or function applications); therefore, the organization had a heterogeneous cloud deployment environment, which was difficult to manage, govern, and secure [1].

The requirements for the unified cloud architecture were that it be secure, scalable, automated, and the particular application teams use the same architecture. Additionally, the new cloud architecture would need to provide an equal level of security and compliance across all application teams, and the architecture would need to provide redundancy and reliability for mission-critical business systems. This article shares the innovations in cloud architecture, cloud architectural implementations, and measurable results achieved during the cloud transformation process, and serves as a reference for enterprise architects who are undergoing a similar cloud modernization project.

II.LITERATURE SURVEY

Extensive literature exists in both academic studies and industry best practices documenting the challenges and solutions to consider when migrating an enterprise to the cloud. Literature pertaining to the four domains discussed in this section include frameworks for adopting cloud technology; automated infrastructure; security architecture; and disaster recovery patterns.

2.1 Cloud Adoption and Landing Zone Architectures

Cloud Adoption Framework (CAF), published by Microsoft, will assist in making cloud transformation easier for the enterprise with a scalable enterprise landing zone architecture that brings together industry best practices across many design areas such as: identity, security, network, governance and operations. The landing zone architecture is modular in nature, allowing enterprises to design foundational landing zones that will scale with theirbusiness. The Azure Landing Zones reference implementations show companies how to achieve scalable with policy driven governance and operations automation [6].

2.2 Infrastructure as Code (IaC) Approaches

Infrastructure as Code has become a critical practice used for producing version-controlled (often multiple copies) of our infrastructure deployments. Using IaC can help to eliminate configuration drift (i.e., make sure our infrastructure is set to the same specifications between deployments), produce reproducible environments (i.e., create and provide the same environment), and consistently enforce and audit security policies on all our deployments [7].

The Azure ecosystem supports multiple forms of IaC, where Microsoft has created a domain-specific language (DSL) called Bicep that can be used as an ARM-native way to deploy an infrastructure using IaC. In addition, Terraform provides consistency of IaC (i.e., It provides a consistent manner to deploy to multiple Cloud providers) through its use of Providers. The Azure Verified Modules (AVM) program will speed the development of user solutions by providing a set of public opinionated modules that are created based on the best practices of Microsoft [2].

2.3 Zero Trust Security Implementation

The security model of Zero Trust ("never trust; always verify; assume breach") is now the leading model of cloud security architecture today. Microsoft has provided extensive guidance on how organizations can implement Zero Trust principles across their Azure infrastructures, focusing on private endpoints, segmenting networks, and using identity-based access management systems in Azure. Microsoft's primary recommendation is that for PaaS services, organizations should avoid using public endpoints altogether and instead use Azure Private Link to connect these services to their existing virtual networks, maintaining all traffic within the Microsoft backbone network. Research has shown that by implementing network security groups with baseline deny rules, enabling flow logging, and creating RBAC roles specifically for the management of networks, organizations can increase their overall level of security [4].

2.4 High Availability and Disaster Recovery Patterns

When developing a cloud application business continuity plan it is important to take into account the RPO/RTO of your application. Azure SQL Database offers active geo-replication and failover groups as a way to provide regional outage protection while allowing for globally deployed applications with fast local access. Two main models exist for active geo-replication: active-passive and active-active. Active-passive means that your secondary site will remain dark until a failover occurs, while active-active allows for the use of your secondary site with read-only access when the primary site is unavailable. For SQL Server workloads requiring high availability and no additional licensing costs, Failure Cluster Instance (FCI) in geo-clustered environments offer another viable option, but add added complexity associated with managing the associated shared storage and cross-region replication [3][8].

2.5 Financial Services Cloud Adoption

Financial Services organizations have looked at case studies and shown how unique some asset managers and private equity firms are on their migration of cloud technology. Migration of critical automation processes with complex dependencies, maintain data security and data integrity while migrating, and comply with regulatory requirements while doing so are just a few of the challenges. Successful migration demonstrates that proactive risk management, phased execution strategies, and close collaboration among infrastructure, security, and development teams are all necessary [5]. They also demonstrate how recent innovations in cross-region connectivity allow financial institutions to extend zero trust principles for multi region deployments by using azure firewall as a dns proxy and user assigned managed identities for secretless authentication [9].

III.PROBLEM LANDSCAPE

The organization's cloud adoption initiative had serious gaps and fragmentation problems that put the organization’s operational stability and assurance of security compliance at risk.

3.1 Decentralized and Manual Deployments

With each application team independently creating Azure assets via the Azure portal, every organization's infrastructure, across the enterprise, ended up using a variety of ways of structuring the Azure hardware. These independent teams deployed:

- Virtual networks and subnets with different address spaces and topologies.
- Storage accounts with varying types of redundancy.
- Key vault(s) with inconsistent Access Policies.
- Function applications with different run time configurations.

The absence of coherent and consistent infrastructure architecture or naming conventions resulted in a lack of information about the overall cloud footprint and no means of effectively managing and administering the organization's resources in a unified manner.

3.2 Security and Governance Deficiencies

Inconsistently enforced security policies occurred due to manually deploying resources necessitating an urgent need for a standardized method for securing stateful resources. Some examples include applications deploying with one or more exposed public-facing endpoints; poor tier segmentation resulting from incomplete network segmentation; inconsistent identity control policies; lack of standardized private endpoint configurations; lack of standardized private DNS resolution configurations; inconsistent Network Security Group configurations (NSGs) across teams; and lack of established standards governing firewall configuration. Assigning role-based access controls (RBACs) across teams has resulted in some teams assigning their accounts access to more privileges than required in violation of the principle of least privilege.

3.3 Operational and Resilience Gaps

Since automated deployment mechanisms did not exist, it was impossible to have reproducible environments; they were all one of a kind. As a result, experienced operational pain points: there was configuration drift; difficulty implementing or testing disaster recovery; and lack of a clear high availability and/or disaster recovery architecture for the business critical applications. The organization had little insight into what applications had an SLA requiring either 99.99% availability, and no processes were in place to enable the organization to use repeatable patterns to create zonal resiliency or failover across multiple regions.

3.4 Governance Challenges at Scale

Engineering teams operated independently of one another, making it challenging for the organization to enforce governance on a large scale. There was no centralized way to ensure compliance with the organization's security policy, cost management guidelines, or operational best practices. Without a standard way of doing things, when migrating a new application, there would be no way to create previously used tools or reusable processes, leading to duplicated work across multiple engineering teams, and extended time-to-market for business initiatives due to the need to create new tools and processes for each new application migration event.

IV.METHODOLOGY

The approach to the transformation was composed of four different area divisions: designing architecture, selecting technology, implementing, and validating - in applying these different methods together created a process for collecting and analyzing data that included all pieces of the effort itself [1].

4.1 Enterprise Landing Zone Architecture Design

During this design phase, we created an enterprise cloud architecture that can be centralised across the enterprise; this architecture was based upon the Microsoft Cloud Adoption Framework (CAF) and principles of enterprise-scale landing zones. The Architecture established standards in several areas:

- **Network Topology/Segmentation:** the model we went with is a hub/spoke model where the hub is a central point for connectivity (with shared Networking Services such as Azure Firewall, VPN Gateway, & ExpressRoute Gateways) and an isolated spoke for the application workload. Each Spoke Virtual Network (VNet) was designed to have its own subnets clearly delineated by application tier (i.e. Subnet-1 for Front-End Web Servers, Subnet-2 for Application Servers, Subnet-3 for Database Servers), using Network Security Groups (NSGs) at the Subnet Level to implement east-west traffic segmentation [4].
- **Resources Organization:** A common resource group layout was developed for all application deployments so that networking Resources were separated from application components, data tier and monitoring configuration; this group layout would allow for each resource type being logically contained within a single resource group (i.e. All of the resources used to support the web tier of an application would be in 1 resource group). Also, tagging standards were established to support costing allocation, operational management and compliance reporting.
- **Identity and Access Management:** Microsoft Entra ID (previously 'Azure Active Directory [AD]') was selected as the primary Identity Provider; furthermore, we established Custom Role Based Access Control (RBAC) Roles for networking resources scoped to allow only the permissions that were required. The least amount of Privilege principles were enforced on all Role Assignments via Security Groups and not assigned at the user level.
- **Encryption and Secret Management:** Azure Key Vault was chosen as the primary method for storing Secrets and standardised Key Management Policies (rotation, soft delete, and purge protection) were established for key management. Customer Managed Keys (CMKs) were required for any encryption use cases where a compliance requirement exists which indicates that the customer controls the encryption material [9].

4.2 Infrastructure as Code Implementation

In the next step after developing the architecture blueprint, the entire Azure platform will be automated via Infrastructure as Code using two IaC languages that are used together:

- Microsoft Bicep for ARM-native deployments that benefit from tight integration with azure resource manager due to its straightforward syntax & native for all azure resource types made bicep well suited for core platform components (modular by design, separate modules for each type of resource to create a complete deployment of a landing zone) [7].

- HashiCorp Terraform was used where desired to achieve multi-cloud consistency and would enable the organization to leverage their current investment in Terraform expertise; the AzureRM provider was used to deploy publicly available features and the AzAPI provider was generally deployed to enable access to preview features as needed [2].

All of the following resources were provisioned via Infrastructure as Code (IaC):

- VNETs, subnets, and NSGs
- Private endpoints and private DNS zones for all PaaS services
- WAF rules associated with Application Gateway
- AKS Clusters with managed identities
- Azure SQL Databases with geo-replication settings
- Storage accounts that allow private access only
- Key Vaults with advanced threat protection enabled
- Log Analytics Workspaces and Diagnostics Settings

Each deployment was managed in Git with a pull request workflow enforcing peer review and automated validation prior to deploying into a production environment.

4.3 High Availability and Disaster Recovery Design

For Tier-1 programs with a 99.99% only availability ratio, a full HA/DR architecture was built as determined by the criticality classification of the application. The application was classified into a tier on the basis of its degree of criticalness to the business there by working with business stakeholders to identify uses on the basis of RTO and RPO requirements, availability service level agreement (SLA) targets

Zonal redundancy: With regards to resiliency on an intra-region basis, resources have been configured based on the availability zone deployment pattern, where the requirements support an availability zone deployment. Examples of these configurations include [3] [8]:

i. the Business Critical tier of Azure SQL Database is configured using zone redundancy;
ii. AKS node pools have been deployed across multiple zones; and
iii. load balancers have been deployed as zone redundant .

- **Multi-region patterns:** With respect to resiliency on a cross-region basis, 2 base patterns have been implemented based on application characteristics, as discussed below:

i. **Active-Passive Pattern:** Used for applications that require minimal downtime but allow for certain levels of data loss. Active and Passive configurations have been deployed with active resources residing in a primary region and inactive resources residing in a paired secondary region. Failover groups have been deployed for Azure SQL Database management via automatic failover connectivity, replication, and database connectivity/failover. With respect to the Azure Traffic Manager, the service enabled user traffic to flow to the primary region under normal state and to the secondary region in the event of an outage; and

ii. **Active-Passive with Read-Scale:** For applications that would absolutely not tolerate data loss, however the application was still acceptable to function in a read only mode during an outage; there was an expanded design established for this additional requirement to provide a longer period of grace before the failover was considered completed. During the state of primary region outage, the application would have continued to run in read only mode from the secondary database until such time as the (1) grace period was expired or (2) primary region came back into service.

- **Automated failover pipelines:** All DR configuration are created in full using IaC, and the automated process for executing the failover runbooks are conducted via Azure Automation or DevOps pipelines. In addition, regular DR tests occur to validate that the processes identified to recover DR events will be performed and meet the RTO requirements.

4.4 Security and Governance Integration

We implemented Security throughout every deployment in a combination of structural configurations and policy enforcement methods:

- **Zero Trust Network Principles:** PaaS Services with Public Access Disabled: In order for any PaaS Services to have public access they will need to go through a private endpoint which means the only possible way applications can communicate with each other or the data services is through the Microsoft Backbone and not over the public internet [4].
- **User Assigned Managed Identities (UAMIs) for Identity Based Access Control:** By implementing UAMIs as the only method of accessing application workloads we no longer needed connection strings or service principal secrets [9]. As users are assigned UAMIs and given a RBAC role of least privileged permissions, those RBAC roles were scoped to specific Resource Groups or Resources.
- **Azure Policy as Code:** All subscriptions had azure policies defined validating their compliance with enterprise policies. Some of the requirements imposed by these Azure Policies include:

✓ Storage accounts require secure transfer
✓ Key vaults have soft delete
✓ Disable IP forwarding on all network interfaces
✓ Enable azure defender on all sql servers
✓ Every resource requires mandatory tags.

- **Centralized Logging and Monitoring:** All diagnostics from all subscriptions were logged into a log analytics workspace and log analytics workspace Insights is used to view how much each workspace has been utilized and how much data is being

ingested. Network security group flow logs are enabled so we can see what traffic patterns exist and can use them in future security investigations.

V.ARCHITECTURE DIAGRAM

The enterprise landing zone design that has been utilized by the private equity firm has been illustrated through an architectural diagram showing how this solution will be used by their team.

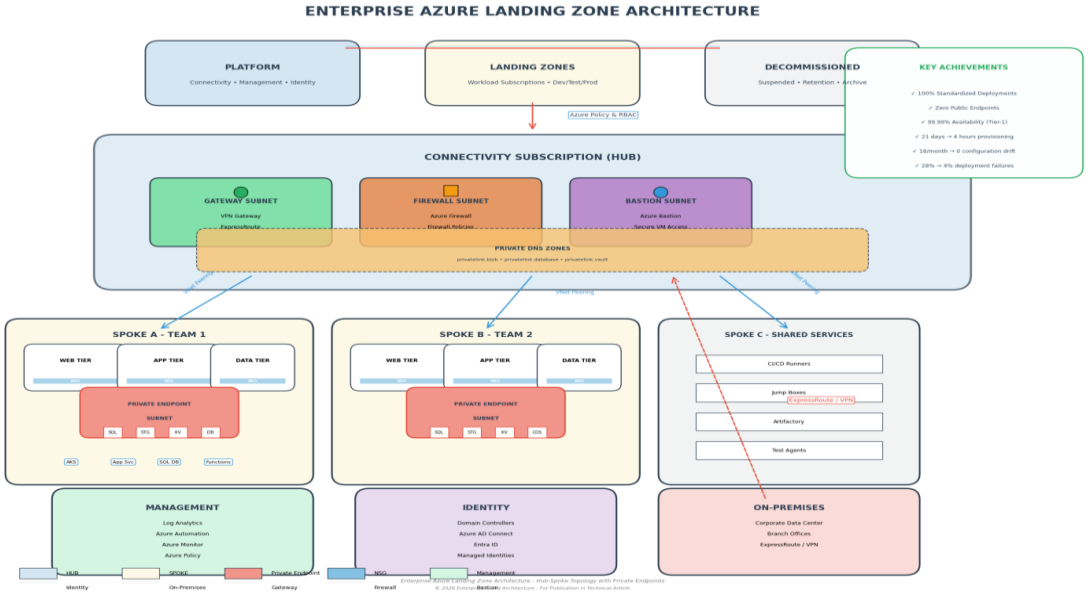

Figure 1: Enterprise Azure Landing Zone Architecture

VI.RESULTS AND PERFORMANCE METRICS

The implementation of automated deployment frameworks and enterprise landing zone architecture will provide quantifiable benefits across multiple areas.

6.1 Operational Efficiency Metrics

Before the implementations for provisioning by date took about 2-4 weeks with about 90 per cent improvement down 2 to 4 hours to provision an environment. Provisions were reduced in number (approximately from 15 to 20 per month) to 0. That's 100 per cent reduction based on use of Infrastructure as Code (IaC). The failure rate for deployments decreased from 25-30 per cent to under 5, representing an approximate +80 per cent improvement. The standardization process improved by eliminating inconsistencies from team A vs. team B, creating 100% standardization (total homogeneity) among the various teams. Finally, the amount of time it will take you to onboard a new application decreased from an average of 4-6 weeks to 3-5 days. The reduction here is at least 70 per cent. An example of the improvements made can be seen in the following image: Image 2 (See below):

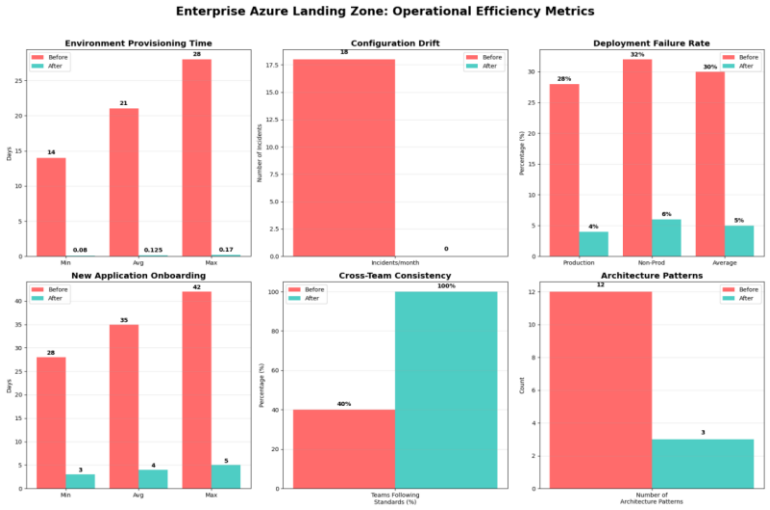

Figure 2: Enterprise Azure Landing Zone: Operational Efficiency Metrics

Bicep and Terraform were used to automate the deployment of infrastructure, preventing manual configuration errors and making sure that all environments were exact copies of the templates stored in version control. With this, it took weeks to set up development environments, but these are now created in hours so developers can create new environments whenever they need them for developing or testing features [10].

6.2 Security Posture Improvements

Security Control	Pre-Implementation	Post-Implementation
Public endpoints on PaaS services	40% of deployments	0% (all private endpoints)
Network security groups with default deny	<10% of subnets	100% of subnets
Encryption at rest with customer-managed keys	Ad-hoc	Enforced via policy
Private DNS zone integration	Inconsistent	Standardized across all services
RBAC least privilege compliance	60%	98% (remaining exceptions documented)
Security baseline violations	Discovered manually	Prevented via policy-as-code

Table 1: Security Control Pre & Post Implementation

Zero Trust's architecture has removed the ability for anybody to access critical systems publicly; all deployments are automatically assigned as private endpoints (publicly disabled). In addition, our baseline deny rules in network security groups enforce least-privilegenetwork access control policies, while Azure Policy provides ongoing verification of our compliance with security standards [11].

6.3 Resiliency Achievements for Tier-1 Applications

Based on the Resilience Metrics, the 12 Tier 1 Applications met their 99.99% availability measure. Examples of performance include: The Investment Portfolio System has an RPO of 8 minutes with no loss of data for an RTO; the Trading Platform achieved 99.99% availability, an RPO of 15 minutes, and no loss for an RTO; the Client Reporting Engine is at 99.95% availability with a 1-hour RPO and no loss for an RTO; and the Fund Accounting System has an RPO of 15 minutes, RTO of 3 minutes at 99.99% availability. The ability to failover across multiple regions and automated DR pipelines helped achieve recovery times well below the target thresholds. The continual execution of DR drills confirmed that the failover procedures work as designed and that the operations teams are ready to execute them.

6.4 Financial and Efficiency Impact

The Financial Impact Metric refers primarily to a lower cloud-dev op exp (thirty-five percent lower annually), as well as the expectation to save 8-10 full-time equivalents as a result of removing redundant engineering work and optimizing networking costs (fifteen percent less). Additionally, using reusable modules to develop new patterns in Infrastructure as Code (IaC), sped up the time to complete such development by 70 percent and improved the total amount of time required to develop & deliver commercial projects. This will result in a projected increase of two to three million dollars in the company's value.

By centralizing all architectural patterns and creating reusable modules, redundancy has been reduced by eliminating the need for teams to repeat engineering work for multiple teams with the migration each new application necessitates by eliminating the need to reproduce the same networking, security, or monitoring configuration, permitting them to consume the standard templates and instead concentrate on application-specific requirements.

VII.DISCUSSION

7.1 Critical Success Factors

The following points were very important in achieving this architectural transformation:

- **Executive Support and Directive:** The authority to mandate the creation of a Common Architecture was provided by top management, thus facilitating the ability to enforce standards across a decentralized organization. Had this support not come from the top down, there would have been resistance from individual teams to adopt centralized patterns.
- **Cross Functional Collaboration:** The success of enterprise-level architecture depends on collaboration among different disciplines, including identity, security, network and application development. Having regular working sessions with stakeholders from each of these disciplines helped to make sure that real-world requirements were reflected in the architecture and buy-in from the implementation teams was achieved.
- **Incremental Implementation Strategy:** Rather than going through a "big bang" type of migration, the architecture was built up over time. The grounding foundation was created with a new connectivity subscription, and as application teams either provisioned new environments or replaced existing ones, those teams transitioned to using the new architectural patterns. This approach provided continuity of service while steadily increasing the adoption rate.
- **Investment in Automation:** The decision to automate the entire platform with Infrastructure as Code (IaC) has been the most significant contribution to the overall success of the project. Automation promoted consistency, but also provided an effect similar to "documenting code" where the actual code itself (infrastructure definition) became the official source of truth for the architecture. The new developers could read the code in order to become familiar with the architecture and the code could be reviewed and approved using traditional pull request processes.

7.2 Challenges Encountered

Several obstacles occurred throughout the implementation process, despite its success overall:

- **Legacy Application Restrictions:** Some applications had dependencies that made it difficult to migrate them when moving to the new architecture. Applications using hard-coded references to public endpoints needed to change their code to be able to take advantage of private endpoints. Applications with strict RTO/RPO requirements required extensive planning for how to migrate entire applications across multiple geographic locations without impacting business operations.
- **Learning Curve for Teams:** Bicep and Terraform's reduced complexity will be seen over time, but at the outset there was a steep learning curve for teams used to deploying manually from the portal. An investment in training, documentation and internal communities of practice helped speed up this process.
- **DNS Resolution Complexity:** By implementing private endpoints in multiple geographic locations, we experienced DNS resolution issues. We meticulously configured private DNS zones, DNS links and Azure Firewall as a DNS chain to allow resources to resolve private endpoint IP addresses.

VIII.CONCLUSION

In this case study, you will see how an enterprise-level approach to cloud architecture (via enterprise landing zone design, Infrastructure as Code automation, zero trust security, and HA/DR planning) provides a way to take fragmented cloud adoption to a scalable, governed, and enterprise-grade platform.

The outcomes demonstrated in this private equity firm's case will be transformation by removing manual configuration errors, reducing the average time required to provision environments from weeks to minutes, enabling Tier-1 applications to achieve 99.99% availability, and utilizing a financial services regulatory-compliant security posture. Beyond immediate operational improvements from the architecture, the architecture has also positioned the company within its business for future innovation by creating the required Infrastructure backbone to support the company's strategic analytics, investment platforms, and AI/ML initiatives.

The principles and patterns illustrated in this article also apply generally across industries for purposes of enterprise-level cloud transformation. Therefore, organizations embarking on similar types of initiatives should take into consideration the following: beginning with a well-architected foundation from established frameworks such as the Cloud Adoption Framework, investing heavily in Infrastructure as Code & automation, integrating security within the overall architecture (rather than as an afterthought), and architecting for resilience from day one (rather than retrofitting later).

While cloud platforms will continue to develop and grow, the foundational architecture developed as part of this engagement provides a durable architecture that can continue to grow and change in response to new services/capabilities while providing the enterprise operation's required consistency, stability/security, and governance in all aspects of the enterprise.

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