

AWS Well-Architected Framework

# Reliability Pillar



# Reliability Pillar: AWS Well-Architected Framework

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# Reliability Pillar - AWS Well-Architected Framework

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The focus of this paper is the reliability pillar of the [AWS Well-Architected Framework](#). It provides guidance to help customers apply best practices in the design, delivery, and maintenance of Amazon Web Services (AWS) environments.

## Introduction

The [AWS Well-Architected Framework](#) helps you understand the pros and cons of decisions you make while building workloads on AWS. By using the Framework you will learn architectural best practices for designing and operating reliable, secure, efficient, cost-effective, and sustainable workloads in the cloud. It provides a way to consistently measure your architectures against best practices and identify areas for improvement. We believe that having well-architected workload greatly increases the likelihood of business success.

The AWS Well-Architected Framework is based on six pillars:

- Operational Excellence
- Security
- Reliability
- Performance Efficiency
- Cost Optimization
- Sustainability

This paper focuses on the reliability pillar and how to apply it to your solutions. Achieving reliability can be challenging in traditional on-premises environments due to single points of failure, lack of automation, and lack of elasticity. By adopting the practices in this paper you will build architectures that have strong foundations, resilient architecture, consistent change management, and proven failure recovery processes.

This paper is intended for those in technology roles, such as chief technology officers (CTOs), architects, developers, and operations team members. After reading this paper, you will understand AWS best practices and strategies to use when designing cloud architectures for reliability. This

paper includes high-level implementation details and architectural patterns, as well as references to additional resources.



# Reliability

The reliability pillar encompasses the ability of a workload to perform its intended function correctly and consistently when it's expected to. This includes the ability to operate and test the workload through its total lifecycle. This paper provides in-depth, best practice guidance for implementing reliable workloads on AWS.

## Topics

- [Shared Responsibility Model for Resiliency](#)
- [Design principles](#)
- [Definitions](#)
- [Understanding availability needs](#)

## Shared Responsibility Model for Resiliency

Resiliency is a shared responsibility between AWS and you. It is important that you understand how disaster recovery (DR) and availability, as part of resiliency, operate under this shared model.

### AWS responsibility - Resiliency of the cloud

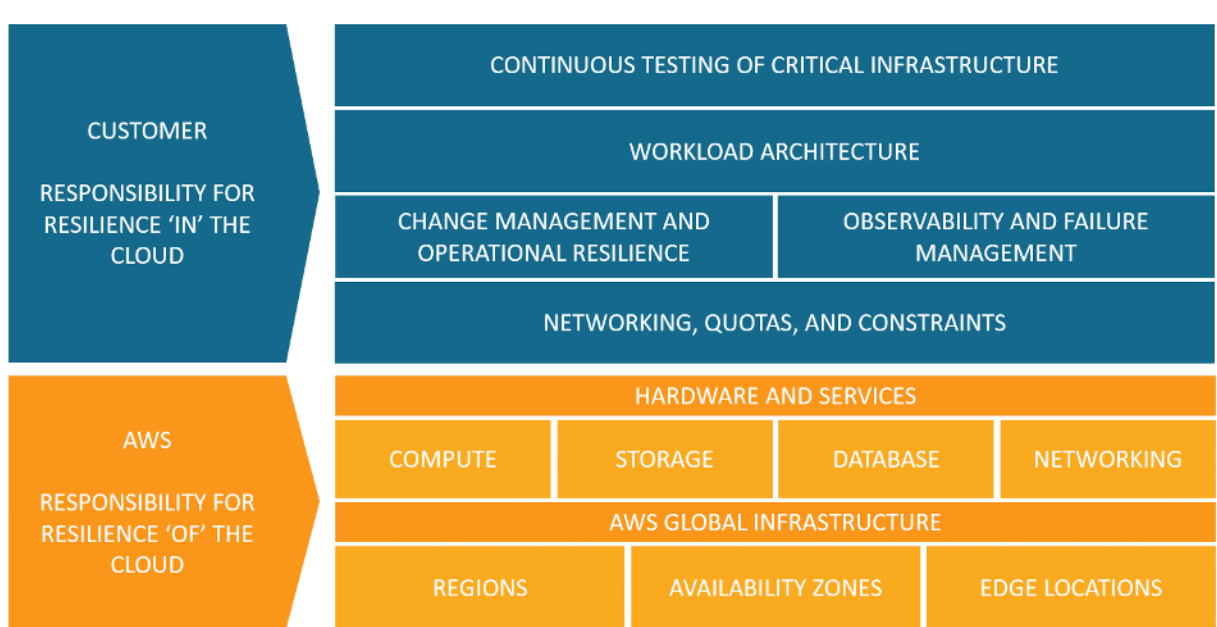
AWS is responsible for resiliency of the infrastructure that runs all of the services offered in the AWS Cloud. This infrastructure comprises the hardware, software, networking, and facilities that run AWS Cloud services. AWS uses commercially reasonable efforts to make these AWS Cloud services available, ensuring service availability meets or exceeds [AWS Service Level Agreements \(SLAs\)](#).

The [AWS Global Cloud Infrastructure](#) is designed to allow customers to build highly resilient workload architectures. Each AWS Region is fully isolated and consists of multiple [Availability Zones](#), which are physically isolated partitions of infrastructure. Availability Zones isolate faults that could impact workload resilience, preventing them from impacting other zones in the Region. But at the same time, all zones in an AWS Region are interconnected with high-bandwidth, low-latency networking, over fully redundant, dedicated metro fiber providing high-throughput, low-latency networking between zones. All traffic between zones is encrypted. The network performance is sufficient to accomplish synchronous replication between zones. When an application is partitioned across AZs, companies are better isolated and protected from issues such as power outages, lightning strikes, tornadoes, hurricanes, and more.

## Customer responsibility - Resiliency in the cloud

Your responsibility is determined by the AWS Cloud services that you select. This determines the amount of configuration work you must perform as part of your resiliency responsibilities. For example, a service such as Amazon Elastic Compute Cloud (Amazon EC2) requires the customer to perform all of the necessary resiliency configuration and management tasks. Customers that deploy Amazon EC2 instances are responsible for [deploying Amazon EC2 instances across multiple locations](#) (such as AWS Availability Zones), [implementing self-healing](#) using services like Auto Scaling, and using [resilient workload architecture best practices](#) for applications installed on the instances. For managed services, such as Amazon S3 and Amazon DynamoDB, AWS operates the infrastructure layer, the operating system, and platforms, and customers access the endpoints to store and retrieve data. You are responsible for managing resiliency of your data including backup, versioning, and replication strategies.

Deploying your workload across multiple Availability Zones in an AWS Region is part of a high availability strategy designed to protect workloads by isolating issues to one Availability Zone, which uses the redundancy of the other Availability Zones to continue serving requests. A Multi-AZ architecture is also part of a DR strategy designed to make workloads better isolated and protected from issues such as power outages, lightning strikes, tornadoes, earthquakes, and more. DR strategies may also make use of multiple AWS Regions. For example, in an active/passive configuration, service for the workload fails over from its active Region to its DR Region if the active Region can no longer serve requests.



*Responsibility for resilience in and of the cloud for customers and AWS.*

You can use AWS services to achieve your resilience objectives. As a customer, you are responsible for management of the following aspects of your system to achieve resilience in the cloud. For more detail on each service in particular, see [AWS documentation](#).

### Networking, quotas, and constraints

- Best practices for this area of the shared responsibility model are described in detail under [Foundations](#).
- Plan your architecture with adequate room to scale and understand the [service quotas](#) and constraints of the services you include, based on expected load request increases where applicable.
- Design your [network topology](#) to be highly available, redundant, and scalable.

### Change management and operational resilience

- [Change management](#) includes how to introduce and manage change in your environment. [Implementing change](#) requires building and keeping runbooks up to date and deployment strategies for your application and infrastructure.
- A resilient strategy for [monitoring workload resources](#) considers all components, including both technical and business metrics, notifications, automation, and analysis.
- Workloads in the cloud must [adapt to changes in demand](#) scaling in reaction to impairments or fluctuations in usage.

### Observability and failure management

- Observing failures through monitoring is required to automate healing so that your workloads can [withstand component failures](#).
- [Failure management](#) requires [backing up data](#), applying best practices to allow your workload to withstand component failures, and [planning for disaster recovery](#).

### Workload architecture

- Your [workload architecture](#) includes how you design services around business domains, apply SOA and distributed system design to prevent failures, and build in capabilities like throttling, retries, queue management, timeouts, and emergency levers.

- Rely on proven [AWS solutions](#), the [Amazon Builders Library](#), and [serverless patterns](#) to align with best practices and jump start implementations.
- Use continuous improvement to decompose your system into distributed services to scale and innovate faster. Use [AWS microservices](#) guidance and managed service options to simplify and accelerate your ability to introduce change and innovate.

### Continuous testing of critical infrastructure

- [Testing reliability](#) means testing at the functional, performance, and chaos levels, as well as adopting incident analysis and game day practices to build expertise in resolving issues that are not well understood.
- For both cloud all-in and hybrid applications, knowing how your application behaves when issues arise or components go down allows you to quickly and reliably recover from outages.
- Create and document repeatable experiments to understand how your system behaves when things don't work as expected. These tests will prove effectiveness of your overall resilience and provide a feedback loop for your operational procedures before facing real failure scenarios.

## Design principles

In the cloud, there are a number of principles that can help you increase reliability. Keep these in mind as we discuss best practices:

- **Automatically recover from failure:** By monitoring a workload for key performance indicators (KPIs), you can run automation when a threshold is breached. These KPIs should be a measure of business value, not of the technical aspects of the operation of the service. This allows for automatic notification and tracking of failures, and for automated recovery processes that work around or repair the failure. With more sophisticated automation, it's possible to anticipate and remediate failures before they occur.
- **Test recovery procedures:** In an on-premises environment, testing is often conducted to prove that the workload works in a particular scenario. Testing is not typically used to validate recovery strategies. In the cloud, you can test how your workload fails, and you can validate your recovery procedures. You can use automation to simulate different failures or to recreate scenarios that led to failures before. This approach exposes failure pathways that you can test and fix *before* a real failure scenario occurs, thus reducing risk.

- **Scale horizontally to increase aggregate workload availability:** Replace one large resource with multiple small resources to reduce the impact of a single failure on the overall workload. Distribute requests across multiple, smaller resources to ensure that they don't share a common point of failure.
- **Stop guessing capacity:** A common cause of failure in on-premises workloads is resource saturation, when the demands placed on a workload exceed the capacity of that workload (this is often the objective of denial of service attacks). In the cloud, you can monitor demand and workload utilization, and automate the addition or removal of resources to maintain the optimal level to satisfy demand without over- or under-provisioning. There are still limits, but some quotas can be controlled and others can be managed (see [Manage Service Quotas and Constraints](#)).
- **Manage change through automation:** Changes to your infrastructure should be made using automation. The changes that need to be managed include changes to the automation, which then can be tracked and reviewed.

## Definitions

This whitepaper covers reliability in the cloud, describing best practice for these four areas:

- Foundations
- Workload Architecture
- Change Management
- Failure Management

To achieve reliability you must start with the foundations—an environment where service quotas and network topology accommodate the workload. The workload architecture of the distributed system must be designed to prevent and mitigate failures. The workload must handle changes in demand or requirements, and it must be designed to detect failure and automatically heal itself.

### Topics

- [Resiliency, and the components of reliability](#)
- [Availability](#)
- [Disaster Recovery \(DR\) objectives](#)

## Resiliency, and the components of reliability

Reliability of a workload in the cloud depends on several factors, the primary of which is *Resiliency*:

- **Resiliency** is the ability of a workload to recover from infrastructure or service disruptions, dynamically acquire computing resources to meet demand, and mitigate disruptions, such as misconfigurations or transient network issues.

The other factors impacting workload reliability are:

- Operational Excellence, which includes automation of changes, use of playbooks to respond to failures, and Operational Readiness Reviews (ORRs) to confirm that applications are ready for production operations.
- Security, which includes preventing harm to data or infrastructure from malicious actors, which would impact availability. For example, encrypt backups to ensure that data is secure.
- Performance Efficiency, which includes designing for maximum request rates and minimizing latencies for your workload.
- Cost Optimization, which includes trade-offs such as whether to spend more on EC2 instances to achieve static stability, or to rely on automatic scaling when more capacity is needed.

Resiliency is the primary focus of this whitepaper.

The other four aspects are also important and they are covered by their respective pillars of the [AWS Well-Architected Framework](#). Many of the best practices here also address those aspects of reliability, but the focus is on resiliency.

## Availability

*Availability* (also known as *service availability*) is both a commonly used metric to quantitatively measure resiliency, as well as a target resiliency objective.

- **Availability** is the percentage of time that a workload is available for use.

*Available for use* means that it performs its agreed function successfully when required.

This percentage is calculated over a period of time, such as a month, year, or trailing three years. Applying the strictest possible interpretation, availability is reduced anytime that the application

isn't operating normally, including both scheduled and unscheduled interruptions. We define *availability* as follows:

$$\textit{Availability} = \frac{\textit{Available for Use Time}}{\textit{Total Time}}$$

- Availability is a percentage uptime (such as 99.9%) over a period of time (commonly a month or year)
- Common short-hand refers only to the “number of nines”; for example, “five nines” translates to being 99.999% available
- Some customers choose to exclude scheduled service downtime (for example, planned maintenance) from the *Total Time* in the formula. However, this is not advised, as your users will likely want to use your service during these times.

Here is a table of common application availability design goals and the maximum length of time that interruptions can occur within a year while still meeting the goal. The table contains examples of the types of applications we commonly see at each availability tier. Throughout this document, we refer to these values.

Availability	Maximum Unavailability (per year)	Application Categories
<a href="#">99%</a>	3 days 15 hours	Batch processing, data extraction, transfer, and load jobs
<a href="#">99.9%</a>	8 hours 45 minutes	Internal tools like knowledge management, project tracking
<a href="#">99.95%</a>	4 hours 22 minutes	Online commerce, point of sale
<a href="#">99.99%</a>	52 minutes	Video delivery, broadcast <b>workloads</b>

Availability	Maximum Unavailability (per year)	Application Categories
<a href="#">99.999%</a>	5 minutes	ATM transactions, telecommunications <b>workloads</b>

**Measuring availability based on requests.** For your service it may be easier to count successful and failed requests instead of “time available for use”. In this case the following calculation can be used:

$$\text{Availability} = \frac{\text{Successful Responses}}{\text{Valid Requests}}$$

This is often measured for one-minute or five-minute periods. Then a monthly uptime percentage (time-base availability measurement) can be calculated from the average of these periods. If no requests are received in a given period it is counted at 100% available for that time.

**Calculating availability with hard dependencies.** Many systems have hard dependencies on other systems, where an interruption in a dependent system directly translates to an interruption of the invoking system. This is opposed to a soft dependency, where a failure of the dependent system is compensated for in the application. Where such hard dependencies occur, the invoking system’s availability is the product of the dependent systems’ availabilities. For example, if you have a system designed for 99.99% availability that has a hard dependency on two other independent systems that each are designed for 99.99% availability, the workload can theoretically achieve 99.97% availability:

$$\text{Avail}_{\text{invok}} \times \text{Avail}_{\text{dep1}} \times \text{Avail}_{\text{dep2}} = \text{Avail}_{\text{workload}}$$

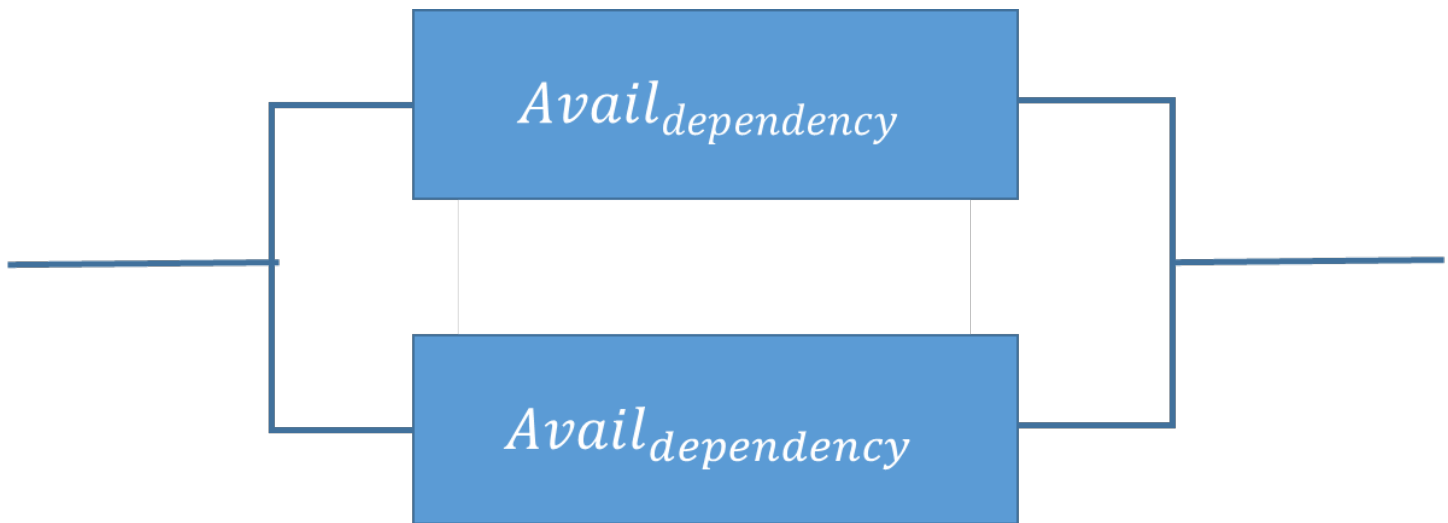
$$99.99\% \times 99.99\% \times 99.99\% = 99.97\%$$

It’s therefore important to understand your dependencies and their availability design goals as you calculate your own.

**Calculating availability with redundant components.** When a system involves the use of independent, redundant components (for example, redundant resources in different Availability



Zones), the theoretical availability is computed as 100% minus the product of the component failure rates. For example, if a system makes use of two independent components, each with an availability of 99.9%, the effective availability of this dependency is 99.9999%:



$$Avail_{\text{effective}} = Avail_{\text{MAX}} - ((100\% - Avail_{\text{dependency}}) \times (100\% - Avail_{\text{dependency}}))$$

$$99.9999\% = 100\% - (0.1\% \times 0.1\%)$$

*Shortcut calculation:* If the availabilities of all components in your calculation consist solely of the digit nine, then you can sum the count of the number of nines digits to get your answer. In the above example two redundant, independent components with three nines availability results in six nines.

**Calculating dependency availability.** Some dependencies provide guidance on their availability, including availability design goals for many AWS services. But in cases where this isn't available (for example, a component where the manufacturer does not publish availability information), one way to estimate is to determine the **Mean Time Between Failure (MTBF)** and **Mean Time to Recover (MTTR)**. An availability estimate can be established by:

$$Avail_{\text{EST}} = \frac{MTBF}{MTBF + MTTR}$$

For example, if the MTBF is 150 days and the MTTR is 1 hour, the availability estimate is 99.97%.

For additional details, see [Availability and Beyond: Understanding and improving the resilience of distributed systems on AWS](#), which can help you calculate your availability.

**Costs for availability.** Designing applications for higher levels of availability typically results in increased cost, so it's appropriate to identify the true availability needs before embarking on your application design. High levels of availability impose stricter requirements for testing and validation under exhaustive failure scenarios. They require automation for recovery from all manner of failures, and require that all aspects of system operations be similarly built and tested to the same standards. For example, the addition or removal of capacity, the deployment or rollback of updated software or configuration changes, or the migration of system data must be conducted to the desired availability goal. Compounding the costs for software development, at very high levels of availability, innovation suffers because of the need to move more slowly in deploying systems. The guidance, therefore, is to be thorough in applying the standards and considering the appropriate availability target for the entire lifecycle of operating the system.

Another way that costs escalate in systems that operate with higher availability design goals is in the selection of dependencies. At these higher goals, the set of software or services that can be chosen as dependencies diminishes based on which of these services have had the deep investments we previously described. As the availability design goal increases, it's typical to find fewer multi-purpose services (such as a relational database) and more purpose-built services. This is because the latter are easier to evaluate, test, and automate, and have a reduced potential for surprise interactions with included but unused functionality.

## Disaster Recovery (DR) objectives

In addition to availability objectives, your resiliency strategy should also include Disaster Recovery (DR) objectives based on strategies to recover your workload in case of a disaster event. Disaster Recovery focuses on one-time recovery objectives in response to natural disasters, large-scale technical failures, or human threats such as attack or error. This is different than availability which measures mean resiliency over a period of time in response to component failures, load spikes, or software bugs.

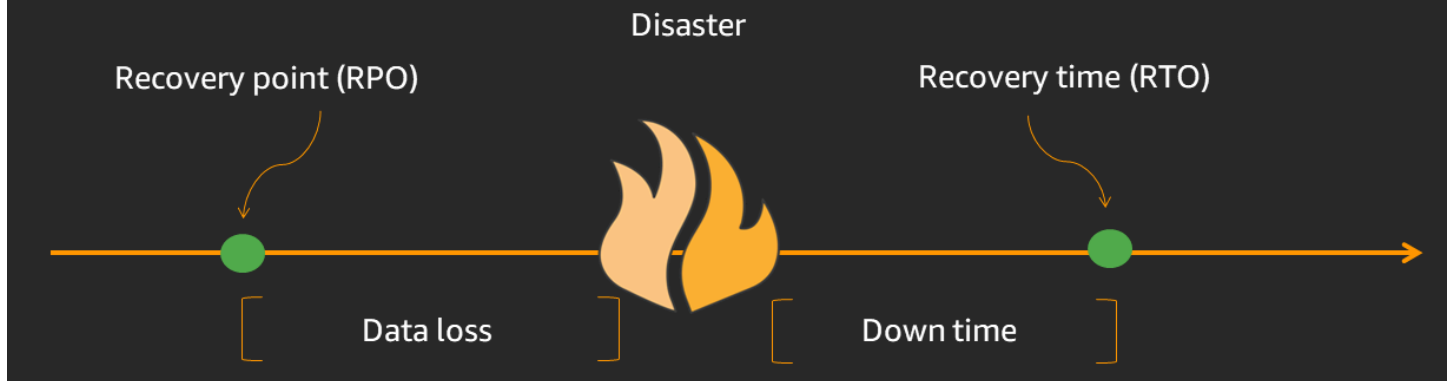
**Recovery Time Objective (RTO)** Defined by the organization. RTO is the maximum acceptable delay between the interruption of service and restoration of service. This determines what is considered an acceptable time window when service is unavailable.

**Recovery Point Objective (RPO)** Defined by the organization. RPO is the maximum acceptable amount of time since the last data recovery point. This determines what is considered an acceptable loss of data between the last recovery point and the interruption of service.

# Business continuity

How much data can you afford to recreate or lose?

How quickly must you recover?  
What is the cost of downtime?



*The relationship of RPO (Recovery Point Objective), RTO (Recovery Time Objective), and the disaster event.*

RTO is similar to MTTR (Mean Time to Recovery) in that both measure the time between the start of an outage and workload recovery. However MTTR is a mean value taken over several availability impacting events over a period of time, while RTO is a target, or maximum value allowed, for a *single* availability impacting event.

## Understanding availability needs

It's common to initially think of an application's availability as a single target for the application as a whole. However, upon closer inspection, we frequently find that certain aspects of an application or service have different availability requirements. For example, some systems might prioritize the ability to receive and store new data ahead of retrieving existing data. Other systems prioritize real-time operations over operations that change a system's configuration or environment. Services might have very high availability requirements during certain hours of the day, but can tolerate much longer periods of disruption outside of these hours. These are a few of the ways that you can decompose a single application into constituent parts, and evaluate the availability requirements for each. The benefit of doing this is to focus your efforts (and expense) on availability according to specific needs, rather than engineering the whole system to the strictest requirement.

## Recommendation

Critically evaluate the unique aspects to your applications and, where appropriate, differentiate the availability and disaster recovery design goals to reflect the needs of your business.

Within AWS, we commonly divide services into the “data plane” and the “control plane.” The data plane is responsible for delivering real-time service while control planes are used to configure the environment. For example, Amazon EC2 instances, Amazon RDS databases, and Amazon DynamoDB table read/write operations are all data plane operations. In contrast, launching new EC2 instances or RDS databases, or adding or changing table metadata in DynamoDB are all considered control plane operations. While high levels of availability are important for all of these capabilities, the data planes typically have higher availability design goals than the control planes. Therefore workloads with high availability requirements should avoid run-time dependency on control plane operations.

Many AWS customers take a similar approach to critically evaluating their applications and identifying subcomponents with different availability needs. Availability design goals are then tailored to the different aspects, and the appropriate work efforts are performed to engineer the system. AWS has significant experience engineering applications with a range of availability design goals, including services with 99.999% or greater availability. AWS Solution Architects (SAs) can help you design appropriately for your availability goals. Involving AWS early in your design process improves our ability to help you meet your availability goals. Planning for availability is not only done before your workload launches. It’s also done continuously to refine your design as you gain operational experience, learn from real world events, and endure failures of different types. You can then apply the appropriate work effort to improve upon your implementation.

The availability needs that are required for a workload must be aligned to the business need and criticality. By first defining business criticality framework with defined RTO, RPO, and availability, you can then assess each workload. Such an approach requires that the people involved in implementation of the workload are knowledgeable of the framework, and the impact their workload has on business needs.

# Foundations

Foundational requirements are those whose scope extends beyond a single workload or project. Before architecting any system, foundational requirements that influence reliability should be in place. For example, you must have sufficient network bandwidth to your data center.

In an on-premises environment, these requirements can cause long lead times due to dependencies and therefore must be incorporated during initial planning. With AWS however, most of these foundational requirements are already incorporated or can be addressed as needed. The cloud is designed to be nearly limitless, so it's the responsibility of AWS to satisfy the requirement for sufficient networking and compute capacity, leaving you free to change resource size and allocations on demand.

The following sections explain best practices that focus on these considerations for reliability.

## Topics

- [Manage service quotas and constraints](#)
- [Plan your network topology](#)

## Manage service quotas and constraints

For cloud-based workload architectures, there are service quotas (which are also referred to as service limits). These quotas exist to prevent accidentally provisioning more resources than you need and to limit request rates on API operations so as to protect services from abuse. There are also resource constraints, for example, the rate that you can push bits down a fiber-optic cable, or the amount of storage on a physical disk.

If you are using AWS Marketplace applications, you must understand the limitations of those applications. If you are using third-party web services or software as a service, you must be aware of those limits also.

## Best practices

- [REL01-BP01 Aware of service quotas and constraints](#)
- [REL01-BP02 Manage service quotas across accounts and regions](#)
- [REL01-BP03 Accommodate fixed service quotas and constraints through architecture](#)
- [REL01-BP04 Monitor and manage quotas](#)

- [REL01-BP05 Automate quota management](#)
- [REL01-BP06 Ensure that a sufficient gap exists between the current quotas and the maximum usage to accommodate failover](#)

## REL01-BP01 Aware of service quotas and constraints

Be aware of your default quotas and manage your quota increase requests for your workload architecture. Know which cloud resource constraints, such as disk or network, are potentially impactful.

**Desired outcome:** Customers can prevent service degradation or disruption in their AWS accounts by implementing proper guidelines for monitoring key metrics, infrastructure reviews, and automation remediation steps to verify that services quotas and constraints are not reached that could cause service degradation or disruption.

### Common anti-patterns:

- Deploying a workload without understanding the hard or soft quotas and their limits for the services used.
- Deploying a replacement workload without analyzing and reconfiguring the necessary quotas or contacting Support in advance.
- Assuming that cloud services have no limits and the services can be used without consideration to rates, limits, counts, quantities.
- Assuming that quotas will automatically be increased.
- Not knowing the process and timeline of quota requests.
- Assuming that the default cloud service quota is the identical for every service compared across regions.
- Assuming that service constraints can be breached and the systems will auto-scale or add increase the limit beyond the resource's constraints
- Not testing the application at peak traffic in order to stress the utilization of its resources.
- Provisioning the resource without analysis of the required resource size.
- Overprovisioning capacity by choosing resource types that go well beyond actual need or expected peaks.
- Not assessing capacity requirements for new levels of traffic in advance of a new customer event or deploying a new technology.

**Benefits of establishing this best practice:** Monitoring and automated management of service quotas and resource constraints can proactively reduce failures. Changes in traffic patterns for a customer's service can cause a disruption or degradation if best practices are not followed. By monitoring and managing these values across all regions and all accounts, applications can have improved resiliency under adverse or unplanned events.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

Service Quotas is an AWS service that helps you manage your quotas for over 250 AWS services from one location. Along with looking up the quota values, you can also request and track quota increases from the Service Quotas console or using the AWS SDK. AWS Trusted Advisor offers a service quotas check that displays your usage and quotas for some aspects of some services. The default service quotas per service are also in the AWS documentation per respective service (for example, see [Amazon VPC Quotas](#)).

Some service limits, like rate limits on throttled APIs are set within the Amazon API Gateway itself by configuring a usage plan. Some limits that are set as configuration on their respective services include Provisioned IOPS, Amazon RDS storage allocated, and Amazon EBS volume allocations. Amazon Elastic Compute Cloud has its own service limits dashboard that can help you manage your instance, Amazon Elastic Block Store, and Elastic IP address limits. If you have a use case where service quotas impact your application's performance and they are not adjustable to your needs, then contact AWS Support to see if there are mitigations.

Service quotas can be Region specific or can also be global in nature. Using an AWS service that reaches its quota will not act as expected in normal usage and may cause service disruption or degradation. For example, a service quota limits the number of DL Amazon EC2 instances used in a Region. That limit may be reached during a traffic scaling event using Auto Scaling groups (ASG).

Service quotas for each account should be assessed for usage on a regular basis to determine what the appropriate service limits might be for that account. These service quotas exist as operational guardrails, to prevent accidentally provisioning more resources than you need. They also serve to limit request rates on API operations to protect services from abuse.

Service constraints are different from service quotas. Service constraints represent a particular resource's limits as defined by that resource type. These might be storage capacity (for example, gp2 has a size limit of 1 GB - 16 TB) or disk throughput (10,000 iops). It is essential that a resource type's constraint be engineered and constantly assessed for usage that might reach its limit. If

a constraint is reached unexpectedly, the account's applications or services may be degraded or disrupted.

If there is a use case where service quotas impact an application's performance and they cannot be adjusted to required needs, contact AWS Support to see if there are mitigations. For more detail on adjusting fixed quotas, see [RELO1-BP03 Accommodate fixed service quotas and constraints through architecture](#).

There are a number of AWS services and tools to help monitor and manage Service Quotas. The service and tools should be leveraged to provide automated or manual checks of quota levels.

- AWS Trusted Advisor offers a service quota check that displays your usage and quotas for some aspects of some services. It can aid in identifying services that are near quota.
- AWS Management Console provides methods to display services quota values, manage, request new quotas, monitor status of quota requests, and display history of quotas.
- AWS CLI and CDKs offer programmatic methods to automatically manage and monitor service quota levels and usage.

## Implementation steps

For Service Quotas:

- [Review AWS Service Quotas](#).
- To be aware of your existing service quotas, determine the services (like IAM Access Analyzer) that are used. There are approximately 250 AWS services controlled by service quotas. Then, determine the specific service quota name that might be used within each account and Region. There are approximately 3000 service quota names per Region.
- Augment this quota analysis with AWS Config to find all [AWS resources](#) used in your AWS accounts.
- Use [AWS CloudFormation data](#) to determine your AWS resources used. Look at the resources that were created either in the AWS Management Console or with the [list-stack-resources](#) AWS CLI command. You can also see resources configured to be deployed in the template itself.
- Determine all the services your workload requires by looking at the deployment code.
- Determine the service quotas that apply. Use the programmatically accessible information from Trusted Advisor and Service Quotas.



- Establish an automated monitoring method (see [REL01-BP02 Manage service quotas across accounts and regions](#) and [REL01-BP04 Monitor and manage quotas](#)) to alert and inform if services quotas are near or have reached their limit.
- Establish an automated and programmatic method to check if a service quota has been changed in one region but not in other regions in the same account (see [REL01-BP02 Manage service quotas across accounts and regions](#) and [REL01-BP04 Monitor and manage quotas](#)).
- Automate scanning application logs and metrics to determine if there are any quota or service constraint errors. If these errors are present, send alerts to the monitoring system.
- Establish engineering procedures to calculate the required change in quota (see [REL01-BP05 Automate quota management](#)) once it has been identified that larger quotas are required for specific services.
- Create a provisioning and approval workflow to request changes in service quota. This should include an exception workflow in case of request deny or partial approval.
- Create an engineering method to review service quotas prior to provisioning and using new AWS services before rolling out to production or loaded environments. (for example, load testing account).

For service constraints:

- Establish monitoring and metrics methods to alert for resources reading close to their resource constraints. Leverage CloudWatch as appropriate for metrics or log monitoring.
- Establish alert thresholds for each resource that has a constraint that is meaningful to the application or system.
- Create workflow and infrastructure management procedures to change the resource type if the constraint is near utilization. This workflow should include load testing as a best practice to verify that new type is the correct resource type with the new constraints.
- Migrate identified resource to the recommended new resource type, using existing procedures and processes.

## Resources

**Related best practices:**

- [REL01-BP02 Manage service quotas across accounts and regions](#)
- [REL01-BP03 Accommodate fixed service quotas and constraints through architecture](#)

- [REL01-BP04 Monitor and manage quotas](#)
- [REL01-BP05 Automate quota management](#)
- [REL01-BP06 Ensure that a sufficient gap exists between the current quotas and the maximum usage to accommodate failover](#)
- [REL03-BP01 Choose how to segment your workload](#)
- [REL10-BP01 Deploy the workload to multiple locations](#)
- [REL11-BP01 Monitor all components of the workload to detect failures](#)
- [REL11-BP03 Automate healing on all layers](#)
- [REL12-BP05 Test resiliency using chaos engineering](#)

### Related documents:

- [AWS Well-Architected Framework's Reliability Pillar: Availability](#)
- [AWS Service Quotas \(formerly referred to as service limits\)](#)
- [AWS Trusted Advisor Best Practice Checks \(see the Service Limits section\)](#)
- [AWS limit monitor on AWS answers](#)
- [Amazon EC2 Service Limits](#)
- [What is Service Quotas?](#)
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- [Service endpoints and quotas](#)
- [Service Quotas User Guide](#)
- [Quota Monitor for AWS](#)
- [AWS Fault Isolation Boundaries](#)
- [Availability with redundancy](#)
- [AWS for Data](#)
- [What is Continuous Integration?](#)
- [What is Continuous Delivery?](#)
- [APN Partner: partners that can help with configuration management](#)
- [Managing the account lifecycle in account-per-tenant SaaS environments on AWS](#)
- [Managing and monitoring API throttling in your workloads](#)
- [View AWS Trusted Advisor recommendations at scale with AWS Organizations](#)

- [Automating Service Limit Increases and Enterprise Support with AWS Control Tower](#)

**Related videos:**

- [AWS Live re:Inforce 2019 - Service Quotas](#)
- [View and Manage Quotas for AWS Services Using Service Quotas](#)
- [AWS IAM Quotas Demo](#)

**Related tools:**

- [Amazon CodeGuru Reviewer](#)
- [AWS CodeDeploy](#)
- [AWS CloudTrail](#)
- [Amazon CloudWatch](#)
- [Amazon EventBridge](#)
- [Amazon DevOps Guru](#)
- [AWS Config](#)
- [AWS Trusted Advisor](#)
- [AWS CDK](#)
- [AWS Systems Manager](#)
- [AWS Marketplace](#)

## REL01-BP02 Manage service quotas across accounts and regions

If you are using multiple accounts or Regions, request the appropriate quotas in all environments in which your production workloads run.

**Desired outcome:** Services and applications should not be affected by service quota exhaustion for configurations that span accounts or Regions or that have resilience designs using zone, Region, or account failover.

**Common anti-patterns:**

- Allowing resource usage in one isolation Region to grow with no mechanism to maintain capacity in the other ones.

- Manually setting all quotas independently in isolation Regions.
- Not considering the effect of resiliency architectures (like active or passive) in future quota needs during a degradation in the non-primary Region.
- Not evaluating quotas regularly and making necessary changes in every Region and account the workload runs.
- Not leveraging [quota request templates](#) to request increases across multiple Regions and accounts.
- Not updating service quotas due to incorrectly thinking that increasing quotas has cost implications like compute reservation requests.

**Benefits of establishing this best practice:** Verifying that you can handle your current load in secondary regions or accounts if regional services become unavailable. This can help reduce the number of errors or levels of degradations that occur during region loss.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

Service quotas are tracked per account. Unless otherwise noted, each quota is AWS Region-specific. In addition to the production environments, also manage quotas in all applicable non-production environments so that testing and development are not hindered. Maintaining a high degree of resiliency requires that service quotas are assessed continually (whether automated or manual).

With more workloads spanning Regions due to the implementation of designs using *Active/Active*, *Active/Passive – Hot*, *Active/Passive-Cold*, and *Active/Passive-Pilot Light* approaches, it is essential to understand all Region and account quota levels. Past traffic patterns are not always a good indicator if the service quota is set correctly.

Equally important, the service quota name limit is not always the same for every Region. In one Region, the value could be five, and in another region the value could be ten. Management of these quotas must span all the same services, accounts, and Regions to provide consistent resilience under load.

Reconcile all the service quota differences across different Regions (Active Region or Passive Region) and create processes to continually reconcile these differences. The testing plans of passive Region failovers are rarely scaled to peak active capacity, meaning that game day or table top exercises can fail to find differences in service quotas between Regions and also then maintain the correct limits.

*Service quota drift*, the condition where service quota limits for a specific named quota is changed in one Region and not all Regions, is very important to track and assess. Changing the quota in Regions with traffic or potentially could carry traffic should be considered.

- Select relevant accounts and Regions based on your service requirements, latency, regulatory, and disaster recovery (DR) requirements.
- Identify service quotas across all relevant accounts, Regions, and Availability Zones. The limits are scoped to account and Region. These values should be compared for differences.

## Implementation steps

- Review Service Quotas values that might have breached beyond the a risk level of usage. AWS Trusted Advisor provides alerts for 80% and 90% threshold breaches.
- Review values for service quotas in any Passive Regions (in an Active/Passive design). Verify that load will successfully run in secondary Regions in the event of a failure in the primary Region.
- Automate assessing if any service quota drift has occurred between Regions in the same account and act accordingly to change the limits.
- If the customer Organizational Units (OU) are structured in the supported manner, service quota templates should be updated to reflect changes in any quotas that should be applied to multiple Regions and accounts.
  - Create a template and associate Regions to the quota change.
  - Review all existing service quota templates for any changes required (Region, limits, and accounts).

## Resources

### Related best practices:

- [REL01-BP01 Aware of service quotas and constraints](#)
- [REL01-BP03 Accommodate fixed service quotas and constraints through architecture](#)
- [REL01-BP04 Monitor and manage quotas](#)
- [REL01-BP05 Automate quota management](#)
- [REL01-BP06 Ensure that a sufficient gap exists between the current quotas and the maximum usage to accommodate failover](#)
- [REL03-BP01 Choose how to segment your workload](#)

- [REL10-BP01 Deploy the workload to multiple locations](#)
- [REL11-BP01 Monitor all components of the workload to detect failures](#)
- [REL11-BP03 Automate healing on all layers](#)
- [REL12-BP05 Test resiliency using chaos engineering](#)

**Related documents:**

- [AWS Well-Architected Framework's Reliability Pillar: Availability](#)
- [AWS Service Quotas \(formerly referred to as service limits\)](#)
- [AWS Trusted Advisor Best Practice Checks \(see the Service Limits section\)](#)
- [AWS limit monitor on AWS answers](#)
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- [Automating Service Limit Increases and Enterprise Support with AWS Control Tower](#)

**Related videos:**

- [AWS Live re:Inforce 2019 - Service Quotas](#)

- [View and Manage Quotas for AWS Services Using Service Quotas](#)
- [AWS IAM Quotas Demo](#)

**Related services:**

- [Amazon CodeGuru Reviewer](#)
- [AWS CodeDeploy](#)
- [AWS CloudTrail](#)
- [Amazon CloudWatch](#)
- [Amazon EventBridge](#)
- [Amazon DevOps Guru](#)
- [AWS Config](#)
- [AWS Trusted Advisor](#)
- [AWS CDK](#)
- [AWS Systems Manager](#)
- [AWS Marketplace](#)

## REL01-BP03 Accommodate fixed service quotas and constraints through architecture

Be aware of unchangeable service quotas, service constraints, and physical resource limits. Design architectures for applications and services to prevent these limits from impacting reliability.

Examples include network bandwidth, serverless function invocation payload size, throttle burst rate for of an API gateway, and concurrent user connections to a database.

**Desired outcome:** The application or service performs as expected under normal and high traffic conditions. They have been designed to work within the limitations for that resource's fixed constraints or service quotas.

**Common anti-patterns:**

- Choosing a design that uses a resource of a service, unaware that there are design constraints that will cause this design to fail as you scale.

- Performing benchmarking that is unrealistic and will reach service fixed quotas during the testing. For example, running tests at a burst limit but for an extended amount of time.
- Choosing a design that cannot scale or be modified if fixed service quotas are to be exceeded. For example, an SQS payload size of 256KB.
- Observability has not been designed and implemented to monitor and alert on thresholds for service quotas that might be at risk during high traffic events

**Benefits of establishing this best practice:** Verifying that the application will run under all projected services load levels without disruption or degradation.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

Unlike soft service quotas or resources that be replaced with higher capacity units, AWS services' fixed quotas cannot be changed. This means that all these type of AWS services must be evaluated for potential hard capacity limits when used in an application design.

Hard limits are show in the Service Quotas console. If the columns shows ADJUSTABLE = No, the service has a hard limit. Hard limits are also shown in some resources configuration pages. For example, Lambda has specific hard limits that cannot be adjusted.

As an example, when designing a python application to run in a Lambda function, the application should be evaluated to determine if there is any chance of Lambda running longer than 15 minutes. If the code may run more than this service quota limit, alternate technologies or designs must be considered. If this limit is reached after production deployment, the application will suffer degradation and disruption until it can be remediated. Unlike soft quotas, there is no method to change to these limits even under emergency Severity 1 events.

Once the application has been deployed to a testing environment, strategies should be used to find if any hard limits can be reached. Stress testing, load testing, and chaos testing should be part of the introduction test plan.

## Implementation steps

- Review the complete list of AWS services that could be used in the application design phase.
- Review the soft quota limits and hard quota limits for all these services. Not all limits are shown in the Service Quotas console. Some services [describe these limits in alternate locations](#).



- As you design your application, review your workload's business and technology drivers, such as business outcomes, use case, dependent systems, availability targets, and disaster recovery objects. Let your business and technology drivers guide the process to identify the distributed system that is right for your workload.
- Analyze service load across Regions and accounts. Many hard limits are regionally based for services. However, some limits are account based.
- Analyze resilience architectures for resource usage during a zonal failure and Regional failure. In the progression of multi-Region designs using active/active, active/passive – hot, active/passive – cold, and active/passive – pilot light approaches, these failure cases will cause higher usage. This creates a potential use case for hitting hard limits.

## Resources

### Related best practices:

- [REL01-BP01 Aware of service quotas and constraints](#)
- [REL01-BP02 Manage service quotas across accounts and regions](#)
- [REL01-BP04 Monitor and manage quotas](#)
- [REL01-BP05 Automate quota management](#)
- [REL01-BP06 Ensure that a sufficient gap exists between the current quotas and the maximum usage to accommodate failover](#)
- [REL03-BP01 Choose how to segment your workload](#)
- [REL10-BP01 Deploy the workload to multiple locations](#)
- [REL11-BP01 Monitor all components of the workload to detect failures](#)
- [REL11-BP03 Automate healing on all layers](#)
- [REL12-BP05 Test resiliency using chaos engineering](#)

### Related documents:

- [AWS Well-Architected Framework's Reliability Pillar: Availability](#)
- [AWS Service Quotas \(formerly referred to as service limits\)](#)
- [AWS Trusted Advisor Best Practice Checks \(see the Service Limits section\)](#)
- [AWS limit monitor on AWS answers](#)
- [Amazon EC2 Service Limits](#)

- [What is Service Quotas?](#)
- [How to Request Quota Increase](#)
- [Service endpoints and quotas](#)
- [Service Quotas User Guide](#)
- [Quota Monitor for AWS](#)
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- [View AWS Trusted Advisor recommendations at scale with AWS Organizations](#)
- [Automating Service Limit Increases and Enterprise Support with AWS Control Tower](#)
- [Actions, resources, and condition keys for Service Quotas](#)

**Related videos:**

- [AWS Live re:Inforce 2019 - Service Quotas](#)
- [View and Manage Quotas for AWS Services Using Service Quotas](#)
- [AWS IAM Quotas Demo](#)
- [AWS re:Invent 2018: Close Loops and Opening Minds: How to Take Control of Systems, Big and Small](#)

**Related tools:**

- [AWS CodeDeploy](#)
- [AWS CloudTrail](#)
- [Amazon CloudWatch](#)
- [Amazon EventBridge](#)

- [Amazon DevOps Guru](#)
- [AWS Config](#)
- [AWS Trusted Advisor](#)
- [AWS CDK](#)
- [AWS Systems Manager](#)
- [AWS Marketplace](#)

## REL01-BP04 Monitor and manage quotas

Evaluate your potential usage and increase your quotas appropriately, allowing for planned growth in usage.

**Desired outcome:** Active and automated systems that manage and monitor have been deployed. These operations solutions ensure that quota usage thresholds are nearing being reached. These would be proactively remediated by requested quota changes.

### Common anti-patterns:

- Not configuring monitoring to check for service quota thresholds
- Not configuring monitoring for hard limits, even though those values cannot be changed.
- Assuming that amount of time required to request and secure a soft quota change is immediate or a short period.
- Configuring alarms for when service quotas are being approached, but having no process on how to respond to an alert.
- Only configuring alarms for services supported by AWS Service Quotas and not monitoring other AWS services.
- Not considering quota management for multiple Region resiliency designs, like active/active, active/passive – hot, active/passive - cold, and active/passive - pilot light approaches.
- Not assessing quota differences between Regions.
- Not assessing the needs in every Region for a specific quota increase request.
- Not leveraging [templates for multi-Region quota management](#).

**Benefits of establishing this best practice:** Automatic tracking of the AWS Service Quotas and monitoring your usage against those quotas will allow you to see when you are approaching a

quota limit. You can also use this monitoring data to help limit any degradations due to quota exhaustion.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

For supported services, you can monitor your quotas by configuring various different services that can assess and then send alerts or alarms. This can aid in monitoring usage and can alert you to approaching quotas. These alarms can be invoked from AWS Config, Lambda functions, Amazon CloudWatch, or from AWS Trusted Advisor. You can also use metric filters on CloudWatch Logs to search and extract patterns in logs to determine if usage is approaching quota thresholds.

### Implementation steps

For monitoring:

- Capture current resource consumption (for example, buckets or instances). Use service API operations, such as the Amazon EC2 `DescribeInstances` API, to collect current resource consumption.
- Capture your current quotas that are essential and applicable to the services using:
  - AWS Service Quotas
  - AWS Trusted Advisor
  - AWS documentation
  - AWS service-specific pages
  - AWS Command Line Interface (AWS CLI)
  - AWS Cloud Development Kit (AWS CDK)
- Use AWS Service Quotas, an AWS service that helps you manage your quotas for over 250 AWS services from one location.
- Use Trusted Advisor service limits to monitor your current service limits at various thresholds.
- Use the service quota history (console or AWS CLI) to check on regional increases.
- Compare service quota changes in each Region and each account to create equivalency, if required.

For management:

- **Automated:** Set up an AWS Config custom rule to scan service quotas across Regions and compare for differences.
- **Automated:** Set up a scheduled Lambda function to scan service quotas across Regions and compare for differences.
- **Manual:** Scan services quota through AWS CLI, API, or AWS Console to scan service quotas across Regions and compare for differences. Report the differences.
- If differences in quotas are identified between Regions, request a quota change, if required.
- Review the result of all requests.

## Resources

### Related best practices:

- [REL01-BP01 Aware of service quotas and constraints](#)
- [REL01-BP02 Manage service quotas across accounts and regions](#)
- [REL01-BP03 Accommodate fixed service quotas and constraints through architecture](#)
- [REL01-BP05 Automate quota management](#)
- [REL01-BP06 Ensure that a sufficient gap exists between the current quotas and the maximum usage to accommodate failover](#)
- [REL03-BP01 Choose how to segment your workload](#)
- [REL10-BP01 Deploy the workload to multiple locations](#)
- [REL11-BP01 Monitor all components of the workload to detect failures](#)
- [REL11-BP03 Automate healing on all layers](#)
- [REL12-BP05 Test resiliency using chaos engineering](#)

### Related documents:

- [AWS Well-Architected Framework's Reliability Pillar: Availability](#)
- [AWS Service Quotas \(formerly referred to as service limits\)](#)
- [AWS Trusted Advisor Best Practice Checks \(see the Service Limits section\)](#)
- [AWS limit monitor on AWS answers](#)
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- [What is Service Quotas?](#)

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- [Service endpoints and quotas](#)
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- [AWS re:Invent 2018: Close Loops and Opening Minds: How to Take Control of Systems, Big and Small](#)

### Related tools:

- [AWS CodeDeploy](#)
- [AWS CloudTrail](#)
- [Amazon CloudWatch](#)
- [Amazon EventBridge](#)
- [Amazon DevOps Guru](#)
- [AWS Config](#)

- [AWS Trusted Advisor](#)
- [AWS CDK](#)
- [AWS Systems Manager](#)
- [AWS Marketplace](#)

## REL01-BP05 Automate quota management

Implement tools to alert you when thresholds are being approached. You can automate quota increase requests by using AWS Service Quotas APIs.

If you integrate your Configuration Management Database (CMDB) or ticketing system with Service Quotas, you can automate the tracking of quota increase requests and current quotas. In addition to the AWS SDK, Service Quotas offers automation using the AWS Command Line Interface (AWS CLI).

### Common anti-patterns:

- Tracking the quotas and usage in spreadsheets.
- Running reports on usage daily, weekly, or monthly, and then comparing usage to the quotas.

**Benefits of establishing this best practice:** Automated tracking of the AWS service quotas and monitoring of your usage against that quota allows you to see when you are approaching a quota. You can set up automation to assist you in requesting a quota increase when needed. You might want to consider lowering some quotas when your usage trends in the opposite direction to realize the benefits of lowered risk (in case of compromised credentials) and cost savings.

**Level of risk exposed if this best practice is not established:** Medium

### Implementation guidance

- Set up automated monitoring. Implement tools using SDKs to alert you when thresholds are being approached.
  - Use Service Quotas and augment the service with an automated quota monitoring solution, such as AWS Limit Monitor or an offering from AWS Marketplace.
    - [What is Service Quotas?](#)
    - [Quota Monitor on AWS - AWS Solution](#)

- Set up automated responses based on quota thresholds, using Amazon SNS and AWS Service Quotas APIs.
- Test automation.
  - Configure limit thresholds.
  - Integrate with change events from AWS Config, deployment pipelines, Amazon EventBridge, or third parties.
  - Artificially set low quota thresholds to test responses.
  - Set up automated operations to take appropriate action on notifications and contact AWS Support when necessary.
  - Manually start change events.
  - Run a game day to test the quota increase change process.

## Resources

### Related documents:

- [APN Partner: partners that can help with configuration management](#)
- [AWS Marketplace: CMDB products that help track limits](#)
- [AWS Service Quotas \(formerly referred to as service limits\)](#)
- [AWS Trusted Advisor Best Practice Checks \(see the Service Limits section\)](#)
- [Quota Monitor on AWS - AWS Solution](#)
- [Amazon EC2 Service Limits](#)
- [What is Service Quotas?](#)

### Related videos:

- [AWS Live re:Inforce 2019 - Service Quotas](#)

## REL01-BP06 Ensure that a sufficient gap exists between the current quotas and the maximum usage to accommodate failover

This article explains how to maintain space between the resource quota and your usage, and how it can benefit your organization. After you finish using a resource, the usage quota may



continue to account for that resource. This can result in a failing or inaccessible resource. Prevent resource failure by verifying that your quotas cover the overlap of inaccessible resources and their replacements. Consider cases like network failure, Availability Zone failure, or Region failures when calculating this gap.

**Desired outcome:** Small or large failures in resources or resource accessibility can be covered within the current service thresholds. Zone failures, network failures, or even Regional failures have been considered in the resource planning.

### **Common anti-patterns:**

- Setting service quotas based on current needs without accounting for failover scenarios.
- Not considering the principals of static stability when calculating the peak quota for a service.
- Not considering the potential of inaccessible resources in calculating total quota needed for each Region.
- Not considering AWS service fault isolation boundaries for some services and their potential abnormal usage patterns.

**Benefits of establishing this best practice:** When service disruption events impact application availability, use the cloud to implement strategies to recover from these events. An example strategy is creating additional resources to replace inaccessible resources to accommodate failover conditions without exhausting your service limit.

**Level of risk exposed if this best practice is not established:** Medium

## **Implementation guidance**

When evaluating a quota limit, consider failover cases that might occur due to some degradation. Consider the following failover cases.

- A disrupted or inaccessible VPC.
- An inaccessible subnet.
- A degraded Availability Zone that impacts resource accessibility.
- Networking routes or ingress and egress points are blocked or changed.
- A degraded Region that impacts resource accessibility.
- A subset of resources affected by a failure in a Region or an Availability Zone.

The decision to failover is unique for each situation, as the business impact can vary. Address resource capacity planning in the failover location and the resources' quotas before deciding to failover an application or service.

Consider higher than normal peaks of activity when reviewing quotas for each service. These peaks might be related to resources that are inaccessible due to networking or permissions, but are still active. Unterminated active resources count against the service quota limit.

## Implementation steps

- Maintain space between your service quota and your maximum usage to accommodate for a failover or loss of accessibility.
- Determine your service quotas. Account for typical deployment patterns, availability requirements, and consumption growth.
- Request quota increases if necessary. Anticipate a wait time for the quota increase request.
- Determine your reliability requirements (also known as your number of nines).
- Understand potential fault scenarios such as loss of a component, an Availability Zone, or a Region.
- Establish your deployment methodology (examples include canary, blue/green, red/black, and rolling).
- Include an appropriate buffer to the current quota limit. An example buffer could be 15%.
- Include calculations for static stability (Zonal and Regional) where appropriate.
- Plan consumption growth and monitor your consumption trends.
- Consider the static stability impact for your most critical workloads. Assess resources conforming to a statically stable system in all Regions and Availability Zones.
- Consider using On-Demand Capacity Reservations to schedule capacity ahead of any failover. This is a useful strategy to implement for critical business schedules to reduce potential risks of obtaining the correct quantity and type of resources during failover.

## Resources

### Related best practices:

- [REL01-BP01 Aware of service quotas and constraints](#)
- [REL01-BP02 Manage service quotas across accounts and regions](#)
- [REL01-BP03 Accommodate fixed service quotas and constraints through architecture](#)

- [REL01-BP04 Monitor and manage quotas](#)
- [REL01-BP05 Automate quota management](#)
- [REL03-BP01 Choose how to segment your workload](#)
- [REL10-BP01 Deploy the workload to multiple locations](#)
- [REL11-BP01 Monitor all components of the workload to detect failures](#)
- [REL11-BP03 Automate healing on all layers](#)
- [REL12-BP05 Test resiliency using chaos engineering](#)

### Related documents:

- [AWS Well-Architected Framework's Reliability Pillar: Availability](#)
- [AWS Service Quotas \(formerly referred to as service limits\)](#)
- [AWS Trusted Advisor Best Practice Checks \(see the Service Limits section\)](#)
- [AWS limit monitor on AWS answers](#)
- [Amazon EC2 Service Limits](#)
- [What is Service Quotas?](#)
- [How to Request Quota Increase](#)
- [Service endpoints and quotas](#)
- [Service Quotas User Guide](#)
- [Quota Monitor for AWS](#)
- [AWS Fault Isolation Boundaries](#)
- [Availability with redundancy](#)
- [AWS for Data](#)
- [What is Continuous Integration?](#)
- [What is Continuous Delivery?](#)
- [APN Partner: partners that can help with configuration management](#)
- [Managing the account lifecycle in account-per-tenant SaaS environments on AWS](#)
- [Managing and monitoring API throttling in your workloads](#)
- [View AWS Trusted Advisor recommendations at scale with AWS Organizations](#)
- [Automating Service Limit Increases and Enterprise Support with AWS Control Tower](#)
- [Actions, resources, and condition keys for Service Quotas](#)

**Related videos:**

- [AWS Live re:Inforce 2019 - Service Quotas](#)
- [View and Manage Quotas for AWS Services Using Service Quotas](#)
- [AWS IAM Quotas Demo](#)
- [AWS re:Invent 2018: Close Loops and Opening Minds: How to Take Control of Systems, Big and Small](#)

**Related tools:**

- [AWS CodeDeploy](#)
- [AWS CloudTrail](#)
- [Amazon CloudWatch](#)
- [Amazon EventBridge](#)
- [Amazon DevOps Guru](#)
- [AWS Config](#)
- [AWS Trusted Advisor](#)
- [AWS CDK](#)
- [AWS Systems Manager](#)
- [AWS Marketplace](#)

## Plan your network topology

Workloads often exist in multiple environments. These include multiple cloud environments (both publicly accessible and private) and possibly your existing data center infrastructure. Plans must include network considerations, such as intrasystem and intersystem connectivity, public IP address management, private IP address management, and domain name resolution.

When architecting systems using IP address-based networks, you must plan network topology and addressing in anticipation of possible failures, and to accommodate future growth and integration with other systems and their networks.

Amazon Virtual Private Cloud (Amazon VPC) lets you provision a private, isolated section of the AWS Cloud where you can launch AWS resources in a virtual network.

## Best practices

- [REL02-BP01 Use highly available network connectivity for your workload public endpoints](#)
- [REL02-BP02 Provision redundant connectivity between private networks in the cloud and on-premises environments](#)
- [REL02-BP03 Ensure IP subnet allocation accounts for expansion and availability](#)
- [REL02-BP04 Prefer hub-and-spoke topologies over many-to-many mesh](#)
- [REL02-BP05 Enforce non-overlapping private IP address ranges in all private address spaces where they are connected](#)

## REL02-BP01 Use highly available network connectivity for your workload public endpoints

Building highly available network connectivity to public endpoints of your workloads can help you reduce downtime due to loss of connectivity and improve the availability and SLA of your workload. To achieve this, use highly available DNS, content delivery networks (CDNs), API gateways, load balancing, or reverse proxies.

**Desired outcome:** It is critical to plan, build, and operationalize highly available network connectivity for your public endpoints. If your workload becomes unreachable due to a loss in connectivity, even if your workload is running and available, your customers will see your system as down. By combining the highly available and resilient network connectivity for your workload's public endpoints, along with a resilient architecture for your workload itself, you can provide the best possible availability and service level for your customers.

AWS Global Accelerator, Amazon CloudFront, Amazon API Gateway, AWS Lambda Function URLs, AWS AppSync APIs, and Elastic Load Balancing (ELB) all provide highly available public endpoints. Amazon Route 53 provides a highly available DNS service for domain name resolution to verify that your public endpoint addresses can be resolved.

You can also evaluate AWS Marketplace software appliances for load balancing and proxying.

### Common anti-patterns:

- Designing a highly available workload without planning out DNS and network connectivity for high availability.
- Using public internet addresses on individual instances or containers and managing the connectivity to them with DNS.

- Using IP addresses instead of domain names for locating services.
- Not testing out scenarios where connectivity to your public endpoints is lost.
- Not analyzing network throughput needs and distribution patterns.
- Not testing and planning for scenarios where internet network connectivity to your public endpoints of your workload might be interrupted.
- Providing content (like web pages, static assets, or media files) to a large geographic area and not using a content delivery network.
- Not planning for distributed denial of service (DDoS) attacks. DDoS attacks risk shutting out legitimate traffic and lowering availability for your users.

**Benefits of establishing this best practice:** Designing for highly available and resilient network connectivity ensures that your workload is accessible and available to your users.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

At the core of building highly available network connectivity to your public endpoints is the routing of the traffic. To verify your traffic is able to reach the endpoints, the DNS must be able to resolve the domain names to their corresponding IP addresses. Use a highly available and scalable [Domain Name System \(DNS\)](#) such as Amazon Route 53 to manage your domain's DNS records. You can also use health checks provided by Amazon Route 53. The health checks verify that your application is reachable, available, and functional, and they can be set up in a way that they mimic your user's behavior, such as requesting a web page or a specific URL. In case of failure, Amazon Route 53 responds to DNS resolution requests and directs the traffic to only healthy endpoints. You can also consider using Geo DNS and Latency Based Routing capabilities offered by Amazon Route 53.

To verify that your workload itself is highly available, use Elastic Load Balancing (ELB). Amazon Route 53 can be used to target traffic to ELB, which distributes the traffic to the target compute instances. You can also use Amazon API Gateway along with AWS Lambda for a serverless solution. Customers can also run workloads in multiple AWS Regions. With [multi-site active/active pattern](#), the workload can serve traffic from multiple Regions. With a multi-site active/passive pattern, the workload serves traffic from the active region while data is replicated to the secondary region and becomes active in the event of a failure in the primary region. Route 53 health checks can then be used to control DNS failover from any endpoint in a primary Region to an endpoint in a secondary Region, verifying that your workload is reachable and available to your users.

Amazon CloudFront provides a simple API for distributing content with low latency and high data transfer rates by serving requests using a network of edge locations around the world. Content delivery networks (CDNs) serve customers by serving content located or cached at a location near to the user. This also improves availability of your application as the load for content is shifted away from your servers over to CloudFront's [edge locations](#). The edge locations and regional edge caches hold cached copies of your content close to your viewers resulting in quick retrieval and increasing reachability and availability of your workload.

For workloads with users spread out geographically, AWS Global Accelerator helps you improve the availability and performance of the applications. AWS Global Accelerator provides Anycast static IP addresses that serve as a fixed entry point to your application hosted in one or more AWS Regions. This allows traffic to ingress onto the AWS global network as close to your users as possible, improving reachability and availability of your workload. AWS Global Accelerator also monitors the health of your application endpoints by using TCP, HTTP, and HTTPS health checks. Any changes in the health or configuration of your endpoints permit redirection of user traffic to healthy endpoints that deliver the best performance and availability to your users. In addition, AWS Global Accelerator has a fault-isolating design that uses two static IPv4 addresses that are serviced by independent network zones increasing the availability of your applications.

To help protect customers from DDoS attacks, AWS provides AWS Shield Standard. Shield Standard comes automatically turned on and protects from common infrastructure (layer 3 and 4) attacks like SYN/UDP floods and reflection attacks to support high availability of your applications on AWS. For additional protections against more sophisticated and larger attacks (like UDP floods), state exhaustion attacks (like TCP SYN floods), and to help protect your applications running on Amazon Elastic Compute Cloud (Amazon EC2), Elastic Load Balancing (ELB), Amazon CloudFront, AWS Global Accelerator, and Route 53, you can consider using AWS Shield Advanced. For protection against Application layer attacks like HTTP POST or GET floods, use AWS WAF. AWS WAF can use IP addresses, HTTP headers, HTTP body, URI strings, SQL injection, and cross-site scripting conditions to determine if a request should be blocked or allowed.

## Implementation steps

1. Set up highly available DNS: Amazon Route 53 is a highly available and scalable [domain name system \(DNS\)](#) web service. Route 53 connects user requests to internet applications running on AWS or on-premises. For more information, see [configuring Amazon Route 53 as your DNS service](#).

2. Setup health checks: When using Route 53, verify that only healthy targets are resolvable. Start by [creating Route 53 health checks and configuring DNS failover](#). The following aspects are important to consider when setting up health checks:
  - a. [How Amazon Route 53 determines whether a health check is healthy](#)
  - b. [Creating, updating, and deleting health checks](#)
  - c. [Monitoring health check status and getting notifications](#)
  - d. [Best practices for Amazon Route 53 DNS](#)
3. [Connect your DNS service to your endpoints](#).
  - a. When using Elastic Load Balancing as a target for your traffic, create an [alias record](#) using Amazon Route 53 that points to your load balancer's regional endpoint. During the creation of the alias record, set the Evaluate target health option to Yes.
  - b. For serverless workloads or private APIs when API Gateway is used, use [Route 53 to direct traffic to API Gateway](#).
4. Decide on a content delivery network.
  - a. For delivering content using edge locations closer to the user, start by understanding [how CloudFront delivers content](#).
  - b. Get started with a [simple CloudFront distribution](#). CloudFront then knows where you want the content to be delivered from, and the details about how to track and manage content delivery. The following aspects are important to understand and consider when setting up CloudFront distribution:
    - i. [How caching works with CloudFront edge locations](#)
    - ii. [Increasing the proportion of requests that are served directly from the CloudFront caches \(cache hit ratio\)](#)
    - iii. [Using Amazon CloudFront Origin Shield](#)
    - iv. [Optimizing high availability with CloudFront origin failover](#)
5. Set up application layer protection: AWS WAF helps you protect against common web exploits and bots that can affect availability, compromise security, or consume excessive resources. To get a deeper understanding, review [how AWS WAF works](#) and when you are ready to implement protections from application layer HTTP POST AND GET floods, review [Getting started with AWS WAF](#). You can also use AWS WAF with CloudFront see the documentation on [how AWS WAF works with Amazon CloudFront features](#).
6. Set up additional DDoS protection: By default, all AWS customers receive protection from common, most frequently occurring network and transport layer DDoS attacks that target



your web site or application with AWS Shield Standard at no additional charge. For additional protection of internet-facing applications running on Amazon EC2, Elastic Load Balancing, Amazon CloudFront, AWS Global Accelerator, and Amazon Route 53 you can consider [AWS Shield Advanced](#) and review [examples of DDoS resilient architectures](#). To protect your workload and your public endpoints from DDoS attacks review [Getting started with AWS Shield Advanced](#).

## Resources

### Related best practices:

- [REL10-BP01 Deploy the workload to multiple locations](#)
- [REL10-BP02 Select the appropriate locations for your multi-location deployment](#)
- [REL11-BP04 Rely on the data plane and not the control plane during recovery](#)
- [REL11-BP06 Send notifications when events impact availability](#)

### Related documents:

- [APN Partner: partners that can help plan your networking](#)
- [AWS Marketplace for Network Infrastructure](#)
- [What Is AWS Global Accelerator?](#)
- [What is Amazon CloudFront?](#)
- [What is Amazon Route 53?](#)
- [What is Elastic Load Balancing?](#)
- [Network Connectivity capability - Establishing Your Cloud Foundations](#)
- [What is Amazon API Gateway?](#)
- [What are AWS WAF, AWS Shield, and AWS Firewall Manager?](#)
- [What is Amazon Route 53 Application Recovery Controller?](#)
- [Configure custom health checks for DNS failover](#)

### Related videos:

- [AWS re:Invent 2022 - Improve performance and availability with AWS Global Accelerator](#)
- [AWS re:Invent 2020: Global traffic management with Amazon Route 53](#)

- [AWS re:Invent 2022 - Operating highly available Multi-AZ applications](#)
- [AWS re:Invent 2022 - Dive deep on AWS networking infrastructure](#)
- [AWS re:Invent 2022 - Building resilient networks](#)

### Related examples:

- [Disaster Recovery with Amazon Route 53 Application Recovery Controller \(ARC\)](#)
- [Reliability Workshops](#)
- [AWS Global Accelerator Workshop](#)

## REL02-BP02 Provision redundant connectivity between private networks in the cloud and on-premises environments

Implement redundancy in your connections between private networks in the cloud and on-premises environments to achieve connectivity resilience. This can be accomplished by deploying two or more links and traffic paths, preserving connectivity in the event of network failures.

### Common anti-patterns:

- You depend on just one network connection, which creates a single point of failure.
- You use only one VPN tunnel or multiple tunnels that end in the same Availability Zone.
- You rely on one ISP for VPN connectivity, which can lead to complete failures during ISP outages.
- Not implementing dynamic routing protocols like BGP, which are crucial for rerouting traffic during network disruptions.
- You ignore the bandwidth limitations of VPN tunnels and overestimate their backup capabilities.

**Benefits of establishing this best practice:** By implementing redundant connectivity between your cloud environment and your corporate or on-premises environment, the dependent services between the two environments can communicate reliably.

**Level of risk exposed if this best practice is not established:** High

### Implementation guidance

When using AWS Direct Connect to connect your on-premises network to AWS, you can achieve maximum network resiliency (SLA of 99.99%) by using separate connections that end on distinct

devices in more than one on-premises location and more than one AWS Direct Connect location. This topology offers resilience against device failures, connectivity issues, and complete location outages. Alternatively, you can achieve high resiliency (SLA of 99.9%) by using two individual connections to multiple locations (each on-premises location connected to a single Direct Connect location). This approach protects against connectivity disruptions caused by fiber cuts or device failures and helps mitigate complete location failures. The AWS Direct Connect Resiliency Toolkit can assist in designing your AWS Direct Connect topology.

You can also consider AWS Site-to-Site VPN ending on an AWS Transit Gateway as a cost-effective backup to your primary AWS Direct Connect connection. This setup enables equal-cost multipath (ECMP) routing across multiple VPN tunnels, allowing for throughput of up to 50Gbps, even though each VPN tunnel is capped at 1.25 Gbps. It's important to note, however, that AWS Direct Connect is still the most effective choice for minimizing network disruptions and providing stable connectivity.

When using VPNs over the internet to connect your cloud environment to your on-premises data center, configure two VPN tunnels as part of a single site-to-site VPN connection. Each tunnel should end in a different Availability Zone for high availability and use redundant hardware to prevent on-premises device failure. Additionally, consider multiple internet connections from various internet service providers (ISPs) at your on-premises location to avoid complete VPN connectivity disruption due to a single ISP outage. Selecting ISPs with diverse routing and infrastructure, especially those with separate physical paths to AWS endpoints, provides high connectivity availability.

In addition to physical redundancy with multiple AWS Direct Connect connections and multiple VPN tunnels (or a combination of both), implementing Border Gateway Protocol (BGP) dynamic routing is also crucial. Dynamic BGP provides automatic rerouting of traffic from one path to another based on real-time network conditions and configured policies. This dynamic behavior is especially beneficial in maintaining network availability and service continuity in the event of link or network failures. It quickly selects alternative paths, enhancing the network's resilience and reliability.

### Implementation steps

- Acquisition highly-available connectivity between AWS and your on-premises environment.
  - Use multiple AWS Direct Connect connections or VPN tunnels between separately deployed private networks.
  - Use multiple AWS Direct Connect locations for high availability.

- If using multiple AWS Regions, create redundancy in at least two of them.
- Use AWS Transit Gateway, when possible, to end your [VPN connection](#).
- Evaluate AWS Marketplace appliances to end VPNs or [extend your SD-WAN to AWS](#). If you use AWS Marketplace appliances, deploy redundant instances for high availability in different Availability Zones.
- Provide a redundant connection to your on-premises environment.
  - You may need redundant connections to multiple AWS Regions to achieve your availability needs.
  - Use the [AWS Direct Connect Resiliency Toolkit](#) to get started.

## Resources

### Related documents:

- [AWS Direct Connect Resiliency Recommendations](#)
- [Using Redundant Site-to-Site VPN Connections to Provide Failover](#)
- [Routing policies and BGP communities](#)
- [Active/Active and Active/Passive Configurations in AWS Direct Connect](#)
- [APN Partner: partners that can help plan your networking](#)
- [AWS Marketplace for Network Infrastructure](#)
- [Amazon Virtual Private Cloud Connectivity Options Whitepaper](#)
- [Building a Scalable and Secure Multi-VPC AWS Network Infrastructure](#)
- [Using redundant Site-to-Site VPN connections to provide failover](#)
- [Using the AWS Direct Connect Resiliency Toolkit to get started](#)
- [VPC Endpoints and VPC Endpoint Services \(AWS PrivateLink\)](#)
- [What Is Amazon VPC?](#)
- [What is a transit gateway?](#)
- [What is AWS Site-to-Site VPN?](#)
- [Working with Direct Connect gateways](#)

### Related videos:

- [AWS re:Invent 2018: Advanced VPC Design and New Capabilities for Amazon VPC](#)

- [AWS re:Invent 2019: AWS Transit Gateway reference architectures for many VPCs](#)

## REL02-BP03 Ensure IP subnet allocation accounts for expansion and availability

Amazon VPC IP address ranges must be large enough to accommodate workload requirements, including factoring in future expansion and allocation of IP addresses to subnets across Availability Zones. This includes load balancers, EC2 instances, and container-based applications.

When you plan your network topology, the first step is to define the IP address space itself. Private IP address ranges (following RFC 1918 guidelines) should be allocated for each VPC. Accommodate the following requirements as part of this process:

- Allow IP address space for more than one VPC per Region.
- Within a VPC, allow space for multiple subnets so that you can cover multiple Availability Zones.
- Consider leaving unused CIDR block space within a VPC for future expansion.
- Ensure that there is IP address space to meet the needs of any transient fleets of Amazon EC2 instances that you might use, such as Spot Fleets for machine learning, Amazon EMR clusters, or Amazon Redshift clusters. Similar consideration should be given to Kubernetes clusters, such as Amazon Elastic Kubernetes Service (Amazon EKS), as each Kubernetes pod is assigned a routable address from the VPC CIDR block by default.
- Note that the first four IP addresses and the last IP address in each subnet CIDR block are reserved and not available for your use.
- Note that the initial VPC CIDR block allocated to your VPC cannot be changed or deleted, but you can add additional non-overlapping CIDR blocks to the VPC. Subnet IPv4 CIDRs cannot be changed, however IPv6 CIDRs can.
- The largest possible VPC CIDR block is a /16, and the smallest is a /28.
- Consider other connected networks (VPC, on-premises, or other cloud providers) and ensure non-overlapping IP address space. For more information, see [REL02-BP05 Enforce non-overlapping private IP address ranges in all private address spaces where they are connected](#).

**Desired outcome:** A scalable IP subnet can help you accommodate for future growth and avoid unnecessary waste.

### Common anti-patterns:

- Failing to consider future growth, resulting in CIDR blocks that are too small and requiring reconfiguration, potentially causing downtime.
- Incorrectly estimating how many IP addresses an elastic load balancer can use.
- Deploying many high traffic load balancers into the same subnets
- Using automated scaling mechanisms whilst failing to monitor IP address consumption.
- Defining excessively large CIDR ranges well beyond future growth expectations, which can lead to difficulty peering with other networks with overlapping address ranges.

**Benefits of establishing this best practice:** This ensures that you can accommodate the growth of your workloads and continue to provide availability as you scale up.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

Plan your network to accommodate for growth, regulatory compliance, and integration with others. Growth can be underestimated, regulatory compliance can change, and acquisitions or private network connections can be difficult to implement without proper planning.

- Select relevant AWS accounts and Regions based on your service requirements, latency, regulatory, and disaster recovery (DR) requirements.
- Identify your needs for regional VPC deployments.
- Identify the size of the VPCs.
  - Determine if you are going to deploy multi-VPC connectivity.
    - [What Is a Transit Gateway?](#)
    - [Single Region Multi-VPC Connectivity](#)
  - Determine if you need segregated networking for regulatory requirements.
  - Make VPCs with appropriately-sized CIDR blocks to accommodate your current and future needs.
    - If you have unknown growth projections, you may wish to err on the side of larger CIDR blocks to reduce the potential for future reconfiguration
  - Consider using [IPv6 addressing](#) for subnets as part of a dual-stack VPC. IPv6 is well suited to being used in private subnets containing fleets of ephemeral instances or containers that would otherwise require large numbers of IPv4 addresses.

## Resources

### Related Well-Architected best practices:

- [REL02-BP05 Enforce non-overlapping private IP address ranges in all private address spaces where they are connected](#)

### Related documents:

- [APN Partner: partners that can help plan your networking](#)
- [AWS Marketplace for Network Infrastructure](#)
- [Amazon Virtual Private Cloud Connectivity Options Whitepaper](#)
- [Multiple data center HA network connectivity](#)
- [Single Region Multi-VPC Connectivity](#)
- [What Is Amazon VPC?](#)
- [IPv6 on AWS](#)
- [IPv6 on reference architectures](#)
- [Amazon Elastic Kubernetes Service launches IPv6 support](#)

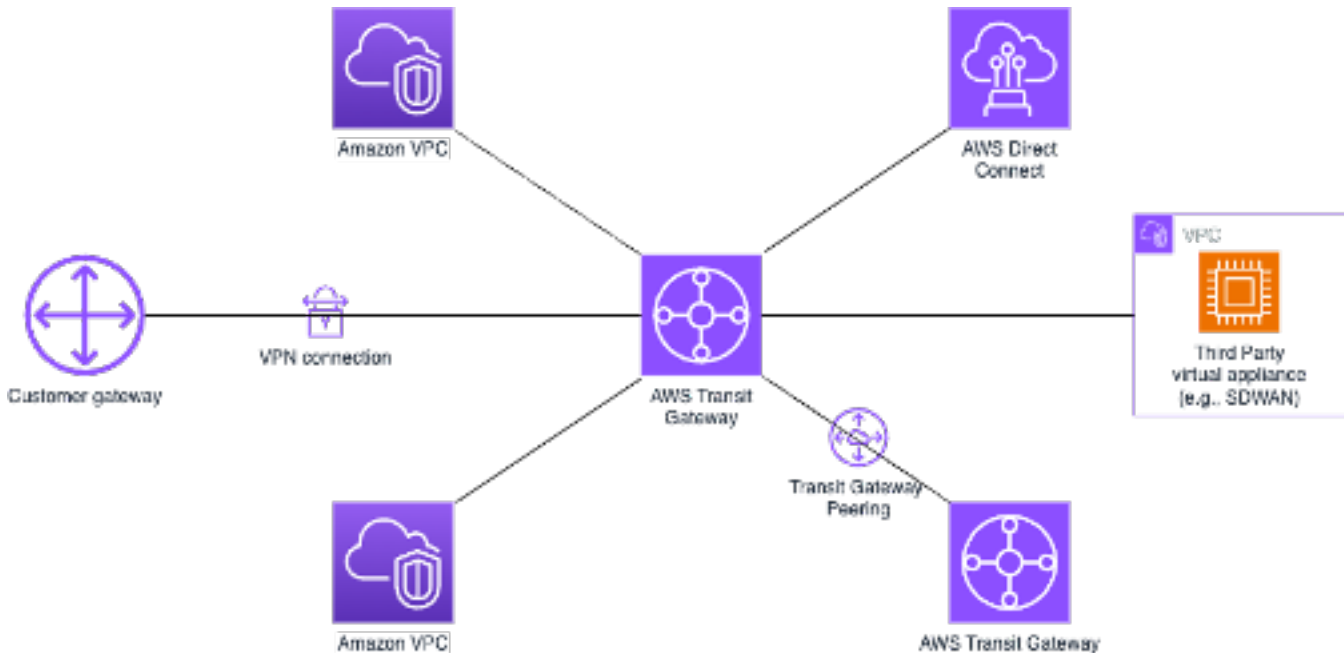
### Related videos:

- [AWS re:Invent 2018: Advanced VPC Design and New Capabilities for Amazon VPC \(NET303\)](#)
- [AWS re:Invent 2019: AWS Transit Gateway reference architectures for many VPCs \(NET406-R1\)](#)
- [AWS re:Invent 2023: AWS Ready for what's next? Designing networks for growth and flexibility \(NET310\)](#)

## REL02-BP04 Prefer hub-and-spoke topologies over many-to-many mesh

When connecting multiple private networks, such as Virtual Private Clouds (VPCs) and on-premises networks, opt for a hub-and-spoke topology over a meshed one. Unlike meshed topologies, where each network connects directly to the others and increases the complexity and management overhead, the hub-and-spoke architecture centralizes connections through a single hub. This centralization simplifies the network structure and enhances its operability, scalability, and control.

AWS Transit Gateway is a managed, scalable, and highly-available service designed for construction of hub-and-spoke networks on AWS. It serves as the central hub of your network that provides network segmentation, centralized routing, and the simplified connection to both cloud and on-premises environments. The following figure illustrates how you can use AWS Transit Gateway to build your hub-and-spoke topology.



### Common anti-patterns:

- You overcomplicate routing policies in a hub-and-spoke architecture, which reduces network efficiency and complicates both troubleshooting and proactive management.
- Insufficient routing-based segmentation within the hub could lead to vulnerabilities, which potentially exposes the network to unauthorized access.
- Without careful optimization, traffic routed through the hub can lead to higher data transfer costs, particularly for traffic crossing Availability Zones and Regions. Effective traffic management strategies are essential to control expenses.

**Benefits of establishing this best practice:** As the number of connected networks increases, management and expansion of meshed connectivity becomes increasingly challenging. AWS Transit Gateway offers a scalable and reliable managed hub for construction and operation of your hub-and-spoke topologies. When you use AWS Transit Gateway, you can establish connections and centralizes traffic routing across multiple networks.



**Level of risk exposed if this best practice is not established: Medium**

## Implementation guidance

- Plan your network.
- Create your AWS Transit Gateway.
- Attach your VPCs.
- If needed, create VPN connections or Direct Connect gateways and associate them with the Transit Gateway.
- Define how traffic is routed between the connected VPCs and other connections through configuration of your Transit Gateway route tables.
- Use Amazon CloudWatch to monitor and adjust configurations as necessary for performance and cost optimization.

## Resources

### Related documents:

- [What Is a Transit Gateway?](#)
- [Building a Scalable and Secure Multi-VPC AWS Network Infrastructure](#)
- [Building a global network using AWS Transit Gateway Inter-Region peering](#)
- [Amazon Virtual Private Cloud Connectivity Options](#)
- [APN Partner: partners that can help plan your networking](#)
- [AWS Marketplace for Network Infrastructure](#)

### Related videos:

- [AWS re:Invent 2023 - AWS networking foundations](#)
- [AWS re:Invent 2023 - Advanced VPC designs and new capabilities](#)

## REL02-BP05 Enforce non-overlapping private IP address ranges in all private address spaces where they are connected

The IP address ranges of each of your VPCs must not overlap when peered, connected via Transit Gateway, or connected over VPN. Avoid IP address conflicts between a VPC and on-premises

environments or with other cloud providers that you use. You must also have a way to allocate private IP address ranges when needed. An IP address management (IPAM) system can help with automating this.

**Desired outcome:**

- No IP address range conflicts between VPCs, on-premises environments, or other cloud providers.
- Proper IP address management allows for easier scaling of network infrastructure to accommodate growth and changes in network requirements.

**Common anti-patterns:**

- Using the same IP range in your VPC as you have on premises, in your corporate network, or other cloud providers
- Not tracking IP ranges of VPCs used to deploy your workloads.
- Relying on manual IP address management processes, such as spreadsheets.
- Over- or under-sizing CIDR blocks, which results in IP address waste or insufficient address space for your workload.

**Benefits of establishing this best practice:** Active planning of your network will ensure that you do not have multiple occurrences of the same IP address in interconnected networks. This prevents routing problems from occurring in parts of the workload that are using the different applications.

**Level of risk exposed if this best practice is not established:** Medium

**Implementation guidance**

Make use of an IPAM, such as the [Amazon VPC IP Address Manager](#), to monitor and manage your CIDR use. Several IPAMs are also available from the AWS Marketplace. Evaluate your potential usage on AWS, add CIDR ranges to existing VPCs, and create VPCs to allow planned growth in usage.

**Implementation steps**

- Capture current CIDR consumption (for example, VPCs and subnets).
  - Use service API operations to collect current CIDR consumption.
  - Use the [Amazon VPC IP Address Manager to discover resources](#).

- Capture your current subnet usage.
  - Use service API operations to [collect subnets](#) per VPC in each Region.
  - Use the [Amazon VPC IP Address Manager to discover resources](#).
- Record the current usage.
- Determine if you created any overlapping IP ranges.
- Calculate the spare capacity.
- Identify overlapping IP ranges. You can either migrate to a new range of addresses or consider using techniques like [private NAT Gateway](#) or [AWS PrivateLink](#) if you need to connect the overlapping ranges.

## Resources

### Related best practices:

- [Protecting networks](#)

### Related documents:

- [APN Partner: partners that can help plan your networking](#)
- [AWS Marketplace for Network Infrastructure](#)
- [Amazon Virtual Private Cloud Connectivity Options Whitepaper](#)
- [Multiple data center HA network connectivity](#)
- [Connecting Networks with Overlapping IP Ranges](#)
- [What Is Amazon VPC?](#)
- [What is IPAM?](#)

### Related videos:

- [AWS re:Invent 2023 - Advanced VPC designs and new capabilities](#)
- [AWS re:Invent 2019: AWS Transit Gateway reference architectures for many VPCs](#)
- [AWS re:Invent 2023 - Ready for what's next? Designing networks for growth and flexibility](#)
- [AWS re:Invent 2021 - {New Launch} Manage your IP addresses at scale on AWS](#)

# Workload architecture

A reliable workload starts with upfront design decisions for both software and infrastructure. Your architecture choices will impact your workload behavior across all six Well-Architected pillars. For reliability, there are specific patterns you must follow.

The following sections explain best practices to use with these patterns for reliability.

## Topics

- [Design your workload service architecture](#)
- [Design interactions in a distributed system to prevent failures](#)
- [Design interactions in a distributed system to mitigate or withstand failures](#)

## Design your workload service architecture

Build highly scalable and reliable workloads using a service-oriented architecture (SOA) or a microservices architecture. Service-oriented architecture (SOA) is the practice of making software components reusable via service interfaces. Microservices architecture goes further to make components smaller and simpler.

Service-oriented architecture (SOA) interfaces use common communication standards so that they can be rapidly incorporated into new workloads. SOA replaced the practice of building monolith architectures, which consisted of interdependent, indivisible units.

At AWS, we have always used SOA, but have now embraced building our systems using microservices. While microservices have several attractive qualities, the most important benefit for availability is that microservices are smaller and simpler. They allow you to differentiate the availability required of different services, and thereby focus investments more specifically to the microservices that have the greatest availability needs. For example, to deliver product information pages on Amazon.com (“detail pages”), hundreds of microservices are invoked to build discrete portions of the page. While there are a few services that must be available to provide the price and the product details, the vast majority of content on the page can simply be excluded if the service isn’t available. Even such things as photos and reviews are not required to provide an experience where a customer can buy a product.

## Best practices

- [REL03-BP01 Choose how to segment your workload](#)

- [REL03-BP02 Build services focused on specific business domains and functionality](#)
- [REL03-BP03 Provide service contracts per API](#)

## REL03-BP01 Choose how to segment your workload

Workload segmentation is important when determining the resilience requirements of your application. Monolithic architecture should be avoided whenever possible. Instead, carefully consider which application components can be broken out into microservices. Depending on your application requirements, this may end up being a combination of a service-oriented architecture (SOA) with microservices where possible. Workloads that are capable of statelessness are more capable of being deployed as microservices.

**Desired outcome:** Workloads should be supportable, scalable, and as loosely coupled as possible.

When making choices about how to segment your workload, balance the benefits against the complexities. What is right for a new product racing to first launch is different than what a workload built to scale from the start needs. When refactoring an existing monolith, you will need to consider how well the application will support a decomposition towards statelessness. Breaking services into smaller pieces allows small, well-defined teams to develop and manage them. However, smaller services can introduce complexities which include possible increased latency, more complex debugging, and increased operational burden.

### Common anti-patterns:

- The [microservice Death Star](#) is a situation in which the atomic components become so highly interdependent that a failure of one results in a much larger failure, making the components as rigid and fragile as a monolith.

### Benefits of establishing this practice:

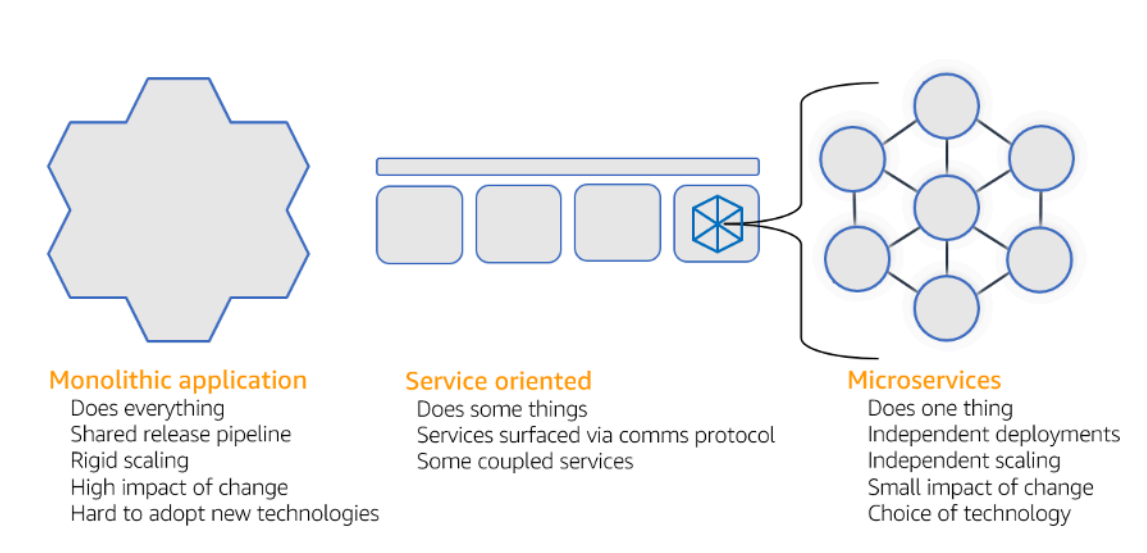
- More specific segments lead to greater agility, organizational flexibility, and scalability.
- Reduced impact of service interruptions.
- Application components may have different availability requirements, which can be supported by a more atomic segmentation.
- Well-defined responsibilities for teams supporting the workload.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

Choose your architecture type based on how you will segment your workload. Choose an SOA or microservices architecture (or in some rare cases, a monolithic architecture). Even if you choose to start with a monolith architecture, you must ensure that it's modular and can ultimately evolve to SOA or microservices as your product scales with user adoption. SOA and microservices offer respectively smaller segmentation, which is preferred as a modern scalable and reliable architecture, but there are trade-offs to consider, especially when deploying a microservice architecture.

One primary trade-off is that you now have a distributed compute architecture that can make it harder to achieve user latency requirements and there is additional complexity in the debugging and tracing of user interactions. You can use AWS X-Ray to assist you in solving this problem. Another effect to consider is increased operational complexity as you increase the number of applications that you are managing, which requires the deployment of multiple independency components.



### *Monolithic, service-oriented, and microservices architectures*

## Implementation steps

- Determine the appropriate architecture to refactor or build your application. SOA and microservices offer respectively smaller segmentation, which is preferred as a modern scalable and reliable architecture. SOA can be a good compromise for achieving smaller segmentation while avoiding some of the complexities of microservices. For more details, see [Microservice Trade-Offs](#).

- If your workload is amenable to it, and your organization can support it, you should use a microservices architecture to achieve the best agility and reliability. For more details, see [Implementing Microservices on AWS](#).
- Consider following the [Strangler Fig pattern](#) to refactor a monolith into smaller components. This involves gradually replacing specific application components with new applications and services. [AWS Migration Hub Refactor Spaces](#) acts as the starting point for incremental refactoring. For more details, see [Seamlessly migrate on-premises legacy workloads using a strangler pattern](#).
- Implementing microservices may require a service discovery mechanism to allow these distributed services to communicate with each other. [AWS App Mesh](#) can be used with service-oriented architectures to provide reliable discovery and access of services. [AWS Cloud Map](#) can also be used for dynamic, DNS-based service discovery.
- If you're migrating from a monolith to SOA, [Amazon MQ](#) can help bridge the gap as a service bus when redesigning legacy applications in the cloud.
- For existing monoliths with a single, shared database, choose how to reorganize the data into smaller segments. This could be by business unit, access pattern, or data structure. At this point in the refactoring process, you should choose to move forward with a relational or non-relational (NoSQL) type of database. For more details, see [From SQL to NoSQL](#).

**Level of effort for the implementation plan:** High

## Resources

### Related best practices:

- [REL03-BP02 Build services focused on specific business domains and functionality](#)

### Related documents:

- [Amazon API Gateway: Configuring a REST API Using OpenAPI](#)
- [What is Service-Oriented Architecture?](#)
- [Bounded Context \(a central pattern in Domain-Driven Design\)](#)
- [Implementing Microservices on AWS](#)
- [Microservice Trade-Offs](#)
- [Microservices - a definition of this new architectural term](#)

- [Microservices on AWS](#)
- [What is AWS App Mesh?](#)

#### Related examples:

- [Iterative App Modernization Workshop](#)

#### Related videos:

- [Delivering Excellence with Microservices on AWS](#)

## REL03-BP02 Build services focused on specific business domains and functionality

Service-oriented architectures (SOA) define services with well-delineated functions defined by business needs. Microservices use domain models and bounded context to draw service boundaries along business context boundaries. Focusing on business domains and functionality helps teams define independent reliability requirements for their services. Bounded contexts isolate and encapsulate business logic, allowing teams to better reason about how to handle failures.

**Desired outcome:** Engineers and business stakeholders jointly define bounded contexts and use them to design systems as services that fulfill specific business functions. These teams use established practices like event storming to define requirements. New applications are designed as services well-defined boundaries and loosely coupling. Existing monoliths are decomposed into [bounded contexts](#) and system designs move towards SOA or microservice architectures. When monoliths are refactored, established approaches like bubble contexts and monolith decomposition patterns are applied.

Domain-oriented services are executed as one or more processes that don't share state. They independently respond to fluctuations in demand and handle fault scenarios in light of domain specific requirements.

#### Common anti-patterns:

- Teams are formed around specific technical domains like UI and UX, middleware, or database instead of specific business domains.



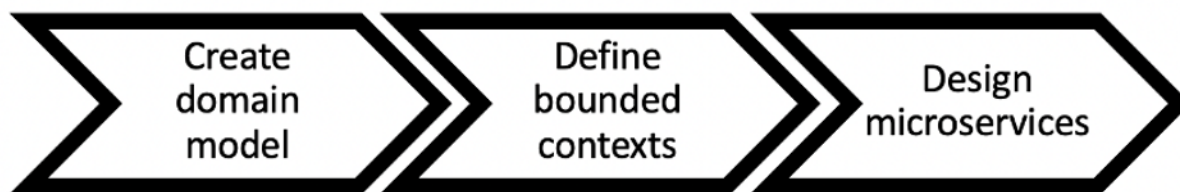
- Applications span domain responsibilities. Services that span bounded contexts can be more difficult to maintain, require larger testing efforts, and require multiple domain teams to participate in software updates.
- Domain dependencies, like domain entity libraries, are shared across services such that changes for one service domain require changes to other service domains
- Service contracts and business logic don't express entities in a common and consistent domain language, resulting in translation layers that complicate systems and increase debugging efforts.

**Benefits of establishing this best practice:** Applications are designed as independent services bounded by business domains and use a common business language. Services are independently testable and deployable. Services meet domain specific resiliency requirements for the domain implemented.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

Domain-driven design (DDD) is the foundational approach of designing and building software around business domains. It's helpful to work with an existing framework when building services focused on business domains. When working with existing monolithic applications, you can take advantage of decomposition patterns that provide established techniques to modernize applications into services.



### *Domain-driven design*

## Implementation steps

- Teams can hold [event storming](#) workshops to quickly identify events, commands, aggregates and domains in a lightweight sticky note format.
- Once domain entities and functions have been formed in a domain context, you can divide your domain into services using [bounded context](#), where entities that share similar features and

attributes are grouped together. With the model divided into contexts, a template for how to boundary microservices emerges.

- For example, the Amazon.com website entities might include package, delivery, schedule, price, discount, and currency.
- Package, delivery, and schedule are grouped into the shipping context, while price, discount, and currency are grouped into the pricing context.
- [Decomposing monoliths into microservices](#) outlines patterns for refactoring microservices. Using patterns for decomposition by business capability, subdomain, or transaction aligns well with domain-driven approaches.
- Tactical techniques such as the [bubble context](#) allow you to introduce DDD in existing or legacy applications without up-front rewrites and full commitments to DDD. In a bubble context approach, a small bounded context is established using a service mapping and coordination, or [anti-corruption layer](#), which protects the newly defined domain model from external influences.

After teams have performed domain analysis and defined entities and service contracts, they can take advantage of AWS services to implement their domain-driven design as cloud-based services.

- Start your development by defining tests that exercise business rules of your domain. Test-driven development (TDD) and behavior-driven development (BDD) help teams keep services focused on solving business problems.
- Select the [AWS services](#) that best meet your business domain requirements and [microservice architecture](#):
  - [AWS Serverless](#) allows your team focus on specific domain logic instead of managing servers and infrastructure.
  - [Containers at AWS](#) simplify the management of your infrastructure, so you can focus on your domain requirements.
  - [Purpose built databases](#) help you match your domain requirements to the best fit database type.
- [Building hexagonal architectures on AWS](#) outlines a framework to build business logic into services working backwards from a business domain to fulfill functional requirements and then attach integration adapters. Patterns that separate interface details from business logic with AWS services help teams focus on domain functionality and improve software quality.

## Resources

### Related best practices:

- [REL03-BP01 Choose how to segment your workload](#)
- [REL03-BP03 Provide service contracts per API](#)

### Related documents:

- [AWS Microservices](#)
- [Implementing Microservices on AWS](#)
- [How to break a Monolith into Microservices](#)
- [Getting Started with DDD when Surrounded by Legacy Systems](#)
- [Domain-Driven Design: Tackling Complexity in the Heart of Software](#)
- [Building hexagonal architectures on AWS](#)
- [Decomposing monoliths into microservices](#)
- [Event Storming](#)
- [Messages Between Bounded Contexts](#)
- [Microservices](#)
- [Test-driven development](#)
- [Behavior-driven development](#)

### Related examples:

- [Designing Cloud Native Microservices on AWS \(from DDD/EventStormingWorkshop\)](#)

### Related tools:

- [AWS Cloud Databases](#)
- [Serverless on AWS](#)
- [Containers at AWS](#)

## REL03-BP03 Provide service contracts per API

Service contracts are documented agreements between API producers and consumers defined in a machine-readable API definition. A contract versioning strategy allows consumers to continue using the existing API and migrate their applications to a newer API when they are ready. Producer deployment can happen any time as long as the contract is followed. Service teams can use the technology stack of their choice to satisfy the API contract.

### Desired outcome:

**Common anti-patterns:** Applications built with service-oriented or microservice architectures are able to operate independently while having integrated runtime dependency. Changes deployed to an API consumer or producer do not interrupt the stability of the overall system when both sides follow a common API contract. Components that communicate over service APIs can perform independent functional releases, upgrades to runtime dependencies, or fail over to a disaster recovery (DR) site with little or no impact to each other. In addition, discrete services are able to independently scale absorbing resource demand without requiring other services to scale in unison.

- Creating service APIs without strongly typed schemas. This results in APIs that cannot be used to generate API bindings and payloads that can't be programmatically validated.
- Not adopting a versioning strategy, which forces API consumers to update and release or fail when service contracts evolve.
- Error messages that leak details of the underlying service implementation rather than describe integration failures in the domain context and language.
- Not using API contracts to develop test cases and mock API implementations to allow for independent testing of service components.

**Benefits of establishing this best practice:** Distributed systems composed of components that communicate over API service contracts can improve reliability. Developers can catch potential issues early in the development process with type checking during compilation to verify that requests and responses follow the API contract and required fields are present. API contracts provide a clear self-documenting interface for APIs and provide better interoperability between different systems and programming languages.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

Once you have identified business domains and determined your workload segmentation, you can develop your service APIs. First, define machine-readable service contracts for APIs, and then implement an API versioning strategy. When you are ready to integrate services over common protocols like REST, GraphQL, or asynchronous events, you can incorporate AWS services into your architecture to integrate your components with strongly-typed API contracts.

### AWS services for service API contracts

Incorporate AWS services including [Amazon API Gateway](#), [AWS AppSync](#), and [Amazon EventBridge](#) into your architecture to use API service contracts in your application. Amazon API Gateway helps you integrate with directly native AWS services and other web services. API Gateway supports the [OpenAPI specification](#) and versioning. AWS AppSync is a managed [GraphQL](#) endpoint you configure by defining a GraphQL schema to define a service interface for queries, mutations and subscriptions. Amazon EventBridge uses event schemas to define events and generate code bindings for your events.

## Implementation steps

- First, define a contract for your API. A contract will express the capabilities of an API as well as define strongly typed data objects and fields for the API input and output.
- When you configure APIs in API Gateway, you can import and export OpenAPI Specifications for your endpoints.
  - [Importing an OpenAPI definition](#) simplifies the creation of your API and can be integrated with AWS infrastructure as code tools like the [AWS Serverless Application Model](#) and [AWS Cloud Development Kit \(AWS CDK\)](#).
  - [Exporting an API definition](#) simplifies integrating with API testing tools and provides services consumer an integration specification.
- You can define and manage GraphQL APIs with AWS AppSync by [defining a GraphQL schema](#) file to generate your contract interface and simplify interaction with complex REST models, multiple database tables or legacy services.
- [AWS Amplify](#) projects that are integrated with AWS AppSync generate strongly typed JavaScript query files for use in your application as well as an AWS AppSync GraphQL client library for [Amazon DynamoDB](#) tables.
- When you consume service events from Amazon EventBridge, events adhere to schemas that already exist in the schema registry or that you define with the OpenAPI Spec. With a schema

defined in the registry, you can also generate client bindings from the schema contract to integrate your code with events.

- Extending or version your API. Extending an API is a simpler option when adding fields that can be configured with optional fields or default values for required fields.
  - JSON based contracts for protocols like REST and GraphQL can be a good fit for contract extension.
  - XML based contracts for protocols like SOAP should be tested with service consumers to determine the feasibility of contract extension.
- When versioning an API, consider implementing proxy versioning where a facade is used to support versions so that logic can be maintained in a single codebase.
  - With API Gateway you can use [request and response mappings](#) to simplify absorbing contract changes by establishing a facade to provide default values for new fields or to strip removed fields from a request or response. With this approach the underlying service can maintain a single codebase.

## Resources

### Related best practices:

- [REL03-BP01 Choose how to segment your workload](#)
- [REL03-BP02 Build services focused on specific business domains and functionality](#)
- [REL04-BP02 Implement loosely coupled dependencies](#)
- [REL05-BP03 Control and limit retry calls](#)
- [REL05-BP05 Set client timeouts](#)

### Related documents:

- [What Is An API \(Application Programming Interface\)?](#)
- [Implementing Microservices on AWS](#)
- [Microservice Trade-Offs](#)
- [Microservices - a definition of this new architectural term](#)
- [Microservices on AWS](#)
- [Working with API Gateway extensions to OpenAPI](#)
- [OpenAPI-Specification](#)

- [GraphQL: Schemas and Types](#)
- [Amazon EventBridge code bindings](#)

### Related examples:

- [Amazon API Gateway: Configuring a REST API Using OpenAPI](#)
- [Amazon API Gateway to Amazon DynamoDB CRUD application using OpenAPI](#)
- [Modern application integration patterns in a serverless age: API Gateway Service Integration](#)
- [Implementing header-based API Gateway versioning with Amazon CloudFront](#)
- [AWS AppSync: Building a client application](#)

### Related videos:

- [Using OpenAPI in AWS SAM to manage API Gateway](#)

### Related tools:

- [Amazon API Gateway](#)
- [AWS AppSync](#)
- [Amazon EventBridge](#)

## Design interactions in a distributed system to prevent failures

Distributed systems rely on communications networks to interconnect components, such as servers or services. Your workload must operate reliably despite data loss or latency in these networks. Components of the distributed system must operate in a way that does not negatively impact other components or the workload. These best practices prevent failures and improve mean time between failures (MTBF).

### Best practices

- [REL04-BP01 Identify the kind of distributed systems you depend on](#)
- [REL04-BP02 Implement loosely coupled dependencies](#)
- [REL04-BP03 Do constant work](#)
- [REL04-BP04 Make all responses idempotent](#)

## REL04-BP01 Identify the kind of distributed systems you depend on

Distributed systems can be synchronous, asynchronous, or batch. Synchronous systems must process requests as quickly as possible and communicate with each other by making synchronous request and response calls using HTTP/S, REST, or remote procedure call (RPC) protocols.

Asynchronous systems communicate with each other by exchanging data asynchronously through an intermediary service without coupling individual systems. Batch systems receive a large volume of input data, run automated data processes without human intervention, and generate output data.

**Desired outcome:** Design a workload that effectively interacts with synchronous, asynchronous, and batch dependencies.

### Common anti-patterns:

- Workload waits indefinitely for a response from its dependencies, which could lead to workload clients timing out, not knowing if their request has been received.
- Workload uses a chain of dependent systems that call each other synchronously. This requires each system to be available and to successfully process a request before the whole chain can succeed, leading to potentially brittle behavior and overall availability.
- Workload communicates with its dependencies asynchronously and rely on the concept of exactly-once guaranteed delivery of messages, when often it is still possible to receive duplicate messages.
- Workload does not use proper batch scheduling tools and allows concurrent execution of the same batch job.

**Benefits of establishing this best practice:** It is common for a given workload to implement one or more style of communication between synchronous, asynchronous, and batch. This best practice helps you identify the different trade-offs associated with each style of communication to make your workload able to tolerate disruptions in any of its dependencies.

**Level of risk exposed if this best practice is not established:** High

### Implementation guidance

The following sections contain both general and specific implementation guidance for each kind of dependency.

#### General guidance



- Make sure that the performance and reliability service-level objectives (SLOs) that your dependencies offer meet the performance and reliability requirements of your workload.
- Use [AWS observability services](#) to [monitor response times and error rates](#) to make sure your dependency is providing service at the levels needed by your workload.
- Identify the potential challenges that your workload may face when communicating with its dependencies. Distributed systems [come with a wide range of challenges](#) that might increase architectural complexity, operational burden, and cost. Common challenges include latency, network disruptions, data loss, scaling, and data replication lag.
- Implement robust error handling and [logging](#) to help you troubleshoot problems when your dependency experiences issues.

## Synchronous dependency

In synchronous communications, your workload sends a request to its dependency and blocks the operation waiting for a response. When its dependency receives the request, it tries to handle it as soon as possible and sends a response back to your workload. A significant challenge with synchronous communication is that it causes temporal coupling, which requires your workload and its dependencies to be available at the same time. When your workload needs to communicate synchronously with its dependencies, consider the following guidance:

- Your workload should not rely on multiple synchronous dependencies to perform a single function. This chain of dependencies increases overall brittleness because all dependencies in the pathway need to be available in order for the request to complete successfully.
- When a dependency is unhealthy or unavailable, determine your error handling and retry strategies. Avoid using bimodal behavior. Bimodal behavior is when your workload exhibits different behavior under normal and failure modes. For more details on bimodal behavior, see [REL11-BP05 Use static stability to prevent bimodal behavior](#).
- Keep in mind that failing fast is better than making your workload wait. For instance, the [AWS Lambda Developer Guide](#) describes how to handle retries and failures when you invoke Lambda functions.
- Set timeouts when your workload calls its dependency. This technique avoids waiting too long or waiting indefinitely for a response. For helpful discussion of this issue, see [Tuning AWS Java SDK HTTP request settings for latency-aware Amazon DynamoDB applications](#).
- Minimize the number of calls made from your workload to its dependency to fulfill a single request. Having chatty calls between them increases coupling and latency.

## Asynchronous dependency

To temporally decouple your workload from its dependency, they should communicate asynchronously. Using an asynchronous approach, your workload can continue with any other processing without having to wait for its dependency, or chain of dependencies, to send a response.

When your workload needs to communicate asynchronously with its dependency, consider the following guidance:

- Determine whether to use messaging or event streaming based on your use case and requirements. [Messaging](#) allows your workload to communicate with its dependency by sending and receiving messages through a message broker. [Event streaming](#) allows your workload and its dependency to use a streaming service to publish and subscribe to events, delivered as continuous streams of data, that need to be processed as soon as possible.
- Messaging and event streaming handle messages differently so you need to make trade-off decisions based on:
  - **Message priority:** message brokers can process high-priority messages ahead of normal messages. In event streaming, all messages have the same priority.
  - **Message consumption:** message brokers ensure that consumers receive the message. Event streaming consumers must keep track of the last message they have read.
  - **Message ordering:** with messaging, receiving messages in the exact order they are sent is not guaranteed unless you use a first-in-first-out (FIFO) approach. Event streaming always preserves the order in which the data was produced.
  - **Message deletion:** with messaging, the consumer must delete the message after processing it. The event streaming service appends the message to a stream and remains in there until the message's retention period expires. This deletion policy makes event streaming suitable for replaying messages.
- Define how your workload knows when its dependency completes its work. For instance, when your workload invokes a [Lambda function asynchronously](#), Lambda places the event in a queue and returns a success response without additional information. After processing is complete, the Lambda function can [send the result to a destination](#), configurable based on success or failure.
- Build your workload to handle duplicate messages by leveraging idempotency. Idempotency means that the results of your workload do not change even if your workload is generated more than once for the same message. It is important to point out that [messaging](#) or [streaming](#)

services will redeliver a message if a network failure occurs or if an acknowledgement has not been received.

- If your workload does not get a response from its dependency, it needs to resubmit the request. Consider limiting the number of retries to preserve your workload's CPU, memory, and network resources to handle other requests. The [AWS Lambda documentation](#) shows how to handle errors for asynchronous invocation.
- Leverage suitable observability, debugging, and tracing tools to manage and operate your workload's asynchronous communication with its dependency. You can use [Amazon CloudWatch](#) to monitor [messaging](#) and [event streaming](#) services. You can also instrument your workload with [AWS X-Ray](#) to quickly [gain insights](#) for troubleshooting problems.

## Batch dependency

Batch systems take input data, initiate a series of jobs to process it, and produce some output data, without manual intervention. Depending on the data size, jobs could run from minutes to, in some cases, several days. When your workload communicates with its batch dependency, consider the following guidance:

- Define the time window when your workload should run the batch job. Your workload can set up a recurrence pattern to invoke a batch system, for example, every hour or at the end of every month.
- Determine the location of the data input and the processed data output. Choose a storage service, such as [Amazon Simple Storage Services \(Amazon S3\)](#), [Amazon Elastic File System \(Amazon EFS\)](#), and [Amazon FSx for Lustre](#), that allows your workload to read and write files at scale.
- If your workload needs to invoke multiple batch jobs, you could leverage [AWS Step Functions](#) to simplify the orchestration of batch jobs that run in AWS or on-premises. This [sample project](#) demonstrates orchestration of batch jobs using Step Functions, [AWS Batch](#), and Lambda.
- Monitor batch jobs to look for abnormalities, such as a job taking longer than it should to complete. You could use tools like [CloudWatch Container Insights](#) to monitor AWS Batch environments and jobs. In this instance, your workload would stop the next job from beginning and inform the relevant staff of the exception.

## Resources

### Related documents:

- [AWS Cloud Operations: Monitoring and Observability](#)
- [The Amazon's Builder Library: Challenges with distributed systems](#)
- [REL11-BP05 Use static stability to prevent bimodal behavior](#)
- [AWS Lambda Developer Guide: Error handling and automatic retries in AWS Lambda](#)
- [Tuning AWS Java SDK HTTP request settings for latency-aware Amazon DynamoDB applications](#)
- [AWS Messaging](#)
- [What is streaming data?](#)
- [AWS Lambda Developer Guide: Asynchronous invocation](#)
- [Amazon Simple Queue Service FAQ: FIFO queues](#)
- [Amazon Kinesis Data Streams Developer Guide: Handling Duplicate Records](#)
- [Amazon Simple Queue Service Developer Guide: Available CloudWatch metrics for Amazon SQS](#)
- [Amazon Kinesis Data Streams Developer Guide: Monitoring the Amazon Kinesis Data Streams Service with Amazon CloudWatch](#)
- [AWS X-Ray Developer Guide: AWS X-Ray concepts](#)
- [AWS Samples on GitHub: AWS Step functions Complex Orchestrator App](#)
- [AWS Batch User Guide: AWS Batch CloudWatch Container Insights](#)

**Related videos:**

- [AWS Summit SF 2022 - Full-stack observability and application monitoring with AWS \(COP310\)](#)

**Related tools:**

- [Amazon CloudWatch](#)
- [Amazon CloudWatch Logs](#)
- [AWS X-Ray](#)
- [Amazon Simple Storage Services \(Amazon S3\)](#)
- [Amazon Elastic File System \(Amazon EFS\)](#)
- [Amazon FSx for Lustre](#)
- [AWS Step Functions](#)
- [AWS Batch](#)

## REL04-BP02 Implement loosely coupled dependencies

Dependencies such as queuing systems, streaming systems, workflows, and load balancers are loosely coupled. Loose coupling helps isolate behavior of a component from other components that depend on it, increasing resiliency and agility.

Decoupling dependencies, such as queuing systems, streaming systems, and workflows, help minimize the impact of changes or failure on a system. This separation isolates a component's behavior from affecting others that depend on it, improving resilience and agility.

In tightly coupled systems, changes to one component can necessitate changes in other components that rely on it, resulting in degraded performance across all components. *Loose* coupling breaks this dependency so that dependent components only need to know the versioned and published interface. Implementing loose coupling between dependencies isolates a failure in one from impacting another.

Loose coupling allows you to modify code or add features to a component while minimizing risk to other components that depend on it. It also allows for granular resilience at a component level where you can scale out or even change underlying implementation of the dependency.

To further improve resiliency through loose coupling, make component interactions asynchronous where possible. This model is suitable for any interaction that does not need an immediate response and where an acknowledgment that a request has been registered will suffice. It involves one component that generates events and another that consumes them. The two components do not integrate through direct point-to-point interaction but usually through an intermediate durable storage layer, such as an Amazon SQS queue, a streaming data platform such as Amazon Kinesis, or AWS Step Functions.

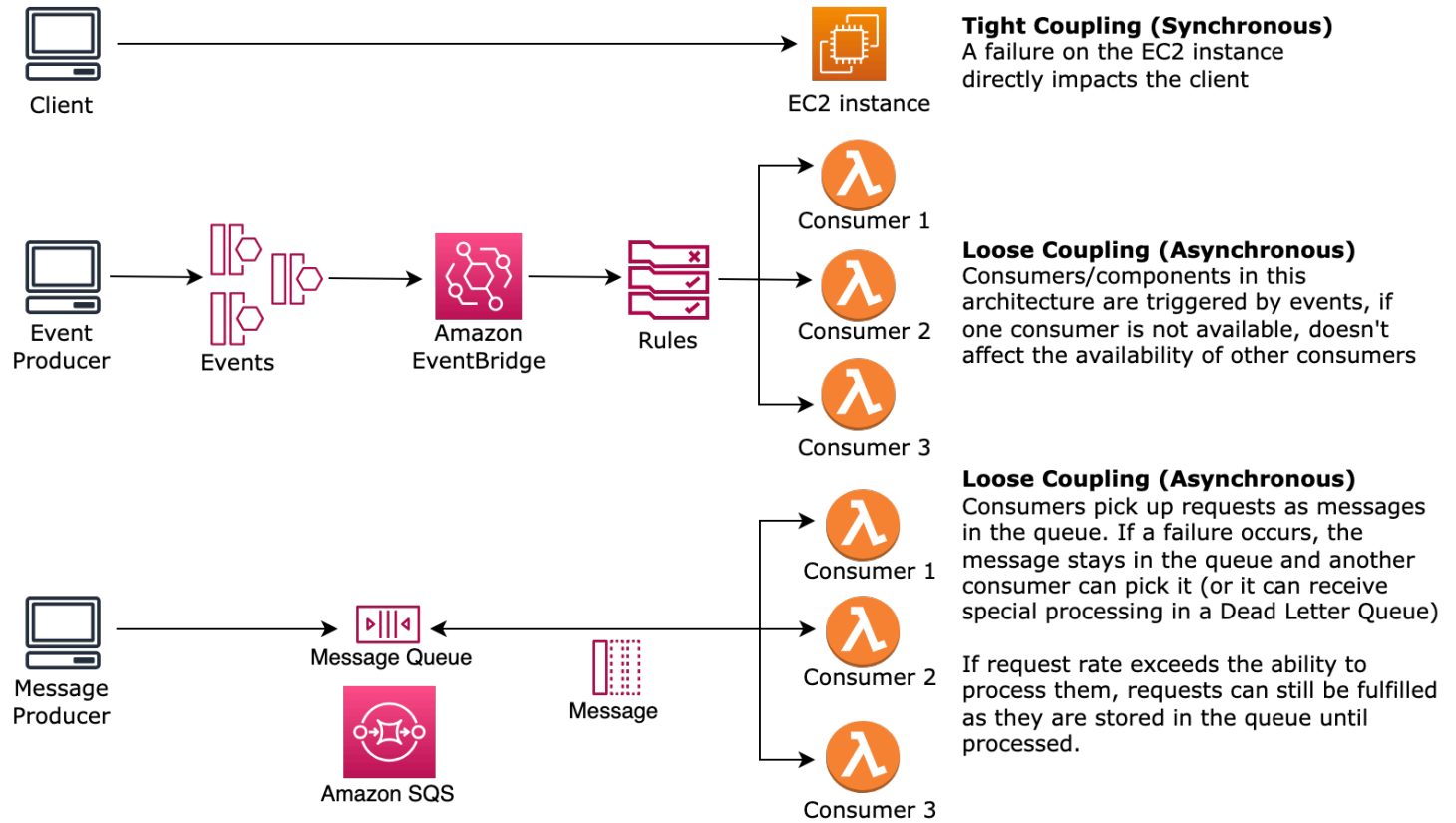


Figure 4: Dependencies such as queuing systems and load balancers are loosely coupled

Amazon SQS queues and AWS Step Functions are just two ways to add an intermediate layer for loose coupling. Event-driven architectures can also be built in the AWS Cloud using Amazon EventBridge, which can abstract clients (event producers) from the services they rely on (event consumers). Amazon Simple Notification Service (Amazon SNS) is an effective solution when you need high-throughput, push-based, many-to-many messaging. Using Amazon SNS topics, your publisher systems can fan out messages to a large number of subscriber endpoints for parallel processing.

While queues offer several advantages, in most hard real-time systems, requests older than a threshold time (often seconds) should be considered stale (the client has given up and is no longer waiting for a response), and not processed. This way more recent (and likely still valid requests) can be processed instead.

**Desired outcome:** Implementing loosely coupled dependencies allows you to minimize the surface area for failure to a component level, which helps diagnose and resolve issues. It also simplifies development cycles, allowing teams to implement changes at a modular level without affecting the performance of other components that depend on it. This approach provides the capability

to scale out at a component level based on resource needs, as well as utilization of a component contributing to cost-effectiveness.

### Common anti-patterns:

- Deploying a monolithic workload.
- Directly invoking APIs between workload tiers with no capability of failover or asynchronous processing of the request.
- Tight coupling using shared data. Loosely coupled systems should avoid sharing data through shared databases or other forms of tightly coupled data storage, which can reintroduce tight coupling and hinder scalability.
- Ignoring back pressure. Your workload should have the ability to slow down or stop incoming data when a component can't process it at the same rate.

**Benefits of establishing this best practice:** Loose coupling helps isolate behavior of a component from other components that depend on it, increasing resiliency and agility. Failure in one component is isolated from others.

**Level of risk exposed if this best practice is not established:** High

### Implementation guidance

Implement loosely coupled dependencies. There are various solutions that allow you to build loosely coupled applications. These include services for implementing fully managed queues, automated workflows, react to events, and APIs among others which can help isolate behavior of components from other components, and as such increasing resilience and agility.

- **Build event-driven architectures:** [Amazon EventBridge](#) helps you build loosely coupled and distributed event-driven architectures.
- **Implement queues in distributed systems:** You can use [Amazon Simple Queue Service \(Amazon SQS\)](#) to integrate and decouple distributed systems.
- **Containerize components as microservices:** [Microservices](#) allow teams to build applications composed of small independent components which communicate over well-defined APIs. [Amazon Elastic Container Service \(Amazon ECS\)](#), and [Amazon Elastic Kubernetes Service \(Amazon EKS\)](#) can help you get started faster with containers.
- **Manage workflows with Step Functions:** [Step Functions](#) help you coordinate multiple AWS services into flexible workflows.

- **Leverage publish-subscribe (pub/sub) messaging architectures:** [Amazon Simple Notification Service \(Amazon SNS\)](#) provides message delivery from publishers to subscribers (also known as producers and consumers).

## Implementation steps

- Components in an event-driven architecture are initiated by events. Events are actions that happen in a system, such as a user adding an item to a cart. When an action is successful, an event is generated that actuates the next component of the system.
  - [Building Event-driven Applications with Amazon EventBridge](#)
  - [AWS re:Invent 2022 - Designing Event-Driven Integrations using Amazon EventBridge](#)
- Distributed messaging systems have three main parts that need to be implemented for a queue based architecture. They include components of the distributed system, the queue that is used for decoupling (distributed on Amazon SQS servers), and the messages in the queue. A typical system has producers which initiate the message into the queue, and the consumer which receives the message from the queue. The queue stores messages across multiple Amazon SQS servers for redundancy.
  - [Basic Amazon SQS architecture](#)
  - [Send Messages Between Distributed Applications with Amazon Simple Queue Service](#)
- Microservices, when well-utilized, enhance maintainability and boost scalability, as loosely coupled components are managed by independent teams. It also allows for the isolation of behaviors to a single component in case of changes.
  - [Implementing Microservices on AWS](#)
  - [Let's Architect! Architecting microservices with containers](#)
- With AWS Step Functions you can build distributed applications, automate processes, orchestrate microservices, among other things. The orchestration of multiple components into an automated workflow allows you to decouple dependencies in your application.
  - [Create a Serverless Workflow with AWS Step Functions and AWS Lambda](#)
  - [Getting Started with AWS Step Functions](#)

## Resources

### Related documents:

- [Amazon EC2: Ensuring Idempotency](#)



- [The Amazon Builders' Library: Challenges with distributed systems](#)
- [The Amazon Builders' Library: Reliability, constant work, and a good cup of coffee](#)
- [What Is Amazon EventBridge?](#)
- [What Is Amazon Simple Queue Service?](#)
- [Break up with your monolith](#)
- [Orchestrate Queue-based Microservices with AWS Step Functions and Amazon SQS](#)
- [Basic Amazon SQS architecture](#)
- [Queue-Based Architecture](#)

#### Related videos:

- [AWS New York Summit 2019: Intro to Event-driven Architectures and Amazon EventBridge \(MAD205\)](#)
- [AWS re:Invent 2018: Close Loops and Opening Minds: How to Take Control of Systems, Big and Small ARC337 \(includes loose coupling, constant work, static stability\)](#)
- [AWS re:Invent 2019: Moving to event-driven architectures \(SVS308\)](#)
- [AWS re:Invent 2019: Scalable serverless event-driven applications using Amazon SQS and Lambda](#)
- [AWS re:Invent 2022 - Designing event-driven integrations using Amazon EventBridge](#)
- [AWS re:Invent 2017: Elastic Load Balancing Deep Dive and Best Practices](#)

## REL04-BP03 Do constant work

Systems can fail when there are large, rapid changes in load. For example, if your workload is doing a health check that monitors the health of thousands of servers, it should send the same size payload (a full snapshot of the current state) each time. Whether no servers are failing, or all of them, the health check system is doing constant work with no large, rapid changes.

For example, if the health check system is monitoring 100,000 servers, the load on it is nominal under the normally light server failure rate. However, if a major event makes half of those servers unhealthy, then the health check system would be overwhelmed trying to update notification systems and communicate state to its clients. So instead the health check system should send the full snapshot of the current state each time. 100,000 server health states, each represented

by a bit, would only be a 12.5-KB payload. Whether no servers are failing, or all of them are, the health check system is doing constant work, and large, rapid changes are not a threat to the system stability. This is actually how Amazon Route 53 handles health checks for endpoints (such as IP addresses) to determine how end users are routed to them.

**Level of risk exposed if this best practice is not established:** Low

## Implementation guidance

- Do constant work so that systems do not fail when there are large, rapid changes in load.
- Implement loosely coupled dependencies. Dependencies such as queuing systems, streaming systems, workflows, and load balancers are loosely coupled. Loose coupling helps isolate behavior of a component from other components that depend on it, increasing resiliency and agility.
  - [The Amazon Builders' Library: Reliability, constant work, and a good cup of coffee](#)
  - [AWS re:Invent 2018: Close Loops and Opening Minds: How to Take Control of Systems, Big and Small ARC337 \(includes constant work\)](#)
    - For the example of a health check system monitoring 100,000 servers, engineer workloads so that payload sizes remain constant regardless of number of successes or failures.

## Resources

### Related documents:

- [Amazon EC2: Ensuring Idempotency](#)
- [The Amazon Builders' Library: Challenges with distributed systems](#)
- [The Amazon Builders' Library: Reliability, constant work, and a good cup of coffee](#)

### Related videos:

- [AWS New York Summit 2019: Intro to Event-driven Architectures and Amazon EventBridge \(MAD205\)](#)
- [AWS re:Invent 2018: Close Loops and Opening Minds: How to Take Control of Systems, Big and Small ARC337 \(includes constant work\)](#)
- [AWS re:Invent 2018: Close Loops and Opening Minds: How to Take Control of Systems, Big and Small ARC337 \(includes loose coupling, constant work, static stability\)](#)

- [AWS re:Invent 2019: Moving to event-driven architectures \(SVS308\)](#)

## REL04-BP04 Make all responses idempotent

An idempotent service promises that each request is completed exactly once, such that making multiple identical requests has the same effect as making a single request. An idempotent service makes it easier for a client to implement retries without fear that a request will be erroneously processed multiple times. To do this, clients can issue API requests with an idempotency token—the same token is used whenever the request is repeated. An idempotent service API uses the token to return a response identical to the response that was returned the first time that the request was completed.

In a distributed system, it's easy to perform an action at most once (client makes only one request), or at least once (keep requesting until client gets confirmation of success). But it's hard to guarantee an action is idempotent, which means it's performed *exactly* once, such that making multiple identical requests has the same effect as making a single request. Using idempotency tokens in APIs, services can receive a mutating request one or more times without creating duplicate records or side effects.

**Level of risk exposed if this best practice is not established:** Medium

### Implementation guidance

- Make all responses idempotent. An idempotent service promises that each request is completed exactly once, such that making multiple identical requests has the same effect as making a single request.
  - Clients can issue API requests with an idempotency token—the same token is used whenever the request is repeated. An idempotent service API uses the token to return a response identical to the response that was returned the first time that the request was completed.
    - [Amazon EC2: Ensuring Idempotency](#)

### Resources

#### Related documents:

- [Amazon EC2: Ensuring Idempotency](#)
- [The Amazon Builders' Library: Challenges with distributed systems](#)

- [The Amazon Builders' Library: Reliability, constant work, and a good cup of coffee](#)

### Related videos:

- [AWS New York Summit 2019: Intro to Event-driven Architectures and Amazon EventBridge \(MAD205\)](#)
- [AWS re:Invent 2018: Close Loops and Opening Minds: How to Take Control of Systems, Big and Small ARC337 \(includes loose coupling, constant work, static stability\)](#)
- [AWS re:Invent 2019: Moving to event-driven architectures \(SVS308\)](#)

## Design interactions in a distributed system to mitigate or withstand failures

Distributed systems rely on communications networks to interconnect components (such as servers or services). Your workload must operate reliably despite data loss or latency over these networks. Components of the distributed system must operate in a way that does not negatively impact other components or the workload. These best practices allow workloads to withstand stresses or failures, more quickly recover from them, and mitigate the impact of such impairments. The result is improved mean time to recovery (MTTR).

These best practices prevent failures and improve mean time between failures (MTBF).

### Best practices

- [REL05-BP01 Implement graceful degradation to transform applicable hard dependencies into soft dependencies](#)
- [REL05-BP02 Throttle requests](#)
- [REL05-BP03 Control and limit retry calls](#)
- [REL05-BP04 Fail fast and limit queues](#)
- [REL05-BP05 Set client timeouts](#)
- [REL05-BP06 Make systems stateless where possible](#)
- [REL05-BP07 Implement emergency levers](#)

## REL05-BP01 Implement graceful degradation to transform applicable hard dependencies into soft dependencies

Application components should continue to perform their core function even if dependencies become unavailable. They might be serving slightly stale data, alternate data, or even no data. This ensures overall system function is only minimally impeded by localized failures while delivering the central business value.

**Desired outcome:** When a component's dependencies are unhealthy, the component itself can still function, although in a degraded manner. Failure modes of components should be seen as normal operation. Workflows should be designed in such a way that such failures do not lead to complete failure or at least to predictable and recoverable states.

### Common anti-patterns:

- Not identifying the core business functionality needed. Not testing that components are functional even during dependency failures.
- Serving no data on errors or when only one out of multiple dependencies is unavailable and partial results can still be returned.
- Creating an inconsistent state when a transaction partially fails.
- Not having an alternative way to access a central parameter store.
- Invalidating or emptying local state as a result of a failed refresh without considering the consequences of doing so.

**Benefits of establishing this best practice:** Graceful degradation improves the availability of the system as a whole and maintains the functionality of the most important functions even during failures.

**Level of risk exposed if this best practice is not established:** High

### Implementation guidance

Implementing graceful degradation helps minimize the impact of dependency failures on component function. Ideally, a component detects dependency failures and works around them in a way that minimally impacts other components or customers.

Architecting for graceful degradation means considering potential failure modes during dependency design. For each failure mode, have a way to deliver most or at least the most

critical functionality of the component to callers or customers. These considerations can become additional requirements that can be tested and verified. Ideally, a component is able to perform its core function in an acceptable manner even when one or multiple dependencies fail.

This is as much a business discussion as a technical one. All business requirements are important and should be fulfilled if possible. However, it still makes sense to ask what should happen when not all of them can be fulfilled. A system can be designed to be available and consistent, but under circumstances where one requirement must be dropped, which one is more important? For payment processing, it might be consistency. For a real-time application, it might be availability. For a customer facing website, the answer may depend on customer expectations.

What this means depends on the requirements of the component and what should be considered its core function. For example:

- An ecommerce website might display data from multiple different systems like personalized recommendations, highest ranked products, and status of customer orders on the landing page. When one upstream system fails, it still makes sense to display everything else instead of showing an error page to a customer.
- A component performing batch writes can still continue processing a batch if one of the individual operations fails. It should be simple to implement a retry mechanism. This can be done by returning information on which operations succeeded, which failed, and why they failed to the caller, or putting failed requests into a dead letter queue to implement asynchronous retries. Information about failed operations should be logged as well.
- A system that processes transactions must verify that either all or no individual updates are executed. For distributed transactions, the saga pattern can be used to roll back previous operations in case a later operation of the same transaction fails. Here, the core function is maintaining consistency.
- Time critical systems should be able to deal with dependencies not responding in a timely manner. In these cases, the circuit breaker pattern can be used. When responses from a dependency start timing out, the system can switch to a closed state where no additional calls are made.
- An application may read parameters from a parameter store. It can be useful to create container images with a default set of parameters and use these in case the parameter store is unavailable.

Note that the pathways taken in case of component failure need to be tested and should be significantly simpler than the primary pathway. Generally, [fallback strategies should be avoided](#).

## Implementation steps

Identify external and internal dependencies. Consider what kinds of failures can occur in them. Think about ways that minimize negative impact on upstream and downstream systems and customers during those failures.

The following is a list of dependencies and how to degrade gracefully when they fail:

- 1. Partial failure of dependencies:** A component may make multiple requests to downstream systems, either as multiple requests to one system or one request to multiple systems each. Depending on the business context, different ways of handling for this may be appropriate (for more detail, see previous examples in Implementation guidance).
- 2. A downstream system is unable to process requests due to high load:** If requests to a downstream system are consistently failing, it does not make sense to continue retrying. This may create additional load on an already overloaded system and make recovery more difficult. The circuit breaker pattern can be utilized here, which monitors failing calls to a downstream system. If a high number of calls are failing, it will stop sending more requests to the downstream system and only occasionally let calls through to test whether the downstream system is available again.
- 3. A parameter store is unavailable:** To transform a parameter store, soft dependency caching or sane defaults included in container or machine images may be used. Note that these defaults need to be kept up-to-date and included in test suites.
- 4. A monitoring service or other non-functional dependency is unavailable:** If a component is intermittently unable to send logs, metrics, or traces to a central monitoring service, it is often best to still execute business functions as usual. Silently not logging or pushing metrics for a long time is often not acceptable. Also, some use cases may require complete auditing entries to fulfill compliance requirements.
- 5. A primary instance of a relational database may be unavailable:** Amazon Relational Database Service, like almost all relational databases, can only have one primary writer instance. This creates a single point of failure for write workloads and makes scaling more difficult. This can partially be mitigated by using a Multi-AZ configuration for high availability or Amazon Aurora Serverless for better scaling. For very high availability requirements, it can make sense to not rely on the primary writer at all. For queries that only read, read replicas can be used, which provide redundancy and the ability to scale out, not just up. Writes can be buffered, for example in an Amazon Simple Queue Service queue, so that write requests from customers can still be accepted even if the primary is temporarily unavailable.

## Resources

### Related documents:

- [Amazon API Gateway: Throttle API Requests for Better Throughput](#)
- [CircuitBreaker \(summarizes Circuit Breaker from “Release It!” book\)](#)
- [Error Retries and Exponential Backoff in AWS](#)
- [Michael Nygard “Release It! Design and Deploy Production-Ready Software”](#)
- [The Amazon Builders' Library: Avoiding fallback in distributed systems](#)
- [The Amazon Builders' Library: Avoiding insurmountable queue backlogs](#)
- [The Amazon Builders' Library: Caching challenges and strategies](#)
- [The Amazon Builders' Library: Timeouts, retries, and backoff with jitter](#)

### Related videos:

- [Retry, backoff, and jitter: AWS re:Invent 2019: Introducing The Amazon Builders' Library \(DOP328\)](#)

### Related examples:

- [Well-Architected lab: Level 300: Implementing Health Checks and Managing Dependencies to Improve Reliability](#)

## REL05-BP02 Throttle requests

Throttle requests to mitigate resource exhaustion due to unexpected increases in demand. Requests below throttling rates are processed while those over the defined limit are rejected with a return a message indicating the request was throttled.

**Desired outcome:** Large volume spikes either from sudden customer traffic increases, flooding attacks, or retry storms are mitigated by request throttling, allowing workloads to continue normal processing of supported request volume.

### Common anti-patterns:

- API endpoint throttles are not implemented or are left at default values without considering expected volumes.



- API endpoints are not load tested or throttling limits are not tested.
- Throttling request rates without considering request size or complexity.
- Testing maximum request rates or maximum request size, but not testing both together.
- Resources are not provisioned to the same limits established in testing.
- Usage plans have not been configured or considered for application to application (A2A) API consumers.
- Queue consumers that horizontally scale do not have maximum concurrency settings configured.
- Rate limiting on a per IP address basis has not been implemented.

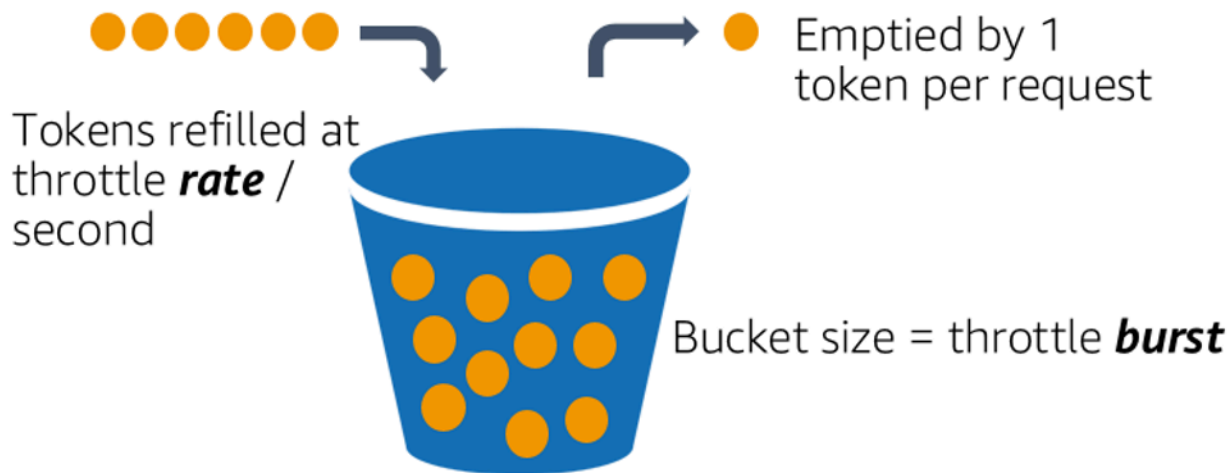
**Benefits of establishing this best practice:** Workloads that set throttle limits are able to operate normally and process accepted request load successfully under unexpected volume spikes. Sudden or sustained spikes of requests to APIs and queues are throttled and do not exhaust request processing resources. Rate limits throttle individual requestors so that high volumes of traffic from a single IP address or API consumer will not exhaust resources impact other consumers.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

Services should be designed to process a known capacity of requests; this capacity can be established through load testing. If request arrival rates exceed limits, the appropriate response signals that a request has been throttled. This allows the consumer to handle the error and retry later.

When your service requires a throttling implementation, consider implementing the token bucket algorithm, where a token counts for a request. Tokens are refilled at a throttle rate per second and emptied asynchronously by one token per request.



*The token bucket algorithm.*

[Amazon API Gateway](#) implements the token bucket algorithm according to account and region limits and can be configured per-client with usage plans. Additionally, [Amazon Simple Queue Service \(Amazon SQS\)](#) and [Amazon Kinesis](#) can buffer requests to smooth out the request rate, and allow higher throttling rates for requests that can be addressed. Finally, you can implement rate limiting with [AWS WAF](#) to throttle specific API consumers that generate unusually high load.

## Implementation steps

You can configure API Gateway with throttling limits for your APIs and return 429 Too Many Requests errors when limits are exceeded. You can use AWS WAF with your AWS AppSync and API Gateway endpoints to enable rate limiting on a per IP address basis. Additionally, where your system can tolerate asynchronous processing, you can put messages into a queue or stream to speed up responses to service clients, which allows you to burst to higher throttle rates.

With asynchronous processing, when you've configured Amazon SQS as an event source for AWS Lambda, you can [configure maximum concurrency](#) to avoid high event rates from consuming available account concurrent execution quota needed for other services in your workload or account.

While API Gateway provides a managed implementation of the token bucket, in cases where you cannot use API Gateway, you can take advantage of language specific open-source implementations (see related examples in Resources) of the token bucket for your services.

- Understand and configure [API Gateway throttling limits](#) at the account level per region, API per stage, and API key per usage plan levels.
- Apply [AWS WAF rate limiting rules](#) to API Gateway and AWS AppSync endpoints to protect against floods and block malicious IPs. Rate limiting rules can also be configured on AWS AppSync API keys for A2A consumers.
- Consider whether you require more throttling control than rate limiting for AWS AppSync APIs, and if so, configure an API Gateway in front of your AWS AppSync endpoint.
- When Amazon SQS queues are set up as triggers for Lambda queue consumers, set [maximum concurrency](#) to a value that processes enough to meet your service level objectives but does not consume concurrency limits impacting other Lambda functions. Consider setting reserved concurrency on other Lambda functions in the same account and region when you consume queues with Lambda.
- Use API Gateway with native service integrations to Amazon SQS or Kinesis to buffer requests.
- If you cannot use API Gateway, look at language specific libraries to implement the token bucket algorithm for your workload. Check the examples section and do your own research to find a suitable library.
- Test limits that you plan to set, or that you plan to allow to be increased, and document the tested limits.
- Do not increase limits beyond what you establish in testing. When increasing a limit, verify that provisioned resources are already equivalent to or greater than those in test scenarios before applying the increase.

## Resources

### Related best practices:

- [REL04-BP03 Do constant work](#)
- [REL05-BP03 Control and limit retry calls](#)

### Related documents:

- [Amazon API Gateway: Throttle API Requests for Better Throughput](#)
- [AWS WAF: Rate-based rule statement](#)
- [Introducing maximum concurrency of AWS Lambda when using Amazon SQS as an event source](#)
- [AWS Lambda: Maximum Concurrency](#)

### Related examples:

- [The three most important AWS WAF rate-based rules](#)
- [Java Bucket4j](#)
- [Python token-bucket](#)
- [Node token-bucket](#)
- [.NET System Threading Rate Limiting](#)

### Related videos:

- [Implementing GraphQL API security best practices with AWS AppSync](#)

### Related tools:

- [Amazon API Gateway](#)
- [AWS AppSync](#)
- [Amazon SQS](#)
- [Amazon Kinesis](#)
- [AWS WAF](#)

## REL05-BP03 Control and limit retry calls

Use exponential backoff to retry requests at progressively longer intervals between each retry. Introduce jitter between retries to randomize retry intervals. Limit the maximum number of retries.

**Desired outcome:** Typical components in a distributed software system include servers, load balancers, databases, and DNS servers. During normal operation, these components can respond to requests with errors that are temporary or limited, and also errors that would be persistent regardless of retries. When clients make requests to services, the requests consume resources including memory, threads, connections, ports, or any other limited resources. Controlling and limiting retries is a strategy to release and minimize consumption of resources so that system components under strain are not overwhelmed.

When client requests time out or receive error responses, they should determine whether or not to retry. If they do retry, they do so with exponential backoff with jitter and a maximum retry

value. As a result, backend services and processes are given relief from load and time to self-heal, resulting in faster recovery and successful request servicing.

### **Common anti-patterns:**

- Implementing retries without adding exponential backoff, jitter, and maximum retry values. Backoff and jitter help avoid artificial traffic spikes due to unintentionally coordinated retries at common intervals.
- Implementing retries without testing their effects or assuming retries are already built into an SDK without testing retry scenarios.
- Failing to understand published error codes from dependencies, leading to retrying all errors, including those with a clear cause that indicates lack of permission, configuration error, or another condition that predictably will not resolve without manual intervention.
- Not addressing observability practices, including monitoring and alerting on repeated service failures so that underlying issues are made known and can be addressed.
- Developing custom retry mechanisms when built-in or third-party retry capabilities suffice.
- Retrying at multiple layers of your application stack in a manner which compounds retry attempts further consuming resources in a retry storm. Be sure to understand how these errors affect your application the dependencies you rely on, then implement retries at only one level.
- Retrying service calls that are not idempotent, causing unexpected side effects like duplicated results.

**Benefits of establishing this best practice:** Retries help clients acquire desired results when requests fail but also consume more of a server's time to get the successful responses they want. When failures are rare or transient, retries work well. When failures are caused by resource overload, retries can make things worse. Adding exponential backoff with jitter to client retries allows servers to recover when failures are caused by resource overload. Jitter avoids alignment of requests into spikes, and backoff diminishes load escalation caused by adding retries to normal request load. Finally, it's important to configure a maximum number of retries or elapsed time to avoid creating backlogs that produce metastable failures.

**Level of risk exposed if this best practice is not established:** High

### **Implementation guidance**

Control and limit retry calls. Use exponential backoff to retry after progressively longer intervals. Introduce jitter to randomize retry intervals and limit the maximum number of retries.

Some AWS SDKs implement retries and exponential backoff by default. Use these built-in AWS implementations where applicable in your workload. Implement similar logic in your workload when calling services that are idempotent and where retries improve your client availability. Decide what the timeouts are and when to stop retrying based on your use case. Build and exercise testing scenarios for those retry use cases.

## Implementation steps

- Determine the optimal layer in your application stack to implement retries for the services your application relies on.
- Be aware of existing SDKs that implement proven retry strategies with exponential backoff and jitter for your language of choice, and favor these over writing your own retry implementations.
- Verify that [services are idempotent](#) before implementing retries. Once retries are implemented, be sure they are both tested and regularly exercised in production.
- When calling AWS service APIs, use the [AWS SDKs](#) and [AWS CLI](#) and understand the retry configuration options. Determine if the defaults work for your use case, test, and adjust as needed.

## Resources

### Related best practices:

- [REL04-BP04 Make all responses idempotent](#)
- [REL05-BP02 Throttle requests](#)
- [REL05-BP04 Fail fast and limit queues](#)
- [REL05-BP05 Set client timeouts](#)
- [REL11-BP01 Monitor all components of the workload to detect failures](#)

### Related documents:

- [Error Retries and Exponential Backoff in AWS](#)
- [The Amazon Builders' Library: Timeouts, retries, and backoff with jitter](#)
- [Exponential Backoff and Jitter](#)
- [Making retries safe with idempotent APIs](#)

**Related examples:**

- [Spring Retry](#)
- [Resilience4j Retry](#)

**Related videos:**

- [Retry, backoff, and jitter: AWS re:Invent 2019: Introducing The Amazon Builders' Library \(DOP328\)](#)

**Related tools:**

- [AWS SDKs and Tools: Retry behavior](#)
- [AWS Command Line Interface: AWS CLI retries](#)

## REL05-BP04 Fail fast and limit queues

When a service is unable to respond successfully to a request, fail fast. This allows resources associated with a request to be released, and permits a service to recover if it's running out of resources. Failing fast is a well-established software design pattern that can be leveraged to build highly reliable workloads in the cloud. Queuing is also a well-established enterprise integration pattern that can smooth load and allow clients to release resources when asynchronous processing can be tolerated. When a service is able to respond successfully under normal conditions but fails when the rate of requests is too high, use a queue to buffer requests. However, do not allow a buildup of long queue backlogs that can result in processing stale requests that a client has already given up on.

**Desired outcome:** When systems experience resource contention, timeouts, exceptions, or grey failures that make service level objectives unachievable, fail fast strategies allow for faster system recovery. Systems that must absorb traffic spikes and can accommodate asynchronous processing can improve reliability by allowing clients to quickly release requests by using queues to buffer requests to backend services. When buffering requests to queues, queue management strategies are implemented to avoid insurmountable backlogs.

**Common anti-patterns:**

- Implementing message queues but not configuring dead letter queues (DLQ) or alarms on DLQ volumes to detect when a system is in failure.
- Not measuring the age of messages in a queue, a measurement of latency to understand when queue consumers are falling behind or erroring out causing retrying.
- Not clearing backlogged messages from a queue, when there is no value in processing these messages if the business need no longer exists.
- Configuring first in first out (FIFO) queues when last in first out (LIFO) queues would better serve client needs, for example when strict ordering is not required and backlog processing is delaying all new and time sensitive requests resulting in all clients experiencing breached service levels.
- Exposing internal queues to clients instead of exposing APIs that manage work intake and place requests into internal queues.
- Combining too many work request types into a single queue which can exacerbate backlog conditions by spreading resource demand across request types.
- Processing complex and simple requests in the same queue, despite needing different monitoring, timeouts and resource allocations.
- Not validating inputs or using assertions to implement fail fast mechanisms in software that bubble up exceptions to higher level components that can handle errors gracefully.
- Not removing faulty resources from request routing, especially when failures are grey emitting both successes and failures due to crashing and restarting, intermittent dependency failure, reduced capacity, or network packet loss.

**Benefits of establishing this best practice:** Systems that fail fast are easier to debug and fix, and often expose issues in coding and configuration before releases are published into production. Systems that incorporate effective queueing strategies provide greater resilience and reliability to traffic spikes and intermittent system fault conditions.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

Fail fast strategies can be coded into software solutions as well as configured into infrastructure. In addition to failing fast, queues are a straightforward yet powerful architectural technique to decouple system components smooth load. [Amazon CloudWatch](#) provides capabilities to monitor for and alarm on failures. Once a system is known to be failing, mitigation strategies can be invoked, including failing away from impaired resources. When systems implement queues with



[Amazon SQS](#) and other queue technologies to smooth load, they must consider how to manage queue backlogs, as well as message consumption failures.

## Implementation steps

- Implement programmatic assertions or specific metrics in your software and use them to explicitly alert on system issues. Amazon CloudWatch helps you create metrics and alarms based on application log pattern and SDK instrumentation.
- Use CloudWatch metrics and alarms to fail away from impaired resources that are adding latency to processing or repeatedly failing to process requests.
- Use asynchronous processing by designing APIs to accept requests and append requests to internal queues using Amazon SQS and then respond to the message-producing client with a success message so the client can release resources and move on with other work while backend queue consumers process requests.
- Measure and monitor for queue processing latency by producing a CloudWatch metric each time you take a message off a queue by comparing now to message timestamp.
- When failures prevent successful message processing or traffic spikes in volumes that cannot be processed within service level agreements, sideline older or excess traffic to a spillover queue. This allows priority processing of new work, and older work when capacity is available. This technique is an approximation of LIFO processing and allows normal system processing for all new work.
- Use dead letter or redrive queues to move messages that can't be processed out of the backlog into a location that can be researched and resolved later
- Either retry or, when tolerable, drop old messages by comparing now to the message timestamp and discarding messages that are no longer relevant to the requesting client.

## Resources

### Related best practices:

- [REL04-BP02 Implement loosely coupled dependencies](#)
- [REL05-BP02 Throttle requests](#)
- [REL05-BP03 Control and limit retry calls](#)
- [REL06-BP02 Define and calculate metrics \(Aggregation\)](#)
- [REL06-BP07 Monitor end-to-end tracing of requests through your system](#)

**Related documents:**

- [Avoiding insurmountable queue backlogs](#)
- [Fail Fast](#)
- [How can I prevent an increasing backlog of messages in my Amazon SQS queue?](#)
- [Elastic Load Balancing: Zonal Shift](#)
- [Amazon Route 53 Application Recovery Controller: Routing control for traffic failover](#)

**Related examples:**

- [Enterprise Integration Patterns: Dead Letter Channel](#)

**Related videos:**

- [AWS re:Invent 2022 - Operating highly available Multi-AZ applications](#)

**Related tools:**

- [Amazon SQS](#)
- [Amazon MQ](#)
- [AWS IoT Core](#)
- [Amazon CloudWatch](#)

## REL05-BP05 Set client timeouts

Set timeouts appropriately on connections and requests, verify them systematically, and do not rely on default values as they are not aware of workload specifics.

**Desired outcome:** Client timeouts should consider the cost to the client, server, and workload associated with waiting for requests that take abnormal amounts of time to complete. Since it is not possible to know the exact cause of any timeout, clients must use knowledge of services to develop expectations of probable causes and appropriate timeouts

Client connections time out based on configured values. After encountering a timeout, clients make decisions to back off and retry or open a [circuit breaker](#). These patterns avoid issuing requests that may exacerbate an underlying error condition.

## Common anti-patterns:

- Not being aware of system timeouts or default timeouts.
- Not being aware of normal request completion timing.
- Not being aware of possible causes for requests to take abnormally long to complete, or the costs to client, service, or workload performance associated with waiting on these completions.
- Not being aware of the probability of impaired network causing a request to fail only once timeout is reached, and the costs to client and workload performance for not adopting a shorter timeout.
- Not testing timeout scenarios both for connections and requests.
- Setting timeouts too high, which can result in long wait times and increase resource utilization.
- Setting timeouts too low, resulting in artificial failures.
- Overlooking patterns to deal with timeout errors for remote calls like circuit breakers and retries.
- Not considering monitoring for service call error rates, service level objectives for latency, and latency outliers. These metrics can provide insight to aggressive or permissive timeouts

**Benefits of establishing this best practice:** Remote call timeouts are configured and systems are designed to handle timeouts gracefully so that resources are conserved when remote calls respond abnormally slow and timeout errors are handled gracefully by service clients.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

Set both a connection timeout and a request timeout on any service dependency call and generally on any call across processes. Many frameworks offer built-in timeout capabilities, but be careful, as some have default values that are infinite or higher than acceptable for your service goals. A value that is too high reduces the usefulness of the timeout because resources continue to be consumed while the client waits for the timeout to occur. A value that is too low can generate increased traffic on the backend and increased latency because too many requests are retried. In some cases, this can lead to complete outages because all requests are being retried.

Consider the following when determining timeout strategies:

- Requests may take longer than normal to process because of their content, impairments in a target service, or a networking partition failure.

- Requests with abnormally expensive content could consume unnecessary server and client resources. In this case, timing out these requests and not retrying can preserve resources. Services should also protect themselves from abnormally expensive content with throttles and server-side timeouts.
- Requests that take abnormally long due to a service impairment can be timed out and retried. Consideration should be given to service costs for the request and retry, but if the cause is a localized impairment, a retry is not likely to be expensive and will reduce client resource consumption. The timeout may also release server resources depending on the nature of the impairment.
- Requests that take a long time to complete because the request or response has failed to be delivered by the network can be timed out and retried. Because the request or response was not delivered, failure would have been the outcome regardless of the length of timeout. Timing out in this case will not release server resources, but it will release client resources and improve workload performance.

Take advantage of well-established design patterns like retries and circuit breakers to handle timeouts gracefully and support fail-fast approaches. [AWS SDKs](#) and [AWS CLI](#) allow for configuration of both connection and request timeouts and for retries with exponential backoff and jitter. [AWS Lambda](#) functions support configuration of timeouts, and with [AWS Step Functions](#), you can build low code circuit breakers that take advantage of pre-built integrations with AWS services and SDKs. [AWS App Mesh](#) Envoy provides timeout and circuit breaker capabilities.

## Implementation steps

- Configure timeouts on remote service calls and take advantage of built-in language timeout features or open source timeout libraries.
- When your workload makes calls with an AWS SDK, review the documentation for language specific timeout configuration.
  - [Python](#)
  - [PHP](#)
  - [.NET](#)
  - [Ruby](#)
  - [Java](#)
  - [Go](#)
  - [Node.js](#)

- [C++](#)
- When using AWS SDKs or AWS CLI commands in your workload, configure default timeout values by setting the AWS [configuration defaults](#) for `connectTimeoutInMillis` and `tlsNegotiationTimeoutInMillis`.
- Apply [command line options](#) `cli-connect-timeout` and `cli-read-timeout` to control one-off AWS CLI commands to AWS services.
- Monitor remote service calls for timeouts, and set alarms on persistent errors so that you can proactively handle error scenarios.
- Implement [CloudWatch Metrics](#) and [CloudWatch anomaly detection](#) on call error rates, service level objectives for latency, and latency outliers to provide insight into managing overly aggressive or permissive timeouts.
- Configure timeouts on [Lambda functions](#).
- API Gateway clients must implement their own retries when handling timeouts. API Gateway supports a [50 millisecond to 29 second integration timeout](#) for downstream integrations and does not retry when integration requests timeout.
- Implement the [circuit breaker](#) pattern to avoid making remote calls when they are timing out. Open the circuit to avoid failing calls and close the circuit when calls are responding normally.
- For container based workloads, review [App Mesh Envoy](#) features to leverage built in timeouts and circuit breakers.
- Use AWS Step Functions to build low code circuit breakers for remote service calls, especially where calling AWS native SDKs and supported Step Functions integrations to simplify your workload.

## Resources

### Related best practices:

- [REL05-BP03 Control and limit retry calls](#)
- [REL05-BP04 Fail fast and limit queues](#)
- [REL06-BP07 Monitor end-to-end tracing of requests through your system](#)

### Related documents:

- [AWS SDK: Retries and Timeouts](#)

- [The Amazon Builders' Library: Timeouts, retries, and backoff with jitter](#)
- [Amazon API Gateway quotas and important notes](#)
- [AWS Command Line Interface: Command line options](#)
- [AWS SDK for Java 2.x: Configure API Timeouts](#)
- [AWS Botocore using the config object and Config Reference](#)
- [AWS SDK for .NET: Retries and Timeouts](#)
- [AWS Lambda: Configuring Lambda function options](#)

### Related examples:

- [Using the circuit breaker pattern with AWS Step Functions and Amazon DynamoDB](#)
- [Martin Fowler: CircuitBreaker](#)

### Related tools:

- [AWS SDKs](#)
- [AWS Lambda](#)
- [Amazon SQS](#)
- [AWS Step Functions](#)
- [AWS Command Line Interface](#)

## REL05-BP06 Make systems stateless where possible

Systems should either not require state, or should offload state such that between different client requests, there is no dependence on locally stored data on disk and in memory. This allows servers to be replaced at will without causing an availability impact.

When users or services interact with an application, they often perform a series of interactions that form a session. A session is unique data for users that persists between requests while they use the application. A stateless application is an application that does not need knowledge of previous interactions and does not store session information.

Once designed to be stateless, you can then use serverless compute services, such as AWS Lambda or AWS Fargate.

In addition to server replacement, another benefit of stateless applications is that they can scale horizontally because any of the available compute resources (such as EC2 instances and AWS Lambda functions) can service any request.

**Benefits of establishing this best practice:** Systems that are designed to be stateless are more adaptable to horizontal scaling, making it possible to add or remove capacity based on fluctuating traffic and demand. They are also inherently resilient to failures and provide flexibility and agility in application development.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

Make your applications stateless. Stateless applications allow horizontal scaling and are tolerant to the failure of an individual node. Analyze and understand the components of your application that maintain state within the architecture. This helps you assess the potential impact of transitioning to a stateless design. A stateless architecture decouples user data and offloads the session data. This provides the flexibility to scale each component independently to meet varying workload demands and optimize resource utilization.

### Implementation steps

- Identify and understand the stateful components in your application.
- Decouple data by separating and managing user data from the core application logic.
  - [Amazon Cognito](#) can decouple user data from application code by using features, such as [identity pools](#), [user pools](#), and [Amazon Cognito Sync](#).
  - You can use [AWS Secrets Manager](#) decouple user data by storing secrets in a secure, centralized location. This means that the application code doesn't need to store secrets, which makes it more secure.
  - Consider using [Amazon S3](#) to store large, unstructured data, such as images and documents. Your application can retrieve this data when required, eliminating the need to store it in memory.
  - Use [Amazon DynamoDB](#) to store information such as user profiles. Your application can query this data in near-real time.
- Offload session data to a database, cache, or external files.
  - [Amazon ElastiCache](#), Amazon DynamoDB, [Amazon Elastic File System](#) (Amazon EFS), and [Amazon MemoryDB](#) are examples of AWS services that you can use to offload session data.

- Design a stateless architecture after you identify which state and user data need to be persisted with your storage solution of choice.

## Resources

### Related best practices:

- [REL11-BP03 Automate healing on all layers](#)

### Related documents:

- [The Amazon Builders' Library: Avoiding fallback in distributed systems](#)
- [The Amazon Builders' Library: Avoiding insurmountable queue backlogs](#)
- [The Amazon Builders' Library: Caching challenges and strategies](#)
- [Best Practices for Stateless Web Tier on AWS](#)

## REL05-BP07 Implement emergency levers

Emergency levers are rapid processes that can mitigate availability impact on your workload.

Emergency levers work by disabling, throttling, or changing the behavior of components or dependencies using known and tested mechanisms. This can alleviate workload impairments caused by resource exhaustion due to unexpected increases in demand and reduce the impact of failures in non-critical components within your workload.

**Desired outcome:** By implementing emergency levers, you can establish known-good processes to maintain the availability of critical components in your workload. The workload should degrade gracefully and continue to perform its business-critical functions during the activation of an emergency lever. For more detail on graceful degradation, see [REL05-BP01 Implement graceful degradation to transform applicable hard dependencies into soft dependencies](#).

### Common anti-patterns:

- Failure of non-critical dependencies impacts the availability of your core workload.
- Not testing or verifying critical component behavior during non-critical component impairment.
- No clear and deterministic criteria defined for activation or deactivation of an emergency lever.



**Benefits of establishing this best practice:** Implementing emergency levers can improve the availability of the critical components in your workload by providing your resolvers with established processes to respond to unexpected spikes in demand or failures of non-critical dependencies.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

- Identify critical components in your workload.
- Design and architect the critical components in your workload to withstand failure of non-critical components.
- Conduct testing to validate the behavior of your critical components during the failure of non-critical components.
- Define and monitor relevant metrics or triggers to initiate emergency lever procedures.
- Define the procedures (manual or automated) that comprise the emergency lever.

## Implementation steps

- Identify business-critical components in your workload.
  - Each technical component in your workload should be mapped to its relevant business function and ranked as critical or non-critical. For examples of critical and non-critical functionality at Amazon, see [Any Day Can Be Prime Day: How Amazon.com Search Uses Chaos Engineering to Handle Over 84K Requests Per Second](#).
  - This is both a technical and business decision, and varies by organization and workload.
- Design and architect the critical components in your workload to withstand failure of non-critical components.
  - During dependency analysis, consider all potential failure modes, and verify that your emergency lever mechanisms deliver the critical functionality to downstream components.
- Conduct testing to validate the behavior of your critical components during activation of your emergency levers.
  - Avoid bimodal behavior. For more detail, see [REL11-BP05 Use static stability to prevent bimodal behavior](#).
- Define, monitor, and alert on relevant metrics to initiate the emergency lever procedure.

- Finding the right metrics to monitor depends on your workload. Some example metrics are latency or the number of failed request to a dependency.
- Define the procedures, manual or automated, that comprise the emergency lever.
  - This may include mechanisms such as [load shedding](#), [throttling requests](#), or implementing [graceful degradation](#).

## Resources

### Related best practices:

- [REL05-BP01 Implement graceful degradation to transform applicable hard dependencies into soft dependencies](#)
- [REL05-BP02 Throttle requests](#)
- [REL11-BP05 Use static stability to prevent bimodal behavior](#)

### Related documents:

- [Automating safe, hands-off deployments](#)
- [Any Day Can Be Prime Day: How Amazon.com Search Uses Chaos Engineering to Handle Over 84K Requests Per Second](#)

### Related videos:

- [AWS re:Invent 2020: Reliability, consistency, and confidence through immutability](#)

# Change management

Changes to your workload or its environment must be anticipated and accommodated to achieve reliable operation of the workload. Changes include those imposed on your workload such as spikes in demand, as well as those from within such as feature deployments and security patches.

The following sections explain the best practices for change management.

## Topics

- [Monitor workload resources](#)
- [Design your workload to adapt to changes in demand](#)
- [Implement change](#)

## Monitor workload resources

Logs and metrics are powerful tools to gain insight into the health of your workload. You can configure your workload to monitor logs and metrics and send notifications when thresholds are crossed or significant events occur. Monitoring allows your workload to recognize when low-performance thresholds are crossed or failures occur, so it can recover automatically in response.

Monitoring is critical to ensure that you are meeting your availability requirements. Your monitoring needs to effectively detect failures. The worst failure mode is the “silent” failure, where the functionality is no longer working, but there is no way to detect it except indirectly. Your customers know before you do. Alerting when you have problems is one of the primary reasons you monitor. Your alerting should be decoupled from your systems as much as possible. If your service interruption removes your ability to alert, you will have a longer period of interruption.

At AWS, we instrument our applications at multiple levels. We record latency, error rates, and availability for each request, for all dependencies, and for key operations within the process. We record metrics of successful operation as well. This allows us to see impending problems before they happen. We don't just consider average latency. We focus even more closely on latency outliers, like the 99.9th and 99.99th percentile. This is because if one request out of 1,000 or 10,000 is slow, that is still a poor experience. Also, although your average may be acceptable, if one in 100 of your requests causes extreme latency, it will eventually become a problem as your traffic grows.

Monitoring at AWS consists of four distinct phases:

1. Generation — Monitor all components for the workload
2. Aggregation — Define and calculate metrics
3. Real-time processing and alarming — Send notifications and automate responses
4. Storage and Analytics

### Best practices

- [REL06-BP01 Monitor all components for the workload \(Generation\)](#)
- [REL06-BP02 Define and calculate metrics \(Aggregation\)](#)
- [REL06-BP03 Send notifications \(Real-time processing and alarming\)](#)
- [REL06-BP04 Automate responses \(Real-time processing and alarming\)](#)
- [REL06-BP05 Analyze logs](#)
- [REL06-BP06 Conduct reviews regularly](#)
- [REL06-BP07 Monitor end-to-end tracing of requests through your system](#)

## REL06-BP01 Monitor all components for the workload (Generation)

Monitor the components of the workload with Amazon CloudWatch or third-party tools. Monitor AWS services with AWS Health Dashboard.

All components of your workload should be monitored, including the front-end, business logic, and storage tiers. Define key metrics, describe how to extract them from logs (if necessary), and set thresholds for invoking corresponding alarm events. Ensure metrics are relevant to the key performance indicators (KPIs) of your workload, and use metrics and logs to identify early warning signs of service degradation. For example, a metric related to business outcomes such as the number of orders successfully processed per minute, can indicate workload issues faster than technical metric, such as CPU Utilization. Use AWS Health Dashboard for a personalized view into the performance and availability of the AWS services underlying your AWS resources.

Monitoring in the cloud offers new opportunities. Most cloud providers have developed customizable hooks and can deliver insights to help you monitor multiple layers of your workload. AWS services such as Amazon CloudWatch apply statistical and machine learning algorithms to continually analyze metrics of systems and applications, determine normal baselines, and surface anomalies with minimal user intervention. Anomaly detection algorithms account for the seasonality and trend changes of metrics.

AWS makes an abundance of monitoring and log information available for consumption that can be used to define workload-specific metrics, change-in-demand processes, and adopt machine learning techniques regardless of ML expertise.

In addition, monitor all of your external endpoints to ensure that they are independent of your base implementation. This active monitoring can be done with synthetic transactions (sometimes referred to as *user canaries*, but not to be confused with canary deployments) which periodically run a number of common tasks matching actions performed by clients of the workload. Keep these tasks short in duration and be sure not to overload your workload during testing. Amazon CloudWatch Synthetics allows you to [create synthetic canaries](#) to monitor your endpoints and APIs. You can also combine the synthetic canary client nodes with AWS X-Ray console to pinpoint which synthetic canaries are experiencing issues with errors, faults, or throttling rates for the selected time frame.

### **Desired Outcome:**

Collect and use critical metrics from all components of the workload to ensure workload reliability and optimal user experience. Detecting that a workload is not achieving business outcomes allows you to quickly declare a disaster and recover from an incident.

### **Common anti-patterns:**

- Only monitoring external interfaces to your workload.
- Not generating any workload-specific metrics and only relying on metrics provided to you by the AWS services your workload uses.
- Only using technical metrics in your workload and not monitoring any metrics related to non-technical KPIs the workload contributes to.
- Relying on production traffic and simple health checks to monitor and evaluate workload state.

**Benefits of establishing this best practice:** Monitoring at all tiers in your workload allows you to more rapidly anticipate and resolve problems in the components that comprise the workload.

**Level of risk exposed if this best practice is not established:** High

## **Implementation guidance**

1. **Turn on logging where available.** Monitoring data should be obtained from all components of the workloads. Turn on additional logging, such as S3 Access Logs, and permit your workload to log workload specific data. Collect metrics for CPU, network I/O, and disk I/O averages from

- services such as Amazon ECS, Amazon EKS, Amazon EC2, Elastic Load Balancing, AWS Auto Scaling, and Amazon EMR. See [AWS Services That Publish CloudWatch Metrics](#) for a list of AWS services that publish metrics to CloudWatch.
- 2. Review all default metrics and explore any data collection gaps.** Every service generates default metrics. Collecting default metrics allows you to better understand the dependencies between workload components, and how component reliability and performance affect the workload. You can also create and [publish your own metrics](#) to CloudWatch using the AWS CLI or an API.
  - 3. Evaluate all the metrics to decide which ones to alert on for each AWS service in your workload.** You may choose to select a subset of metrics that have a major impact on workload reliability. Focusing on critical metrics and threshold allows you to refine the number of [alerts](#) and can help minimize false-positives.
  - 4. Define alerts and the recovery process for your workload after the alert is invoked.** Defining alerts allows you to quickly notify, escalate, and follow steps necessary to recover from an incident and meet your prescribed Recovery Time Objective (RTO). You can use [Amazon CloudWatch Alarms](#) to invoke automated workflows and initiate recovery procedures based on defined thresholds.
  - 5. Explore use of synthetic transactions to collect relevant data about workloads state.** Synthetic monitoring follows the same routes and perform the same actions as a customer, which makes it possible for you to continually verify your customer experience even when you don't have any customer traffic on your workloads. By using [synthetic transactions](#), you can discover issues before your customers do.

## Resources

### Related best practices:

- [REL11-BP03 Automate healing on all layers](#)

### Related documents:

- [Getting started with your AWS Health Dashboard – Your account health](#)
- [AWS Services That Publish CloudWatch Metrics](#)
- [Access Logs for Your Network Load Balancer](#)
- [Access logs for your application load balancer](#)

- [Accessing Amazon CloudWatch Logs for AWS Lambda](#)
- [Amazon S3 Server Access Logging](#)
- [Enable Access Logs for Your Classic Load Balancer](#)
- [Exporting log data to Amazon S3](#)
- [Install the CloudWatch agent on an Amazon EC2 instance](#)
- [Publishing Custom Metrics](#)
- [Using Amazon CloudWatch Dashboards](#)
- [Using Amazon CloudWatch Metrics](#)
- [Using Canaries \(Amazon CloudWatch Synthetics\)](#)
- [What are Amazon CloudWatch Logs?](#)

#### **User guides:**

- [Creating a trail](#)
- [Monitoring memory and disk metrics for Amazon EC2 Linux instances](#)
- [Using CloudWatch Logs with container instances](#)
- [VPC Flow Logs](#)
- [What is Amazon DevOps Guru?](#)
- [What is AWS X-Ray?](#)

#### **Related blogs:**

- [Debugging with Amazon CloudWatch Synthetics and AWS X-Ray](#)

#### **Related examples and workshops:**

- [AWS Well-Architected Labs: Operational Excellence - Dependency Monitoring](#)
- [The Amazon Builders' Library: Instrumenting distributed systems for operational visibility](#)
- [Observability workshop](#)

## **REL06-BP02 Define and calculate metrics (Aggregation)**

Store log data and apply filters where necessary to calculate metrics, such as counts of a specific log event, or latency calculated from log event timestamps.

Amazon CloudWatch and Amazon S3 serve as the primary aggregation and storage layers. For some services, such as AWS Auto Scaling and Elastic Load Balancing, default metrics are provided by default for CPU load or average request latency across a cluster or instance. For streaming services, such as VPC Flow Logs and AWS CloudTrail, event data is forwarded to CloudWatch Logs and you need to define and apply metrics filters to extract metrics from the event data. This gives you time series data, which can serve as inputs to CloudWatch alarms that you define to invoke alerts.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

- Define and calculate metrics (Aggregation). Store log data and apply filters where necessary to calculate metrics, such as counts of a specific log event, or latency calculated from log event timestamps
  - Metric filters define the terms and patterns to look for in log data as it is sent to CloudWatch Logs. CloudWatch Logs uses these metric filters to turn log data into numerical CloudWatch metrics that you can graph or set an alarm on.
    - [Searching and Filtering Log Data](#)
  - Use a trusted third party to aggregate logs.
    - Follow the instructions of the third party. Most third-party products integrate with CloudWatch and Amazon S3.
  - Some AWS services can publish logs directly to Amazon S3. If your main requirement for logs is storage in Amazon S3, you can easily have the service producing the logs send them directly to Amazon S3 without setting up additional infrastructure.
    - [Sending Logs Directly to Amazon S3](#)

## Resources

### Related documents:

- [Amazon CloudWatch Logs Insights Sample Queries](#)
- [Debugging with Amazon CloudWatch Synthetics and AWS X-Ray](#)
- [One Observability Workshop](#)
- [Searching and Filtering Log Data](#)
- [Sending Logs Directly to Amazon S3](#)



- [The Amazon Builders' Library: Instrumenting distributed systems for operational visibility](#)

## REL06-BP03 Send notifications (Real-time processing and alarming)

When organizations detect potential issues, they send real-time notifications and alerts to the appropriate personnel and systems in order to respond quickly and effectively to these issues.

**Desired outcome:** Rapid responses to operational events are possible through configuration of relevant alarms based on service and application metrics. When alarm thresholds are breached, the appropriate personnel and systems are notified so they can address underlying issues.

### Common anti-patterns:

- Configuring alarms with an excessively high threshold, resulting in the failure to send vital notifications.
- Configuring alarms with a threshold that is too low, resulting in inaction on important alerts due to the noise of excessive notifications.
- Not updating alarms and their threshold when usage changes.
- For alarms best addressed through automated actions, sending the notification to personnel instead of generating the automated action results in excessive notifications being sent.

**Benefits of establishing this best practice:** Sending real-time notifications and alerts to the appropriate personnel and systems allows for early detection of issues and rapid responses to operational incidents.

**Level of risk exposed if this best practice is not established:** High

### Implementation guidance

Workloads should be equipped with real-time processing and alarming to improve the detectability of issues that could impact the availability of the application and serve as triggers for automated response. Organizations can perform real-time processing and alarming by creating alerts with defined metrics in order to receive notifications whenever significant events occur or a metric exceeds a threshold.

[Amazon CloudWatch](#) allows you to create [metric](#) and composite alarms using CloudWatch alarms based on static threshold, anomaly detection, and other criteria. For more detail on the

types of alarms you can configure using CloudWatch, see the [alarms section of the CloudWatch documentation](#).

You can construct customized views of metrics and alerts of your AWS resources for your teams using [CloudWatch dashboards](#). The customizable home pages in the CloudWatch console allow you to monitor your resources in a single view across multiple Regions.

Alarms can perform one or more actions, like sending a notification to an [Amazon SNS topic](#), performing an [Amazon EC2](#) action or an [Amazon EC2 Auto Scaling](#) action, or [creating an OpsItem](#) or [incident](#) in AWS Systems Manager.

Amazon CloudWatch uses [Amazon SNS](#) to send notifications when the alarm changes state, providing message delivery from the publishers (producers) to the subscribers (consumers). For more detail on setting up Amazon SNS notifications, see [Configuring Amazon SNS](#).

CloudWatch sends [EventBridge events](#) whenever a CloudWatch alarm is created, updated, deleted, or its state changes. You can use EventBridge with these events to create rules that perform actions, such as notifying you whenever the state of an alarm changes or automatically triggering events in your account using [Systems Manager automation](#).

### **When should you use EventBridge or Amazon SNS?**

Both EventBridge and Amazon SNS can be used to develop event-driven applications, and your choice will depend on your specific needs.

Amazon EventBridge is recommended when you want to build an application that reacts to events from your own applications, SaaS applications, and AWS services. EventBridge is the only event-based service that integrates directly with third-party SaaS partners. EventBridge also automatically ingests events from over 200 AWS services without requiring developers to create any resources in their account.

EventBridge uses a defined JSON-based structure for events, and helps you create rules that are applied across the entire event body to select events to forward to a [target](#). EventBridge currently supports over 20 AWS services as targets, including [AWS Lambda](#), [Amazon SQS](#), Amazon SNS, [Amazon Kinesis Data Streams](#), and [Amazon Data Firehose](#).

Amazon SNS is recommended for applications that need high fan out (thousands or millions of endpoints). A common pattern we see is that customers use Amazon SNS as a target for their rule to filter the events that they need, and fan out to multiple endpoints.

Messages are unstructured and can be in any format. Amazon SNS supports forwarding messages to six different types of targets, including Lambda, Amazon SQS, HTTP/S endpoints, SMS, mobile push, and email. Amazon SNS [typical latency is under 30 milliseconds](#). A wide range of AWS services send Amazon SNS messages by configuring the service to do so (more than 30, including Amazon EC2, [Amazon S3](#), and [Amazon RDS](#)).

## Implementation steps

1. Create an alarm using [Amazon CloudWatch alarms](#).
  - a. A metric alarm monitors a single CloudWatch metric or an expression dependent on CloudWatch metrics. The alarm initiates one or more actions based on the value of the metric or expression in comparison to a threshold over a number of time intervals. The action may consist of sending a notification to an [Amazon SNS topic](#), performing an [Amazon EC2](#) action or an [Amazon EC2 Auto Scaling](#) action, or [creating an OpsItem](#) or [incident](#) in AWS Systems Manager.
  - b. A composite alarm consists of a rule expression that considers the alarm conditions of other alarms you've created. The composite alarm only enters alarm state if all rule conditions are met. The alarms specified in the rule expression of a composite alarm can include metric alarms and additional composite alarms. Composite alarms can send Amazon SNS notifications when their state changes and can create Systems Manager [OpsItems](#) or [incidents](#) when they enter the alarm state, but they cannot perform Amazon EC2 or Auto Scaling actions.
2. Set up [Amazon SNS notifications](#). When creating a CloudWatch alarm, you can include an Amazon SNS topic to send a notification when the alarm changes state.
3. [Create rules in EventBridge](#) that matches specified CloudWatch alarms. Each rule supports multiple targets, including Lambda functions. For example, you can define an alarm that initiates when available disk space is running low, which triggers a Lambda function through an EventBridge rule, to clean up the space. For more detail on EventBridge targets, see [EventBridge targets](#).

## Resources

### Related Well-Architected best practices:

- [REL06-BP01 Monitor all components for the workload \(Generation\)](#)
- [REL06-BP02 Define and calculate metrics \(Aggregation\)](#)

- [REL12-BP01 Use playbooks to investigate failures](#)

**Related documents:**

- [Amazon CloudWatch](#)
- [CloudWatch Logs insights](#)
- [Using Amazon CloudWatch alarms](#)
- [Using Amazon CloudWatch dashboards](#)
- [Using Amazon CloudWatch metrics](#)
- [Setting up Amazon SNS notifications](#)
- [CloudWatch anomaly detection](#)
- [CloudWatch Logs data protection](#)
- [Amazon EventBridge](#)
- [Amazon Simple Notification Service](#)

**Related videos:**

- [reinvent 2022 observability videos](#)
- [AWS re:Invent 2022 - Observability best practices at Amazon](#)

**Related examples:**

- [One Observability Workshop](#)
- [Amazon EventBridge to AWS Lambda with feedback control by Amazon CloudWatch Alarms](#)

## REL06-BP04 Automate responses (Real-time processing and alarming)

Use automation to take action when an event is detected, for example, to replace failed components.

Automated real-time processing of alarms is implemented so that systems can take quick corrective action and attempt to prevent failures or degraded service when alarms are triggered. Automated responses to alarms could include the replacement of failing components, the adjustment of compute capacity, the redirection of traffic to healthy hosts, availability zones, or other regions, and the notification of operators.

**Desired outcome:** Real-time alarms are identified, and automated processing of alarms is set up to invoke the appropriate actions taken to maintain service level objectives and service-level agreements (SLAs). Automation can range from self-healing activities of single components to full-site failover.

**Common anti-patterns:**

- Not having a clear inventory or catalog of key real-time alarms.
- No automated responses on critical alarms (for example, when compute is nearing exhaustion, autoscaling occurs).
- Contradictory alarm response actions.
- No standard operating procedures (SOPs) for operators to follow when they receive alert notifications.
- Not monitoring configuration changes, as undetected configuration changes can cause downtime for workloads.
- Not having a strategy to undo unintended configuration changes.

**Benefits of establishing this best practice:** Automating alarm processing can improve system resiliency. The system takes corrective actions automatically, reducing manual activities that allow for human, error-prone interventions. Workload operates meet availability goals, and reduces service disruption.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

To effectively manage alerts and automate their response, categorize alerts based on their criticality and impact, document response procedures, and plan responses before ranking tasks.

Identify tasks requiring specific actions (often detailed in runbooks), and examine all runbooks and playbooks to determine which tasks can be automated. If actions can be defined, often they can be automated. If actions cannot be automated, document manual steps in an SOP and train operators on them. Continually challenge manual processes for automation opportunities where you can establish and maintain a plan to automate alert responses.

## Implementation steps

1. **Create an inventory of alarms:** To obtain a list of all alarms, you can use the [AWS CLI](#) using the [Amazon CloudWatch](#) command [describe-alarms](#). Depending upon how many alarms you have set up, you might have to use pagination to retrieve a subset of alarms for each call, or alternatively you can use the AWS SDK to obtain the alarms [using an API call](#).
2. **Document all alarm actions:** Update a runbook with all alarms and their actions, irrespective if they are manual or automated. [AWS Systems Manager](#) provides predefined runbooks. For more information about runbooks, see [Working with runbooks](#). For detail on how to view runbook content, see [View runbook content](#).
3. **Set up and manage alarm actions:** For any of the alarms that require an action, specify the [automated action using the CloudWatch SDK](#). For example, you can change the state of your Amazon EC2 instances automatically based on a CloudWatch alarm by creating and enabling actions on an alarm or disabling actions on an alarm.

You can also use [Amazon EventBridge](#) to respond automatically to system events, such as application availability issues or resource changes. You can create rules to indicate which events you're interested in, and the actions to take when an event matches a rule. The actions that can be automatically initiated include invoking an [AWS Lambda](#) function, invoking [Amazon EC2](#) Run Command, relaying the event to [Amazon Kinesis Data Streams](#), and seeing [Automate Amazon EC2 using EventBridge](#).

4. **Standard Operating Procedures (SOPs):** Based on your application components, [AWS Resilience Hub](#) recommends multiple [SOP templates](#). You can use these SOPs to document all the processes an operator should follow in case an alert is raised. You can also [construct a SOP](#) based on Resilience Hub recommendations, where you need an Resilience Hub application with an associated resiliency policy, as well as a historic resiliency assessment against that application. The recommendations for your SOP are produced by the resiliency assessment.

Resilience Hub works with Systems Manager to automate the steps of your SOPs by providing a number of [SSM documents](#) you can use as the basis for those SOPs. For example, Resilience Hub may recommend an SOP for adding disk space based on an existing SSM automation document.

5. **Perform automated actions using Amazon DevOps Guru:** You can use [Amazon DevOps Guru](#) to automatically monitor application resources for anomalous behavior and deliver targeted recommendations to speed up problem identification and remediation times. With DevOps Guru, you can monitor streams of operational data in near real time from multiple sources including Amazon CloudWatch metrics, [AWS Config](#), [AWS CloudFormation](#), and [AWS X-Ray](#). You can

also use DevOps Guru to automatically create [OpsItems](#) in OpsCenter and send events to [EventBridge](#) for additional automation.

## Resources

### Related best practices:

- [REL06-BP01 Monitor all components for the workload \(Generation\)](#)
- [REL06-BP02 Define and calculate metrics \(Aggregation\)](#)
- [REL06-BP03 Send notifications \(Real-time processing and alarming\)](#)
- [REL08-BP01 Use runbooks for standard activities such as deployment](#)

### Related documents:

- [AWS Systems Manager Automation](#)
- [Creating an EventBridge Rule That Triggers on an Event from an AWS Resource](#)
- [One Observability Workshop](#)
- [The Amazon Builders' Library: Instrumenting distributed systems for operational visibility](#)
- [What is Amazon DevOps Guru?](#)
- [Working with Automation Documents \(Playbooks\)](#)

### Related videos:

- [AWS re:Invent 2022 - Observability best practices at Amazon](#)
- [AWS re:Invent 2020: Automate anything with AWS Systems Manager](#)
- [Introduction to AWS Resilience Hub](#)
- [Create Custom Ticket Systems for Amazon DevOps Guru Notifications](#)
- [Enable Multi-Account Insight Aggregation with Amazon DevOps Guru](#)

### Related examples:

- [Reliability Workshops](#)
- [Amazon CloudWatch and Systems Manager Workshop](#)

## REL06-BP05 Analyze logs

Collect log files and metrics histories and analyze these for broader trends and workload insights.

Amazon CloudWatch Logs Insights supports a [simple yet powerful query language](#) that you can use to analyze log data. Amazon CloudWatch Logs also supports subscriptions that allow data to flow seamlessly to Amazon S3 where you can use or Amazon Athena to query the data. It also supports queries on a large array of formats. See [Supported SerDes and Data Formats](#) in the Amazon Athena User Guide for more information. For analysis of huge log file sets, you can run an Amazon EMR cluster to run petabyte-scale analyses.

There are a number of tools provided by AWS Partners and third parties that allow for aggregation, processing, storage, and analytics. These tools include New Relic, Splunk, Loggly, Logstash, CloudHealth, and Nagios. However, outside generation of system and application logs is unique to each cloud provider, and often unique to each service.

An often-overlooked part of the monitoring process is data management. You need to determine the retention requirements for monitoring data, and then apply lifecycle policies accordingly. Amazon S3 supports lifecycle management at the S3 bucket level. This lifecycle management can be applied differently to different paths in the bucket. Toward the end of the lifecycle, you can transition data to Amazon S3 Glacier for long-term storage, and then expiration after the end of the retention period is reached. The S3 Intelligent-Tiering storage class is designed to optimize costs by automatically moving data to the most cost-effective access tier, without performance impact or operational overhead.

**Level of risk exposed if this best practice is not established:** Medium

### Implementation guidance

- CloudWatch Logs Insights allows you to interactively search and analyze your log data in Amazon CloudWatch Logs.
  - [Analyzing Log Data with CloudWatch Logs Insights](#)
  - [Amazon CloudWatch Logs Insights Sample Queries](#)
- Use Amazon CloudWatch Logs send logs to Amazon S3 where you can use or Amazon Athena to query the data.
  - [How do I analyze my Amazon S3 server access logs using Athena?](#)



- Create an S3 lifecycle policy for your server access logs bucket. Configure the lifecycle policy to periodically remove log files. Doing so reduces the amount of data that Athena analyzes for each query.
- [How Do I Create a Lifecycle Policy for an S3 Bucket?](#)

## Resources

### Related documents:

- [Amazon CloudWatch Logs Insights Sample Queries](#)
- [Analyzing Log Data with CloudWatch Logs Insights](#)
- [Debugging with Amazon CloudWatch Synthetics and AWS X-Ray](#)
- [How Do I Create a Lifecycle Policy for an S3 Bucket?](#)
- [How do I analyze my Amazon S3 server access logs using Athena?](#)
- [One Observability Workshop](#)
- [The Amazon Builders' Library: Instrumenting distributed systems for operational visibility](#)

## REL06-BP06 Conduct reviews regularly

Frequently review how workload monitoring is implemented and update it based on significant events and changes.

Effective monitoring is driven by key business metrics. Ensure these metrics are accommodated in your workload as business priorities change.

Auditing your monitoring helps ensure that you know when an application is meeting its availability goals. Root cause analysis requires the ability to discover what happened when failures occur. AWS provides services that allow you to track the state of your services during an incident:

- **Amazon CloudWatch Logs:** You can store your logs in this service and inspect their contents.
- **Amazon CloudWatch Logs Insights:** Is a fully managed service that allows you to analyze massive logs in seconds. It gives you fast, interactive queries and visualizations.
- **AWS Config:** You can see what AWS infrastructure was in use at different points in time.
- **AWS CloudTrail:** You can see which AWS APIs were invoked at what time and by what principal.

At AWS, we conduct a weekly meeting to [review operational performance](#) and to share learnings between teams. Because there are so many teams in AWS, we created [The Wheel](#) to randomly pick a workload to review. Establishing a regular cadence for operational performance reviews and knowledge sharing enhances your ability to achieve higher performance from your operational teams.

### Common anti-patterns:

- Collecting only default metrics.
- Setting a monitoring strategy and never reviewing it.
- Not discussing monitoring when major changes are deployed.

**Benefits of establishing this best practice:** Regularly reviewing your monitoring allows for the anticipation of potential problems, instead of reacting to notifications when an anticipated problem actually occurs.

**Level of risk exposed if this best practice is not established:** Medium

### Implementation guidance

- Create multiple dashboards for the workload. You must have a top-level dashboard that contains the key business metrics, as well as the technical metrics you have identified to be the most relevant to the projected health of the workload as usage varies. You should also have dashboards for various application tiers and dependencies that can be inspected.
  - [Using Amazon CloudWatch Dashboards](#)
- Schedule and conduct regular reviews of the workload dashboards. Conduct regular inspection of the dashboards. You may have different cadences for the depth at which you inspect.
  - Inspect for trends in the metrics. Compare the metric values to historic values to see if there are trends that may indicate that something that needs investigation. Examples of this include: increasing latency, decreasing primary business function, and increasing failure responses.
  - Inspect for outliers/anomalies in your metrics. Averages or medians can mask outliers and anomalies. Look at the highest and lowest values during the time frame and investigate the causes of extreme scores. As you continue to eliminate these causes, lowering your definition of extreme allows you to continue to improve the consistency of your workload performance.
  - Look for sharp changes in behavior. An immediate change in quantity or direction of a metric may indicate that there has been a change in the application, or external factors that you may need to add additional metrics to track.

## Resources

### Related documents:

- [Amazon CloudWatch Logs Insights Sample Queries](#)
- [Debugging with Amazon CloudWatch Synthetics and AWS X-Ray](#)
- [One Observability Workshop](#)
- [The Amazon Builders' Library: Instrumenting distributed systems for operational visibility](#)
- [Using Amazon CloudWatch Dashboards](#)

## REL06-BP07 Monitor end-to-end tracing of requests through your system

Trace requests as they process through service components so product teams can more easily analyze and debug issues and improve performance.

**Desired outcome:** Workloads with comprehensive tracing across all components are easy to debug, improving [mean time to resolution](#) (MTTR) of errors and latency by simplifying root cause discovery. End-to-end tracing reduces the time it takes to discover impacted components and drill into the detailed root causes of errors or latency.

### Common anti-patterns:

- Tracing is used for some components but not for all. For example, without tracing for AWS Lambda, teams might not clearly understand latency caused by cold starts in a spiky workload.
- Synthetic canaries or real-user monitoring (RUM) are not configured with tracing. Without canaries or RUM, client interaction telemetry is omitted from the trace analysis yielding an incomplete performance profile.
- Hybrid workloads include both cloud native and third party tracing tools, but steps have not been taken elect and fully integrate a single tracing solution. Based on the elected tracing solution, cloud native tracing SDKs should be used to instrument components that are not cloud native or third party tools should be configured to ingest cloud native trace telemetry.

**Benefits of establishing this best practice:** When development teams are alerted to issues, they can see a full picture of system component interactions, including component by component correlation to logging, performance, and failures. Because tracing makes it easy to visually identify

root causes, less time is spent investigating root causes. Teams that understand component interactions in detail make better and faster decisions when resolving issues. Decisions like when to invoke disaster recovery (DR) failover or where to best implement self-healing strategies can be improved by analyzing systems traces, ultimately improving customer satisfaction with your services.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

Teams that operate distributed applications can use tracing tools to establish a correlation identifier, collect traces of requests, and build service maps of connected components. All application components should be included in request traces including service clients, middleware gateways and event buses, compute components, and storage, including key value stores and databases. Include synthetic canaries and real-user monitoring in your end-to-end tracing configuration to measure remote client interactions and latency so that you can accurately evaluate your systems performance against your service level agreements and objectives.

You can use [AWS X-Ray](#) and [Amazon CloudWatch Application Monitoring](#) instrumentation services to provide a complete view of requests as they travel through your application. X-Ray collects application telemetry and allows you to visualize and filter it across payloads, functions, traces, services, APIs, and can be turned on for system components with no-code or low-code. CloudWatch application monitoring includes ServiceLens to integrate your traces with metrics, logs, and alarms. CloudWatch application monitoring also includes synthetics to monitor your endpoints and APIs, as well as real-user monitoring to instrument your web application clients.

## Implementation steps

- Use AWS X-Ray on all supported native services like [Amazon S3, AWS Lambda, and Amazon API Gateway](#). These AWS services enable X-Ray with configuration toggles using infrastructure as code, AWS SDKs, or the AWS Management Console.
- Instrument applications [AWS Distro for Open Telemetry and X-Ray](#) or third-party collection agents.
- Review the [AWS X-Ray Developer Guide](#) for programming language specific implementation. These documentation sections detail how to instrument HTTP requests, SQL queries, and other processes specific to your application programming language.

- Use X-Ray tracing for [Amazon CloudWatch Synthetic Canaries](#) and [Amazon CloudWatch RUM](#) to analyze the request path from your end user client through your downstream AWS infrastructure.
- Configure CloudWatch metrics and alarms based on resource health and canary telemetry so that teams are alerted to issues quickly, and can then deep dive into traces and service maps with ServiceLens.
- Enable X-Ray integration for third party tracing tools like [Datadog](#), [New Relic](#), or [Dynatrace](#) if you are using third party tools for your primary tracing solution.

## Resources

### Related best practices:

- [REL06-BP01 Monitor all components for the workload \(Generation\)](#)
- [REL11-BP01 Monitor all components of the workload to detect failures](#)

### Related documents:

- [What is AWS X-Ray?](#)
- [Amazon CloudWatch: Application Monitoring](#)
- [Debugging with Amazon CloudWatch Synthetics and AWS X-Ray](#)
- [The Amazon Builders' Library: Instrumenting distributed systems for operational visibility](#)
- [Integrating AWS X-Ray with other AWS services](#)
- [AWS Distro for OpenTelemetry and AWS X-Ray](#)
- [Amazon CloudWatch: Using synthetic monitoring](#)
- [Amazon CloudWatch: Use CloudWatch RUM](#)
- [Set up Amazon CloudWatch synthetics canary and Amazon CloudWatch alarm](#)
- [Availability and Beyond: Understanding and Improving the Resilience of Distributed Systems on AWS](#)

### Related examples:

- [One Observability Workshop](#)

**Related videos:**

- [AWS re:Invent 2022 - How to monitor applications across multiple accounts](#)
- [How to Monitor your AWS Applications](#)

**Related tools:**

- [AWS X-Ray](#)
- [Amazon CloudWatch](#)
- [Amazon Route 53](#)

## Design your workload to adapt to changes in demand

A scalable **workload** provides elasticity to add or remove resources automatically so that they closely match the current demand at any given point in time.

**Best practices**

- [REL07-BP01 Use automation when obtaining or scaling resources](#)
- [REL07-BP02 Obtain resources upon detection of impairment to a workload](#)
- [REL07-BP03 Obtain resources upon detection that more resources are needed for a workload](#)
- [REL07-BP04 Load test your workload](#)

### REL07-BP01 Use automation when obtaining or scaling resources

When replacing impaired resources or scaling your workload, automate the process by using managed AWS services, such as Amazon S3 and AWS Auto Scaling. You can also use third-party tools and AWS SDKs to automate scaling.

Managed AWS services include Amazon S3, Amazon CloudFront, AWS Auto Scaling, AWS Lambda, Amazon DynamoDB, AWS Fargate, and Amazon Route 53.

AWS Auto Scaling lets you detect and replace impaired instances. It also lets you build scaling plans for resources including [Amazon EC2](#) instances and Spot Fleets, [Amazon ECS](#) tasks, [Amazon DynamoDB](#) tables and indexes, and [Amazon Aurora](#) Replicas.

When scaling EC2 instances, ensure that you use multiple Availability Zones (preferably at least three) and add or remove capacity to maintain balance across these Availability Zones. ECS tasks or

Kubernetes pods (when using Amazon Elastic Kubernetes Service) should also be distributed across multiple Availability Zones.

When using AWS Lambda, instances scale automatically. Every time an event notification is received for your function, AWS Lambda quickly locates free capacity within its compute fleet and runs your code up to the allocated concurrency. You need to ensure that the necessary concurrency is configured on the specific Lambda, and in your Service Quotas.

Amazon S3 automatically scales to handle high request rates. For example, your application can achieve at least 3,500 PUT/COPY/POST/DELETE or 5,500 GET/HEAD requests per second per prefix in a bucket. There are no limits to the number of prefixes in a bucket. You can increase your read or write performance by parallelizing reads. For example, if you create 10 prefixes in an Amazon S3 bucket to parallelize reads, you could scale your read performance to 55,000 read requests per second.

Configure and use Amazon CloudFront or a trusted content delivery network (CDN). A CDN can provide faster end-user response times and can serve requests for content from cache, therefore reducing the need to scale your workload.

### Common anti-patterns:

- Implementing Auto Scaling groups for automated healing, but not implementing elasticity.
- Using automatic scaling to respond to large increases in traffic.
- Deploying highly stateful applications, eliminating the option of elasticity.

**Benefits of establishing this best practice:** Automation removes the potential for manual error in deploying and decommissioning resources. Automation removes the risk of cost overruns and denial of service due to slow response on needs for deployment or decommissioning.

**Level of risk exposed if this best practice is not established:** High

### Implementation guidance

- Configure and use AWS Auto Scaling. This monitors your applications and automatically adjusts capacity to maintain steady, predictable performance at the lowest possible cost. Using AWS Auto Scaling, you can setup application scaling for multiple resources across multiple services.
  - [What is AWS Auto Scaling?](#)

- Configure Auto Scaling on your Amazon EC2 instances and Spot Fleets, Amazon ECS tasks, Amazon DynamoDB tables and indexes, Amazon Aurora Replicas, and AWS Marketplace appliances as applicable.
  - [Managing throughput capacity automatically with DynamoDB Auto Scaling](#)
    - Use service API operations to specify the alarms, scaling policies, warm up times, and cool down times.
- Use Elastic Load Balancing. Load balancers can distribute load by path or by network connectivity.
  - [What is Elastic Load Balancing?](#)
    - Application Load Balancers can distribute load by path.
      - [What is an Application Load Balancer?](#)
        - Configure an Application Load Balancer to distribute traffic to different workloads based on the path under the domain name.
        - Application Load Balancers can be used to distribute loads in a manner that integrates with AWS Auto Scaling to manage demand.
          - [Using a load balancer with an Auto Scaling group](#)
    - Network Load Balancers can distribute load by connection.
      - [What is a Network Load Balancer?](#)
        - Configure a Network Load Balancer to distribute traffic to different workloads using TCP, or to have a constant set of IP addresses for your workload.
        - Network Load Balancers can be used to distribute loads in a manner that integrates with AWS Auto Scaling to manage demand.
  - Use a highly available DNS provider. DNS names allow your users to enter names instead of IP addresses to access your workloads and distributes this information to a defined scope, usually globally for users of the workload.
    - Use Amazon Route 53 or a trusted DNS provider.
      - [What is Amazon Route 53?](#)
    - Use Route 53 to manage your CloudFront distributions and load balancers.
      - Determine the domains and subdomains you are going to manage.
      - Create appropriate record sets using ALIAS or CNAME records.
        - [Working with records](#)



- Use the AWS global network to optimize the path from your users to your applications. AWS Global Accelerator continually monitors the health of your application endpoints and redirects traffic to healthy endpoints in less than 30 seconds.
  - AWS Global Accelerator is a service that improves the availability and performance of your applications with local or global users. It provides static IP addresses that act as a fixed entry point to your application endpoints in a single or multiple AWS Regions, such as your Application Load Balancers, Network Load Balancers or Amazon EC2 instances.
    - [What Is AWS Global Accelerator?](#)
- Configure and use Amazon CloudFront or a trusted content delivery network (CDN). A content delivery network can provide faster end-user response times and can serve requests for content that may cause unnecessary scaling of your workloads.
  - [What is Amazon CloudFront?](#)
    - Configure Amazon CloudFront distributions for your workloads, or use a third-party CDN.
      - You can limit access to your workloads so that they are only accessible from CloudFront by using the IP ranges for CloudFront in your endpoint security groups or access policies.

## Resources

### Related documents:

- [APN Partner: partners that can help you create automated compute solutions](#)
- [AWS Auto Scaling: How Scaling Plans Work](#)
- [AWS Marketplace: products that can be used with auto scaling](#)
- [Managing Throughput Capacity Automatically with DynamoDB Auto Scaling](#)
- [Using a load balancer with an Auto Scaling group](#)
- [What Is AWS Global Accelerator?](#)
- [What Is Amazon EC2 Auto Scaling?](#)
- [What is AWS Auto Scaling?](#)
- [What is Amazon CloudFront?](#)
- [What is Amazon Route 53?](#)
- [What is Elastic Load Balancing?](#)
- [What is a Network Load Balancer?](#)
- [What is an Application Load Balancer?](#)

- [Working with records](#)

## REL07-BP02 Obtain resources upon detection of impairment to a workload

Scale resources reactively when necessary if availability is impacted, to restore workload availability.

You first must configure health checks and the criteria on these checks to indicate when availability is impacted by lack of resources. Then, either notify the appropriate personnel to manually scale the resource, or start automation to automatically scale it.

Scale can be manually adjusted for your workload (for example, changing the number of EC2 instances in an Auto Scaling group, or modifying throughput of a DynamoDB table through the AWS Management Console or AWS CLI). However, automation should be used whenever possible (refer to **Use automation when obtaining or scaling resources**).

**Desired outcome:** Scaling activities (either automatically or manually) are initiated to restore availability upon detection of a failure or degraded customer experience.

**Level of risk exposed if this best practice is not established:** Medium

### Implementation guidance

Implement observability and monitoring across all components in your workload, to monitor customer experience and detect failure. Define the procedures, manual or automated, that scale the required resources. For more information, see [REL11-BP01 Monitor all components of the workload to detect failures](#).

### Implementation steps

- Define the procedures, manual or automated, that scale the required resources.
  - Scaling procedures depend on how the different components within your workload are designed.
  - Scaling procedures also vary depending on the underlying technology utilized.
    - Components using AWS Auto Scaling can use scaling plans to configure a set of instructions for scaling your resources. If you work with AWS CloudFormation or add tags to AWS resources, you can set up scaling plans for different sets of resources per application. Auto

Scaling provides recommendations for scaling strategies customized to each resource. After you create your scaling plan, Auto Scaling combines dynamic scaling and predictive scaling methods together to support your scaling strategy. For more detail, see [How scaling plans work](#).

- Amazon EC2 Auto Scaling verifies that you have the correct number of Amazon EC2 instances available to handle the load for your application. You create collections of EC2 instances, called Auto Scaling groups. You can specify the minimum and maximum number of instances in each Auto Scaling group, and Amazon EC2 Auto Scaling ensures that your group never goes below or above these limits. For more detail, see [What is Amazon EC2 Auto Scaling?](#)
- Amazon DynamoDB auto scaling uses the Application Auto Scaling service to dynamically adjust provisioned throughput capacity on your behalf, in response to actual traffic patterns. This allows a table or a global secondary index to increase its provisioned read and write capacity to handle sudden increases in traffic, without throttling. For more detail, see [Managing throughput capacity automatically with DynamoDB auto scaling](#).

## Resources

### Related best practices:

- [REL07-BP01 Use automation when obtaining or scaling resources](#)
- [REL11-BP01 Monitor all components of the workload to detect failures](#)

### Related documents:

- [AWS Auto Scaling: How Scaling Plans Work](#)
- [Managing Throughput Capacity Automatically with DynamoDB Auto Scaling](#)
- [What Is Amazon EC2 Auto Scaling?](#)

## REL07-BP03 Obtain resources upon detection that more resources are needed for a workload

Scale resources proactively to meet demand and avoid availability impact.

Many AWS services automatically scale to meet demand. If using Amazon EC2 instances or Amazon ECS clusters, you can configure automatic scaling of these to occur based on usage metrics that

correspond to demand for your workload. For Amazon EC2, average CPU utilization, load balancer request count, or network bandwidth can be used to scale out (or scale in) EC2 instances. For Amazon ECS, average CPU utilization, load balancer request count, and memory utilization can be used to scale out (or scale in) ECS tasks. Using Target Auto Scaling on AWS, the autoscaler acts like a household thermostat, adding or removing resources to maintain the target value (for example, 70% CPU utilization) that you specify.

Amazon EC2 Auto Scaling can also do [Predictive Auto Scaling](#), which uses machine learning to analyze each resource's historical workload and regularly forecasts the future load.

Little's Law helps calculate how many instances of compute (EC2 instances, concurrent Lambda functions, etc.) that you need.

$$L = \lambda W$$

L = number of instances (or mean concurrency in the system)

$\lambda$  = mean rate at which requests arrive (req/sec)

W = mean time that each request spends in the system (sec)

For example, at 100 rps, if each request takes 0.5 seconds to process, you will need 50 instances to keep up with demand.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

- Obtain resources upon detection that more resources are needed for a workload. Scale resources proactively to meet demand and avoid availability impact.
  - Calculate how many compute resources you will need (compute concurrency) to handle a given request rate.
    - [Telling Stories About Little's Law](#)
  - When you have a historical pattern for usage, set up scheduled scaling for Amazon EC2 auto scaling.
    - [Scheduled Scaling for Amazon EC2 Auto Scaling](#)
  - Use AWS predictive scaling.
    - [Predictive scaling for Amazon EC2 Auto Scaling](#)

## Resources

### Related documents:

- [AWS Marketplace: products that can be used with auto scaling](#)
- [Managing Throughput Capacity Automatically with DynamoDB Auto Scaling](#)
- [Predictive Scaling for EC2, Powered by Machine Learning](#)
- [Scheduled Scaling for Amazon EC2 Auto Scaling](#)
- [Telling Stories About Little's Law](#)
- [What Is Amazon EC2 Auto Scaling?](#)

## REL07-BP04 Load test your workload

Adopt a load testing methodology to measure if scaling activity meets workload requirements.

It's important to perform sustained load testing. Load tests should discover the breaking point and test the performance of your workload. AWS makes it easy to set up temporary testing environments that model the scale of your production workload. In the cloud, you can create a production-scale test environment on demand, complete your testing, and then decommission the resources. Because you only pay for the test environment when it's running, you can simulate your live environment for a fraction of the cost of testing on premises.

Load testing in production should also be considered as part of game days where the production system is stressed, during hours of lower customer usage, with all personnel on hand to interpret results and address any problems that arise.

### Common anti-patterns:

- Performing load testing on deployments that are not the same configuration as your production.
- Performing load testing only on individual pieces of your workload, and not on the entire workload.
- Performing load testing with a subset of requests and not a representative set of actual requests.
- Performing load testing to a small safety factor above expected load.

**Benefits of establishing this best practice:** You know what components in your architecture fail under load and be able to identify what metrics to watch to indicate that you are approaching that load in time to address the problem, preventing the impact of that failure.

**Level of risk exposed if this best practice is not established: Medium**

## Implementation guidance

- Perform load testing to identify which aspect of your workload indicates that you must add or remove capacity. Load testing should have representative traffic similar to what you receive in production. Increase the load while watching the metrics you have instrumented to determine which metric indicates when you must add or remove resources.
- [Distributed Load Testing on AWS: simulate thousands of connected users](#)
  - Identify the mix of requests. You may have varied mixes of requests, so you should look at various time frames when identifying the mix of traffic.
  - Implement a load driver. You can use custom code, open source, or commercial software to implement a load driver.
  - Load test initially using small capacity. You see some immediate effects by driving load onto a lesser capacity, possibly as small as one instance or container.
  - Load test against larger capacity. The effects will be different on a distributed load, so you must test against as close to a product environment as possible.

## Resources

### Related documents:

- [Distributed Load Testing on AWS: simulate thousands of connected users](#)
- [Load testing applications](#)

### Related videos:

- [AWS Summit ANZ 2023: Accelerate with confidence through AWS Distributed Load Testing](#)

## Implement change

Controlled changes are necessary to deploy new functionality and to ensure that the workloads and the operating environment are running known, properly patched software. If these changes are uncontrolled, then it makes it difficult to predict the effect of these changes, or to address issues that arise because of them.

## Additional deployment patterns to minimize risk

[Feature flags \(also known as feature toggles\)](#) are configuration options on an application. You can deploy the software with a feature turned off, so that your customers don't see the feature. You can then turn on the feature, as you'd do for a canary deployment, or you can set the change pace to 100% to see the effect. If the deployment has problems, you can simply turn the feature back off without rolling back.

[Fault isolated zonal deployment](#): One of the most important rules AWS has established for its own deployments is to avoid touching multiple Availability Zones within a Region at the same time. This is critical to ensuring that Availability Zones are independent for purposes of our availability calculations. We recommend that you use similar considerations in your deployments.

## Operational Readiness Reviews (ORRs)

AWS finds it useful to perform operational readiness reviews that evaluate the completeness of the testing, ability to monitor, and importantly, the ability to audit the application's performance to its SLAs and provide data in the event of an interruption or other operational anomaly. A formal ORR is conducted prior to initial production deployment. AWS will repeat ORRs periodically (once per year, or before critical performance periods) to ensure that there has not been drift from operational expectations. For more information on operational readiness, see the [Operational Excellence pillar](#) of the [AWS Well-Architected Framework](#).

## Best practices

- [REL08-BP01 Use runbooks for standard activities such as deployment](#)
- [REL08-BP02 Integrate functional testing as part of your deployment](#)
- [REL08-BP03 Integrate resiliency testing as part of your deployment](#)
- [REL08-BP04 Deploy using immutable infrastructure](#)
- [REL08-BP05 Deploy changes with automation](#)

## REL08-BP01 Use runbooks for standard activities such as deployment

Runbooks are the predefined procedures to achieve specific outcomes. Use runbooks to perform standard activities, whether done manually or automatically. Examples include deploying a workload, patching a workload, or making DNS modifications.

For example, put processes in place to [ensure rollback safety during deployments](#). Ensuring that you can roll back a deployment without any disruption for your customers is critical in making a service reliable.

For runbook procedures, start with a valid effective manual process, implement it in code, and invoke it to automatically run where appropriate.

Even for sophisticated workloads that are highly automated, runbooks are still useful for [running game days](#) or meeting rigorous reporting and auditing requirements.

Note that playbooks are used in response to specific incidents, and runbooks are used to achieve specific outcomes. Often, runbooks are for routine activities, while playbooks are used for responding to non-routine events.

### Common anti-patterns:

- Performing unplanned changes to configuration in production.
- Skipping steps in your plan to deploy faster, resulting in a failed deployment.
- Making changes without testing the reversal of the change.

**Benefits of establishing this best practice:** Effective change planning increases your ability to successfully run the change because you are aware of all the systems impacted. Validating your change in test environments increases your confidence.

**Level of risk exposed if this best practice is not established:** High

### Implementation guidance

- Provide consistent and prompt responses to well-understood events by documenting procedures in runbooks.
  - [AWS Well-Architected Framework: Concepts: Runbook](#)
- Use the principle of infrastructure as code to define your infrastructure. By using AWS CloudFormation (or a trusted third party) to define your infrastructure, you can use version control software to version and track changes.
  - Use AWS CloudFormation (or a trusted third-party provider) to define your infrastructure.
    - [What is AWS CloudFormation?](#)
  - Create templates that are singular and decoupled, using good software design principles.
    - Determine the permissions, templates, and responsible parties for implementation.



- [Controlling access with AWS Identity and Access Management](#)
- Use source control, like AWS CodeCommit or a trusted third-party tool, for version control.
- [What is AWS CodeCommit?](#)

## Resources

### Related documents:

- [APN Partner: partners that can help you create automated deployment solutions](#)
- [AWS Marketplace: products that can be used to automate your deployments](#)
- [AWS Well-Architected Framework: Concepts: Runbook](#)
- [What is AWS CloudFormation?](#)
- [What is AWS CodeCommit?](#)

### Related examples:

- [Automating operations with Playbooks and Runbooks](#)

## REL08-BP02 Integrate functional testing as part of your deployment

Functional tests are run as part of automated deployment. If success criteria are not met, the pipeline is halted or rolled back. These tests are run in a pre-production environment, which is staged prior to production in the pipeline. Ideally, this is done as part of a deployment pipeline.

Desired outcome: You use automation to perform functional tests, and the associated test data reduces test duration and expense and improves accuracy of test results. You integrate functional tests as part of your deployment process, which helps you automate your release pipelines for fast and reliable application and infrastructure updates.

### Common anti-patterns:

- You manually perform tests outside the deployment pipeline.
- You skip testing steps in your automation through manual emergency workflows.
- You don't follow your established test plans and processes in favor of accelerated timelines.

**Benefits of establishing this best practice:** Functional tests validate that the system operates according to specified requirements. It is used to consistently verify the intended working order of

components such as user interfaces, APIs, databases, and source code. When you examine these components of the system, functional tests verify that each feature behaves as expected, which protects both user expectations and the software's integrity. Integrate functional tests as part of your regular deployment, and use automation to deploy all changes, which reduces the potential for introduction of human errors.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

Integrate functional testing as part of your deployment. Functional tests are run as part of automated deployment. If success criteria are not met, the pipeline is halted or rolled back. AWS CodePipeline provides a continuous delivery pipeline for automated testing, which allows testers to automate the entire testing and deployment process. It integrates with AWS services such as AWS CodeBuild and AWS CodeDeploy to automate the build, test, and deployment phases of the software development lifecycle.

### Implementation steps

- **Configure your pipeline:** Set up your source, build, test, and deploy stages using the AWS CodePipeline console or AWS Command Line Interface (CLI).
- **Define your source:** With AWS CodePipeline, you can automatically retrieve source code from version control systems like GitHub, AWS CodeCommit, or Bitbucket, which verifies that the latest code is always used for testing.
- **Automate builds and tests:** AWS CodeBuild can automatically build and test your code and generate test reports. It supports popular testing frameworks like JUnit, NUnit, and TestNG.
- **Deploy your code:** Once the code has been built and tested, AWS CodeDeploy can deploy it to your testing environment, including Amazon EC2 instances, AWS Lambda functions, or on-premises servers.
- **Monitor pipelines:** AWS CodePipeline can track the progress of your pipeline and the status of each stage. You can also use quality checks to block the pipeline as per test execution status. You can also receive notifications for any pipeline stage failure or pipeline completion.

## Resources

### Related documents:

- [Use AWS CodePipeline with AWS CodeBuild to test code and run builds](#)

- [Logging and monitoring in AWS CodeBuild](#)
- [Indicators for functional testing](#)

## REL08-BP03 Integrate resiliency testing as part of your deployment

Integrate resiliency testing by consciously introducing failures in your system to measure its capability in case of disruptive scenarios. Resilience tests are different from unit and function tests that are usually integrated in deployment cycles, as they focus on the identification of unanticipated failures in your system. While it is safe to start with resiliency testing integration in pre-production, set a goal to implement these tests in production as a part of your [game days](#).

**Desired outcome:** Resiliency testing helps build confidence in the system's ability to withstand degradation in production. Experiments identify weak points that could lead to failure, which helps you improve your system to automatically and efficiently mitigate failure and degradation.

### Common anti-patterns:

- Lack of observability and monitoring in deployment processes
- Reliance on humans to resolve system failures
- Poor quality analysis mechanisms
- Focus on known issues in a system and a lack of experimentation to identify any unknowns
- Identification of failures, but no resolution
- No documentation of findings and runbooks

**Benefits of establishing best practices:** Resilience testing integrated in your deployments helps to identify unknown issues in the system that otherwise go unnoticed, which can lead to downtime in production. Identification of these unknowns in a system helps you document findings, integrate testing into your CI/CD process, and build runbooks, which simplify mitigation through efficient, repeatable mechanisms.

**Level of risk exposed if this best practice is not established:** Medium

### Implementation guidance

The most common resiliency testing forms that can be integrated in your system's deployments are disaster recovery and chaos engineering.

- Include updates to your disaster recovery plans and standard operating procedures (SOPs) with any significant deployment.
- Integrate reliability testing into your automated deployment pipelines. Services such as [AWS Resilience Hub](#) can be [integrated into your CI/CD pipeline](#) to establish continuous resilience assessments that are automatically evaluated as part of every deployment.
- Define your applications in AWS Resilience Hub. Resilience assessments generate code snippets that help you create recovery procedures as AWS Systems Manager documents for your applications and provide a list of recommended Amazon CloudWatch monitors and alarms.
- Once your DR plans and SOPs are updated, complete disaster recovery testing to verify that they are effective. Disaster recovery testing helps you determine if you can restore your system after an event and return to normal operations. You can simulate various disaster recovery strategies and identify whether your planning is sufficient to meet your uptime requirements. Common disaster recovery strategies include backup and restore, pilot light, cold standby, warm standby, hot standby, and active-active, and they all differ in cost and complexity. Before disaster recovery testing, we recommend that you define your recovery time objective (RTO) and recovery point objective (RPO) to simplify the choice of strategy to simulate. AWS offers disaster recovery tools like [AWS Elastic Disaster Recovery](#) to help you get started with your planning and testing.
- Chaos engineering experiments introduce disruptions to the system, such as network outages and service failures. By simulating with controlled failures, you can discover your system's vulnerabilities while containing the impacts of the injected failures. Just like the other strategies, run controlled failure simulations in non-production environments using services like [AWS Fault Injection Service](#) to gain confidence before deploying in production.

## Resources

### Related documents:

- [Experiment with failure using resilience testing to build recovery preparedness](#)
- [Continually assessing application resilience with AWS Resilience Hub and AWS CodePipeline](#)
- [Disaster recovery \(DR\) architecture on AWS, part 1: Strategies for recovery in the cloud](#)
- [Verify the resilience of your workloads using Chaos Engineering](#)
- [Principles of Chaos Engineering](#)
- [Chaos Engineering Workshop](#)

### Related videos:

- [AWS re:Invent 2020: Testing Resilience using Chaos Engineering](#)
- [Improve Application Resilience with AWS Fault Injection Service](#)
- [Prepare & Protect Your Applications From Disruption With AWS Resilience Hub](#)

## REL08-BP04 Deploy using immutable infrastructure

Immutable infrastructure is a model that mandates that no updates, security patches, or configuration changes happen in-place on production workloads. When a change is needed, the architecture is built onto new infrastructure and deployed into production.

Follow an immutable infrastructure deployment strategy to increase the reliability, consistency, and reproducibility in your workload deployments.

**Desired outcome:** With immutable infrastructure, no [in-place modifications](#) are allowed to run infrastructure resources within a workload. Instead, when a change is needed, a new set of updated infrastructure resources containing all the necessary changes are deployed in parallel to your existing resources. This deployment is validated automatically, and if successful, traffic is gradually shifted to the new set of resources.

This deployment strategy applies to software updates, security patches, infrastructure changes, configuration updates, and application updates, among others.

### Common anti-patterns:

- Implementing in-place changes to running infrastructure resources.

### Benefits of establishing this best practice:

- **Increased consistency across environments:** Since there are no differences in infrastructure resources across environments, consistency is increased and testing is simplified.
- **Reduction in configuration drifts:** By replacing infrastructure resources with a known and version-controlled configuration, the infrastructure is set to a known, tested, and trusted state, avoiding configuration drifts.
- **Reliable atomic deployments:** Deployments either complete successfully or nothing changes, increasing consistency and reliability in the deployment process.
- **Simplified deployments:** Deployments are simplified because they don't need to support upgrades. Upgrades are just new deployments.

- **Safer deployments with fast rollback and recovery processes:** Deployments are safer because the previous working version is not changed. You can roll back to it if errors are detected.
- **Enhanced security posture:** By not allowing changes to infrastructure, remote access mechanisms (such as SSH) can be disabled. This reduces the attack vector, improving your organization's security posture.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

### Automation

When defining an immutable infrastructure deployment strategy, it is recommended to use [automation](#) as much as possible to increase reproducibility and minimize the potential of human error. For more detail, see [REL08-BP05 Deploy changes with automation](#) and [Automating safe, hands-off deployments](#).

With [Infrastructure as code \(IaC\)](#), infrastructure provisioning, orchestration, and deployment steps are defined in a programmatic, descriptive, and declarative way and stored in a source control system. Leveraging infrastructure as code makes it simpler to automate infrastructure deployment and helps achieve infrastructure immutability.

### Deployment patterns

When a change in the workload is required, the immutable infrastructure deployment strategy mandates that a new set of infrastructure resources is deployed, including all necessary changes. It is important for this new set of resources to follow a rollout pattern that minimizes user impact. There are two main strategies for this deployment:

**[Canary deployment:](#)** The practice of directing a small number of your customers to the new version, usually running on a single service instance (the canary). You then deeply scrutinize any behavior changes or errors that are generated. You can remove traffic from the canary if you encounter critical problems and send the users back to the previous version. If the deployment is successful, you can continue to deploy at your desired velocity, while monitoring the changes for errors, until you are fully deployed. AWS CodeDeploy can be configured with a [deployment configuration](#) that allows a canary deployment.

**[Blue/green deployment:](#)** Similar to the canary deployment, except that a full fleet of the application is deployed in parallel. You alternate your deployments across the two stacks (blue and green). Once again, you can send traffic to the new version, and fall back to the old version

if you see problems with the deployment. Commonly all traffic is switched at once, however you can also use fractions of your traffic to each version to dial up the adoption of the new version using the weighted DNS routing capabilities of Amazon Route 53. AWS CodeDeploy and [AWS Elastic Beanstalk](#) can be configured with a deployment configuration that allows a blue/green deployment.

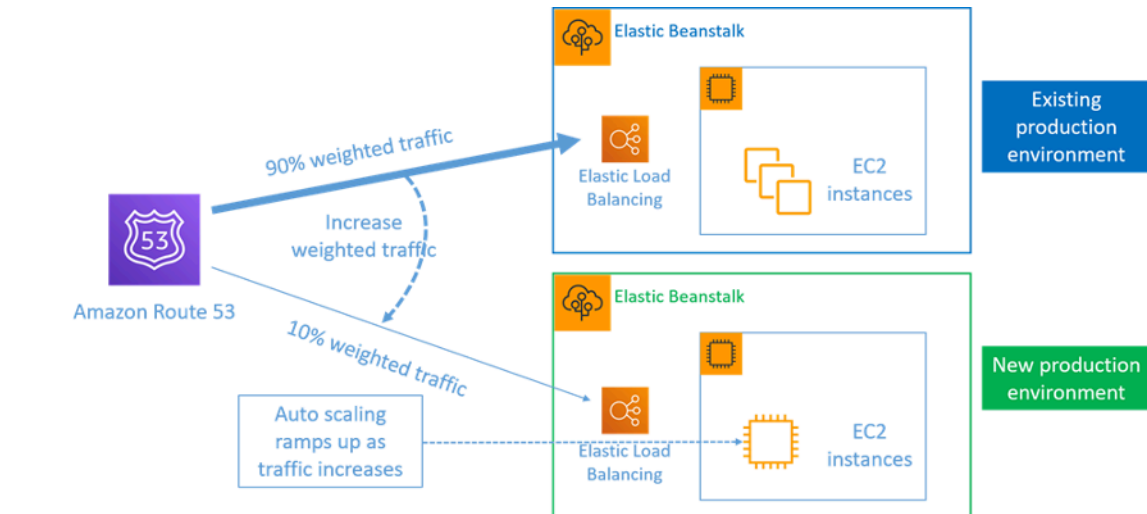


Figure 8: Blue/green deployment with AWS Elastic Beanstalk and Amazon Route 53

## Drift detection

*Drift* is defined as any change that causes an infrastructure resource to have a different state or configuration to what is expected. Any type of unmanaged configuration change goes against the notion of immutable infrastructure, and should be detected and remediated in order to have a successful implementation of immutable infrastructure.

## Implementation steps

- Disallow the in-place modification of running infrastructure resources.
  - You can use [AWS Identity and Access Management \(IAM\)](#) to specify who or what can access services and resources in AWS, centrally manage fine-grained permissions, and analyze access to refine permissions across AWS.
- Automate the deployment of infrastructure resources to increase reproducibility and minimize the potential of human error.
  - As described in the [Introduction to DevOps on AWS whitepaper](#), automation is a cornerstone with AWS services and is internally supported in all services, features, and offerings.
  - [Prebaking](#) your Amazon Machine Image (AMI) can speed up the time to launch them. [EC2 Image Builder](#) is a fully managed AWS service that helps you automate the creation,

maintenance, validation, sharing, and deployment of customized, secure, and up-to-date Linux or Windows custom AMI.

- Some of the services that support automation are:
  - [AWS Elastic Beanstalk](#) is a service to rapidly deploy and scale web applications developed with Java, .NET, PHP, Node.js, Python, Ruby, Go, and Docker on familiar servers such as Apache, NGINX, Passenger, and IIS.
  - [AWS Proton](#) helps platform teams connect and coordinate all the different tools your development teams need for infrastructure provisioning, code deployments, monitoring, and updates. AWS Proton enables automated infrastructure as code provisioning and deployment of serverless and container-based applications.
- Leveraging infrastructure as code makes it easy to automate infrastructure deployment, and helps achieve infrastructure immutability. AWS provides services that enable the creation, deployment, and maintenance of infrastructure in a programmatic, descriptive, and declarative way.
  - [AWS CloudFormation](#) helps developers create AWS resources in an orderly and predictable fashion. Resources are written in text files using JSON or YAML format. The templates require a specific syntax and structure that depends on the types of resources being created and managed. You author your resources in JSON or YAML with any code editor such as AWS Cloud9, check it into a version control system, and then CloudFormation builds the specified services in safe, repeatable manner.
  - [AWS Serverless Application Model \(AWS SAM\)](#) is an open-source framework that you can use to build serverless applications on AWS. AWS SAM integrates with other AWS services, and is an extension of AWS CloudFormation.
  - [AWS Cloud Development Kit \(AWS CDK\)](#) is an open-source software development framework to model and provision your cloud application resources using familiar programming languages. You can use AWS CDK to model application infrastructure using TypeScript, Python, Java, and .NET. AWS CDK uses AWS CloudFormation in the background to provision resources in a safe, repeatable manner.
  - [AWS Cloud Control API](#) introduces a common set of Create, Read, Update, Delete, and List (CRUDL) APIs to help developers manage their cloud infrastructure in an easy and consistent way. The Cloud Control API common APIs allow developers to uniformly manage the lifecycle of AWS and third-party services.
- Implement deployment patterns that minimize user impact.
  - Canary deployments:



- [Set up an API Gateway canary release deployment](#)
- [Create a pipeline with canary deployments for Amazon ECS using AWS App Mesh](#)
- Blue/green deployments: the [Blue/Green Deployments on AWS whitepaper](#) describes [example techniques](#) to implement blue/green deployment strategies.
- Detect configuration or state drifts. For more detail, see [Detecting unmanaged configuration changes to stacks and resources](#).

## Resources

### Related best practices:

- [REL08-BP05 Deploy changes with automation](#)

### Related documents:

- [Automating safe, hands-off deployments](#)
- [Leveraging AWS CloudFormation to create an immutable infrastructure at Nubank](#)
- [Infrastructure as code](#)
- [Implementing an alarm to automatically detect drift in AWS CloudFormation stacks](#)

### Related videos:

- [AWS re:Invent 2020: Reliability, consistency, and confidence through immutability](#)

## REL08-BP05 Deploy changes with automation

Deployments and patching are automated to eliminate negative impact.

Making changes to production systems is one of the largest risk areas for many organizations. We consider deployments a first-class problem to be solved alongside the business problems that the software addresses. Today, this means the use of automation wherever practical in operations, including testing and deploying changes, adding or removing capacity, and migrating data.

**Desired outcome:** You build automated deployment safety into the release process with extensive pre-production testing, automatic rollbacks, and staggered production deployments. This

automation minimizes the potential impact on production caused by failed deployments, and developers no longer need to actively watch deployments to production.

### Common anti-patterns:

- You perform manual changes.
- You skip steps in your automation through manual emergency workflows.
- You don't follow your established plans and processes in favor of accelerated timelines.
- You perform rapid follow-on deployments without allowing for bake time.

**Benefits of establishing this best practice:** When you use automation to deploy all changes, you remove the potential for introduction of human error and provide the ability to test before you change production. Performing this process prior to production push verifies that your plans are complete. Additionally, automatic rollback into your release process can identify production issues and return your workload to its previously-working operational state.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

Automate your deployment pipeline. Deployment pipelines allow you to invoke automated testing and detection of anomalies, and either halt the pipeline at a certain step before production deployment, or automatically roll back a change. An integral part of this is the adoption of the culture of [continuous integration and continuous delivery/deployment](#) (CI/CD), where a commit or code change passes through various automated stage gates from build and test stages to deployment on production environments.

Although conventional wisdom suggests that you keep people in the loop for the most difficult operational procedures, we suggest that you automate the most difficult procedures for that very reason.

### Implementation steps

You can automate deployments to remove manual operations by following these steps:

- **Set up a code repository to store your code securely:** Use [AWS CodeCommit](#), to create a secure Git-based repository.

- **Configure a continuous integration service to compile your source code, run tests, and create deployment artifacts:** To set up a build project for this purpose, see [Getting started with AWS CodeBuild using the console](#).
- **Set up a deployment service that automates application deployments and handles the complexity of application updates without reliance on error-prone manual deployments:** [AWS CodeDeploy](#) automates software deployments to a variety of compute services, such as Amazon EC2, [AWS Fargate](#), [AWS Lambda](#), and your on-premise servers. To configure these steps, see [Getting started with CodeDeploy](#).
- **Set up a continuous delivery service that automates your release pipelines for quicker and more reliable application and infrastructure updates:** Consider using [AWS CodePipeline](#) to help you automate your release pipelines. For more detail, see [CodePipeline tutorials](#).

## Resources

### Related best practices:

- [OPS05-BP04 Use build and deployment management systems](#)
- [OPS05-BP10 Fully automate integration and deployment](#)
- [OPS06-BP02 Test deployments](#)
- [OPS06-BP04 Automate testing and rollback](#)

### Related documents:


- [Continuous Delivery of Nested AWS CloudFormation Stacks Using AWS CodePipeline](#)
- [Complete CI/CD with AWS CodeCommit, AWS CodeBuild, AWS CodeDeploy, and AWS CodePipeline](#)
- [APN Partner: partners that can help you create automated deployment solutions](#)
- [AWS Marketplace: products that can be used to automate your deployments](#)
- [Automate chat messages with webhooks](#)
- [The Amazon Builders' Library: Ensuring rollback safety during deployments](#)
- [The Amazon Builders' Library: Going faster with continuous delivery](#)
- [What Is AWS CodePipeline?](#)
- [What Is CodeDeploy?](#)
- [AWS Systems Manager Patch Manager](#)

- [What is Amazon SES?](#)
- [What is Amazon Simple Notification Service?](#)

**Related videos:**

- [AWS Summit 2019: CI/CD on AWS](#)

# Failure management

 Failures are a given and everything will eventually fail over time: from routers to hard disks, from operating systems to memory units corrupting TCP packets, from transient errors to permanent failures. This is a given, whether you are using the highest-quality hardware or lowest cost components - [Werner Vogels, CTO - Amazon.com](#)

Low-level hardware component failures are something to be dealt with every day in an on-premises data center. In the cloud, however, you should be protected against most of these types of failures. For example, Amazon EBS volumes are placed in a specific Availability Zone where they are automatically replicated to protect you from the failure of a single component. All EBS volumes are designed for 99.999% availability. Amazon S3 objects are stored across a minimum of three Availability Zones providing 99.999999999% durability of objects over a given year. Regardless of your cloud provider, there is the potential for failures to impact your workload. Therefore, you must take steps to implement resiliency if you need your workload to be reliable.

A prerequisite to applying the best practices discussed here is that you must ensure that the people designing, implementing, and operating your workloads are aware of business objectives and the reliability goals to achieve these. These people must be aware of and trained for these reliability requirements.

The following sections explain the best practices for managing failures to prevent impact on your workload.

## Topics

- [Back up data](#)
- [Use fault isolation to protect your workload](#)
- [Design your workload to withstand component failures](#)
- [Test reliability](#)
- [Plan for Disaster Recovery \(DR\)](#)

# Back up data

Back up data, applications, and configuration to meet requirements for recovery time objectives (RTO) and recovery point objectives (RPO).

## Best practices

- [REL09-BP01 Identify and back up all data that needs to be backed up, or reproduce the data from sources](#)
- [REL09-BP02 Secure and encrypt backups](#)
- [REL09-BP03 Perform data backup automatically](#)
- [REL09-BP04 Perform periodic recovery of the data to verify backup integrity and processes](#)

## REL09-BP01 Identify and back up all data that needs to be backed up, or reproduce the data from sources

Understand and use the backup capabilities of the data services and resources used by the workload. Most services provide capabilities to back up workload data.

**Desired outcome:** Data sources have been identified and classified based on criticality. Then, establish a strategy for data recovery based on the RPO. This strategy involves either backing up these data sources, or having the ability to reproduce data from other sources. In the case of data loss, the strategy implemented allows recovery or the reproduction of data within the defined RPO and RTO.

**Cloud maturity phase:** Foundational

### Common anti-patterns:

- Not aware of all data sources for the workload and their criticality.
- Not taking backups of critical data sources.
- Taking backups of only some data sources without using criticality as a criterion.
- No defined RPO, or backup frequency cannot meet RPO.
- Not evaluating if a backup is necessary or if data can be reproduced from other sources.

**Benefits of establishing this best practice:** Identifying the places where backups are necessary and implementing a mechanism to create backups, or being able to reproduce the data from an external source improves the ability to restore and recover data during an outage.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

All AWS data stores offer backup capabilities. Services such as Amazon RDS and Amazon DynamoDB additionally support automated backup that allows point-in-time recovery (PITR), which allows you to restore a backup to any time up to five minutes or less before the current time. Many AWS services offer the ability to copy backups to another AWS Region. AWS Backup is a tool that gives you the ability to centralize and automate data protection across AWS services. [AWS Elastic Disaster Recovery](#) allows you to copy full server workloads and maintain continuous data protection from on-premise, cross-AZ or cross-Region, with a Recovery Point Objective (RPO) measured in seconds.

Amazon S3 can be used as a backup destination for self-managed and AWS-managed data sources. AWS services such as Amazon EBS, Amazon RDS, and Amazon DynamoDB have built in capabilities to create backups. Third-party backup software can also be used.

On-premises data can be backed up to the AWS Cloud using [AWS Storage Gateway](#) or [AWS DataSync](#). Amazon S3 buckets can be used to store this data on AWS. Amazon S3 offers multiple storage tiers such as [Amazon S3 Glacier or S3 Glacier Deep Archive](#) to reduce cost of data storage.

You might be able to meet data recovery needs by reproducing the data from other sources. For example, [Amazon ElastiCache replica nodes](#) or [Amazon RDS read replicas](#) could be used to reproduce data if the primary is lost. In cases where sources like this can be used to meet your [Recovery Point Objective \(RPO\) and Recovery Time Objective \(RTO\)](#), you might not require a backup. Another example, if working with Amazon EMR, it might not be necessary to backup your HDFS data store, as long as you can [reproduce the data into Amazon EMR from Amazon S3](#).

When selecting a backup strategy, consider the time it takes to recover data. The time needed to recover data depends on the type of backup (in the case of a backup strategy), or the complexity of the data reproduction mechanism. This time should fall within the RTO for the workload.

## Implementation steps

- 1. Identify all data sources for the workload.** Data can be stored on a number of resources such as [databases](#), [volumes](#), [filesystems](#), [logging systems](#), and [object storage](#). Refer to the **Resources**

- section to find **Related documents** on different AWS services where data is stored, and the backup capability these services provide.
- 2. Classify data sources based on criticality.** Different data sets will have different levels of criticality for a workload, and therefore different requirements for resiliency. For example, some data might be critical and require a RPO near zero, while other data might be less critical and can tolerate a higher RPO and some data loss. Similarly, different data sets might have different RTO requirements as well.
  - 3. Use AWS or third-party services to create backups of the data.** [AWS Backup](#) is a managed service that allows creating backups of various data sources on AWS. [AWS Elastic Disaster Recovery](#) handles automated sub-second data replication to an AWS Region. Most AWS services also have native capabilities to create backups. The AWS Marketplace has many solutions that provide these capabilities as well. Refer to the **Resources** listed below for information on how to create backups of data from various AWS services.
  - 4. For data that is not backed up, establish a data reproduction mechanism.** You might choose not to backup data that can be reproduced from other sources for various reasons. There might be a situation where it is cheaper to reproduce data from sources when needed rather than creating a backup as there may be a cost associated with storing backups. Another example is where restoring from a backup takes longer than reproducing the data from sources, resulting in a breach in RTO. In such situations, consider tradeoffs and establish a well-defined process for how data can be reproduced from these sources when data recovery is necessary. For example, if you have loaded data from Amazon S3 to a data warehouse (like Amazon Redshift), or MapReduce cluster (like Amazon EMR) to do analysis on that data, this may be an example of data that can be reproduced from other sources. As long as the results of these analyses are either stored somewhere or reproducible, you would not suffer a data loss from a failure in the data warehouse or MapReduce cluster. Other examples that can be reproduced from sources include caches (like Amazon ElastiCache) or RDS read replicas.
  - 5. Establish a cadence for backing up data.** Creating backups of data sources is a periodic process and the frequency should depend on the RPO.

**Level of effort for the Implementation Plan:** Moderate

## Resources

### Related Best Practices:

[REL13-BP01 Define recovery objectives for downtime and data loss](#)



## REL13-BP02 Use defined recovery strategies to meet the recovery objectives

### **Related documents:**

- [What Is AWS Backup?](#)
- [What is AWS DataSync?](#)
- [What is Volume Gateway?](#)
- [APN Partner: partners that can help with backup](#)
- [AWS Marketplace: products that can be used for backup](#)
- [Amazon EBS Snapshots](#)
- [Backing Up Amazon EFS](#)
- [Backing up Amazon FSx for Windows File Server](#)
- [Backup and Restore for ElastiCache for Redis](#)
- [Creating a DB Cluster Snapshot in Neptune](#)
- [Creating a DB Snapshot](#)
- [Creating an EventBridge Rule That Triggers on a Schedule](#)
- [Cross-Region Replication with Amazon S3](#)
- [EFS-to-EFS AWS Backup](#)
- [Exporting Log Data to Amazon S3](#)
- [Object lifecycle management](#)
- [On-Demand Backup and Restore for DynamoDB](#)
- [Point-in-time recovery for DynamoDB](#)
- [Working with Amazon OpenSearch Service Index Snapshots](#)
- [What is AWS Elastic Disaster Recovery?](#)

### **Related videos:**

- [AWS re:Invent 2021 - Backup, disaster recovery, and ransomware protection with AWS](#)
- [AWS Backup Demo: Cross-Account and Cross-Region Backup](#)
- [AWS re:Invent 2019: Deep dive on AWS Backup, ft. Rackspace \(STG341\)](#)

### **Related examples:**

- [Well-Architected Lab - Implementing Bi-Directional Cross-Region Replication \(CRR\) for Amazon S3](#)
- [Well-Architected Lab - Testing Backup and Restore of Data](#)
- [Well-Architected Lab - Backup and Restore with Failback for Analytics Workload](#)
- [Well-Architected Lab - Disaster Recovery - Backup and Restore](#)

## REL09-BP02 Secure and encrypt backups

Control and detect access to backups using authentication and authorization. Prevent and detect if data integrity of backups is compromised using encryption.

### Common anti-patterns:

- Having the same access to the backups and restoration automation as you do to the data.
- Not encrypting your backups.

**Benefits of establishing this best practice:** Securing your backups prevents tampering with the data, and encryption of the data prevents access to that data if it is accidentally exposed.

**Level of risk exposed if this best practice is not established:** High

### Implementation guidance

Control and detect access to backups using authentication and authorization, such as AWS Identity and Access Management (IAM). Prevent and detect if data integrity of backups is compromised using encryption.

Amazon S3 supports several methods of encryption of your data at rest. Using server-side encryption, Amazon S3 accepts your objects as unencrypted data, and then encrypts them as they are stored. Using client-side encryption, your workload application is responsible for encrypting the data before it is sent to Amazon S3. Both methods allow you to use AWS Key Management Service (AWS KMS) to create and store the data key, or you can provide your own key, which you are then responsible for. Using AWS KMS, you can set policies using IAM on who can and cannot access your data keys and decrypted data.

For Amazon RDS, if you have chosen to encrypt your databases, then your backups are encrypted also. DynamoDB backups are always encrypted. When using AWS Elastic Disaster Recovery, all data in transit and at rest is encrypted. With Elastic Disaster Recovery, data at rest can be encrypted

using either the default Amazon EBS encryption Volume Encryption Key or a custom customer-managed key.

## Implementation steps

1. Use encryption on each of your data stores. If your source data is encrypted, then the backup will also be encrypted.
  - [Use encryption in Amazon RDS.](#) You can configure encryption at rest using AWS Key Management Service when you create an RDS instance.
  - [Use encryption on Amazon EBS volumes.](#) You can configure default encryption or specify a unique key upon volume creation.
  - Use the required [Amazon DynamoDB encryption](#). DynamoDB encrypts all data at rest. You can either use an AWS owned AWS KMS key or an AWS managed KMS key, specifying a key that is stored in your account.
  - [Encrypt your data stored in Amazon EFS.](#) Configure the encryption when you create your file system.
  - Configure the encryption in the source and destination Regions. You can configure encryption at rest in Amazon S3 using keys stored in KMS, but the keys are Region-specific. You can specify the destination keys when you configure the replication.
  - Choose whether to use the default or custom [Amazon EBS encryption for Elastic Disaster Recovery](#). This option will encrypt your replicated data at rest on the Staging Area Subnet disks and the replicated disks.
2. Implement least privilege permissions to access your backups. Follow best practices to limit the access to the backups, snapshots, and replicas in accordance with [security best practices](#).

## Resources

### Related documents:

- [AWS Marketplace: products that can be used for backup](#)
- [Amazon EBS Encryption](#)
- [Amazon S3: Protecting Data Using Encryption](#)
- [CRR Additional Configuration: Replicating Objects Created with Server-Side Encryption \(SSE\) Using Encryption Keys stored in AWS KMS](#)
- [DynamoDB Encryption at Rest](#)

- [Encrypting Amazon RDS Resources](#)
- [Encrypting Data and Metadata in Amazon EFS](#)
- [Encryption for Backups in AWS](#)
- [Managing Encrypted Tables](#)
- [Security Pillar - AWS Well-Architected Framework](#)
- [What is AWS Elastic Disaster Recovery?](#)

#### Related examples:

- [Well-Architected Lab - Implementing Bi-Directional Cross-Region Replication \(CRR\) for Amazon S3](#)

## REL09-BP03 Perform data backup automatically

Configure backups to be taken automatically based on a periodic schedule informed by the Recovery Point Objective (RPO), or by changes in the dataset. Critical datasets with low data loss requirements need to be backed up automatically on a frequent basis, whereas less critical data where some loss is acceptable can be backed up less frequently.

**Desired outcome:** An automated process that creates backups of data sources at an established cadence.

#### Common anti-patterns:

- Performing backups manually.
- Using resources that have backup capability, but not including the backup in your automation.

**Benefits of establishing this best practice:** Automating backups verifies that they are taken regularly based on your RPO, and alerts you if they are not taken.

**Level of risk exposed if this best practice is not established:** Medium

### Implementation guidance

AWS Backup can be used to create automated data backups of various AWS data sources. Amazon RDS instances can be backed up almost continuously every five minutes and Amazon S3 objects can be backed up almost continuously every fifteen minutes, providing for point-in-

time recovery (PITR) to a specific point in time within the backup history. For other AWS data sources, such as Amazon EBS volumes, Amazon DynamoDB tables, or Amazon FSx file systems, AWS Backup can run automated backup as frequently as every hour. These services also offer native backup capabilities. AWS services that offer automated backup with point-in-time recovery include [Amazon DynamoDB](#), [Amazon RDS](#), and [Amazon Keyspaces \(for Apache Cassandra\)](#) – these can be restored to a specific point in time within the backup history. Most other AWS data storage services offer the ability to schedule periodic backups, as frequently as every hour.

Amazon RDS and Amazon DynamoDB offer continuous backup with point-in-time recovery. Amazon S3 versioning, once turned on, is automatic. [Amazon Data Lifecycle Manager](#) can be used to automate the creation, copy and deletion of Amazon EBS snapshots. It can also automate the creation, copy, deprecation and deregistration of Amazon EBS-backed Amazon Machine Images (AMIs) and their underlying Amazon EBS snapshots.

AWS Elastic Disaster Recovery provides continuous block-level replication from the source environment (on-premises or AWS) to the target recovery region. Point-in-time Amazon EBS snapshots are automatically created and managed by the service.

For a centralized view of your backup automation and history, AWS Backup provides a fully managed, policy-based backup solution. It centralizes and automates the back up of data across multiple AWS services in the cloud as well as on premises using the AWS Storage Gateway.

In addition to versioning, Amazon S3 features replication. The entire S3 bucket can be automatically replicated to another bucket in the same, or a different AWS Region.

## Implementation steps

1. **Identify data sources** that are currently being backed up manually. For more detail, see [REL09-BP01 Identify and back up all data that needs to be backed up, or reproduce the data from sources](#).
2. **Determine the RPO** for the workload. For more detail, see [REL13-BP01 Define recovery objectives for downtime and data loss](#).
3. **Use an automated backup solution or managed service.** AWS Backup is a fully-managed service that makes it easy to [centralize and automate data protection across AWS services, in the cloud, and on-premises](#). Using backup plans in AWS Backup, create rules which define the resources to backup, and the frequency at which these backups should be created. This frequency should be informed by the RPO established in Step 2. For hands-on guidance on how to create automated backups using AWS Backup, see [Testing Backup and Restore of Data](#). Native

backup capabilities are offered by most AWS services that store data. For example, RDS can be leveraged for automated backups with point-in-time recovery (PITR).

4. **For data sources not supported** by an automated backup solution or managed service such as on-premises data sources or message queues, consider using a trusted third-party solution to create automated backups. Alternatively, you can create automation to do this using the AWS CLI or SDKs. You can use AWS Lambda Functions or AWS Step Functions to define the logic involved in creating a data backup, and use Amazon EventBridge to invoke it at a frequency based on your RPO.

**Level of effort for the Implementation Plan:** Low

## Resources

### Related documents:

- [APN Partner: partners that can help with backup](#)
- [AWS Marketplace: products that can be used for backup](#)
- [Creating an EventBridge Rule That Triggers on a Schedule](#)
- [What Is AWS Backup?](#)
- [What Is AWS Step Functions?](#)
- [What is AWS Elastic Disaster Recovery?](#)

### Related videos:

- [AWS re:Invent 2019: Deep dive on AWS Backup, ft. Rackspace \(STG341\)](#)

### Related examples:

- [Well-Architected Lab - Testing Backup and Restore of Data](#)

## REL09-BP04 Perform periodic recovery of the data to verify backup integrity and processes

Validate that your backup process implementation meets your Recovery Time Objectives (RTO) and Recovery Point Objectives (RPO) by performing a recovery test.

**Desired outcome:** Data from backups is periodically recovered using well-defined mechanisms to verify that recovery is possible within the established recovery time objective (RTO) for the workload. Verify that restoration from a backup results in a resource that contains the original data without any of it being corrupted or inaccessible, and with data loss within the recovery point objective (RPO).

**Common anti-patterns:**

- Restoring a backup, but not querying or retrieving any data to check that the restoration is usable.
- Assuming that a backup exists.
- Assuming that the backup of a system is fully operational and that data can be recovered from it.
- Assuming that the time to restore or recover data from a backup falls within the RTO for the workload.
- Assuming that the data contained on the backup falls within the RPO for the workload
- Restoring when necessary, without using a runbook or outside of an established automated procedure.

**Benefits of establishing this best practice:** Testing the recovery of the backups verifies that data can be restored when needed without having any worry that data might be missing or corrupted, that the restoration and recovery is possible within the RTO for the workload, and any data loss falls within the RPO for the workload.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

Testing backup and restore capability increases confidence in the ability to perform these actions during an outage. Periodically restore backups to a new location and run tests to verify the integrity of the data. Some common tests that should be performed are checking if all data is available, is not corrupted, is accessible, and that any data loss falls within the RPO for the workload. Such tests can also help ascertain if recovery mechanisms are fast enough to accommodate the workload's RTO.

Using AWS, you can stand up a testing environment and restore your backups to assess RTO and RPO capabilities, and run tests on data content and integrity.

Additionally, Amazon RDS and Amazon DynamoDB allow point-in-time recovery (PITR). Using continuous backup, you can restore your dataset to the state it was in at a specified date and time.

If all the data is available, is not corrupted, is accessible, and any data loss falls within the RPO for the workload. Such tests can also help ascertain if recovery mechanisms are fast enough to accommodate the workload's RTO.

AWS Elastic Disaster Recovery offers continual point-in-time recovery snapshots of Amazon EBS volumes. As source servers are replicated, point-in-time states are chronicled over time based on the configured policy. Elastic Disaster Recovery helps you verify the integrity of these snapshots by launching instances for test and drill purposes without redirecting the traffic.

### Implementation steps

1. **Identify data sources** that are currently being backed up and where these backups are being stored. For implementation guidance, see [REL09-BP01 Identify and back up all data that needs to be backed up, or reproduce the data from sources](#).
2. **Establish criteria for data validation** for each data source. Different types of data will have different properties which might require different validation mechanisms. Consider how this data might be validated before you are confident to use it in production. Some common ways to validate data are using data and backup properties such as data type, format, checksum, size, or a combination of these with custom validation logic. For example, this might be a comparison of the checksum values between the restored resource and the data source at the time the backup was created.
3. **Establish RTO and RPO** for restoring the data based on data criticality. For implementation guidance, see [REL13-BP01 Define recovery objectives for downtime and data loss](#).
4. **Assess your recovery capability**. Review your backup and restore strategy to understand if it can meet your RTO and RPO, and adjust the strategy as necessary. Using [AWS Resilience Hub](#), you can run an assessment of your workload. The assessment evaluates your application configuration against the resiliency policy and reports if your RTO and RPO targets can be met.
5. **Do a test restore** using currently established processes used in production for data restoration. These processes depend on how the original data source was backed up, the format and storage location of the backup itself, or if the data is reproduced from other sources. For example, if you are using a managed service such as [AWS Backup, this might be as simple as restoring the backup into a new resource](#). If you used AWS Elastic Disaster Recovery you can [launch a recovery drill](#).



6. **Validate data recovery** from the restored resource based on criteria you previously established for data validation. Does the restored and recovered data contain the most recent record or item at the time of backup? Does this data fall within the RPO for the workload?
7. **Measure time required** for restore and recovery and compare it to your established RTO. Does this process fall within the RTO for the workload? For example, compare the timestamps from when the restoration process started and when the recovery validation completed to calculate how long this process takes. All AWS API calls are timestamped and this information is available in [AWS CloudTrail](#). While this information can provide details on when the restore process started, the end timestamp for when the validation was completed should be recorded by your validation logic. If using an automated process, then services like [Amazon DynamoDB](#) can be used to store this information. Additionally, many AWS services provide an event history which provides timestamped information when certain actions occurred. Within AWS Backup, backup and restore actions are referred to as *jobs*, and these jobs contain timestamp information as part of its metadata which can be used to measure time required for restoration and recovery.
8. **Notify stakeholders** if data validation fails, or if the time required for restoration and recovery exceeds the established RTO for the workload. When implementing automation to do this, [such as in this lab](#), services like Amazon Simple Notification Service (Amazon SNS) can be used to send push notifications such as email or SMS to stakeholders. [These messages can also be published to messaging applications such as Amazon Chime, Slack, or Microsoft Teams](#) or used to [create tasks as OpsItems using AWS Systems Manager OpsCenter](#).
9. **Automate this process to run periodically**. For example, services like AWS Lambda or a State Machine in AWS Step Functions can be used to automate the restore and recovery processes, and Amazon EventBridge can be used to invoke this automation workflow periodically as shown in the architecture diagram below. Learn how to [Automate data recovery validation with AWS Backup](#). Additionally, [this Well-Architected lab](#) provides a hands-on experience on one way to do automation for several of the steps here.

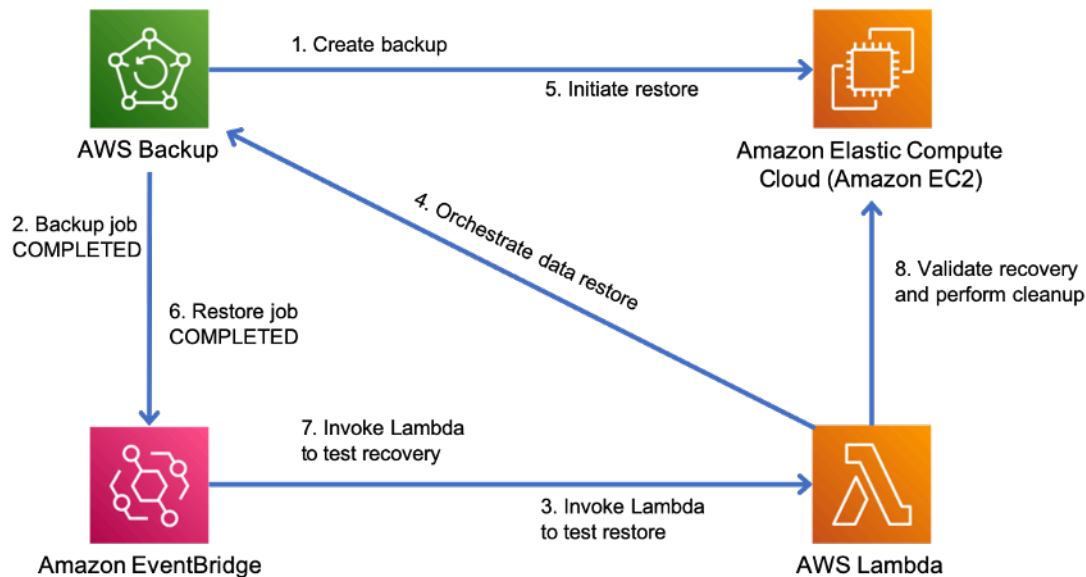


Figure 9. An automated backup and restore process

**Level of effort for the Implementation Plan:** Moderate to high depending on the complexity of the validation criteria.

## Resources

### Related documents:

- [Automate data recovery validation with AWS Backup](#)
- [APN Partner: partners that can help with backup](#)
- [AWS Marketplace: products that can be used for backup](#)
- [Creating an EventBridge Rule That Triggers on a Schedule](#)
- [On-demand backup and restore for DynamoDB](#)
- [What Is AWS Backup?](#)
- [What Is AWS Step Functions?](#)
- [What is AWS Elastic Disaster Recovery](#)
- [AWS Elastic Disaster Recovery](#)

### Related examples:

- [Well-Architected lab: Testing Backup and Restore of Data](#)

# Use fault isolation to protect your workload

Fault isolated boundaries limit the effect of a failure within a workload to a limited number of components. Components outside of the boundary are unaffected by the failure. Using multiple fault isolated boundaries, you can limit the impact on your workload.

## Best practices

- [REL10-BP01 Deploy the workload to multiple locations](#)
- [REL10-BP02 Select the appropriate locations for your multi-location deployment](#)
- [REL10-BP03 Automate recovery for components constrained to a single location](#)
- [REL10-BP04 Use bulkhead architectures to limit scope of impact](#)

## REL10-BP01 Deploy the workload to multiple locations

Distribute workload data and resources across multiple Availability Zones or, where necessary, across AWS Regions. These locations can be as diverse as required.

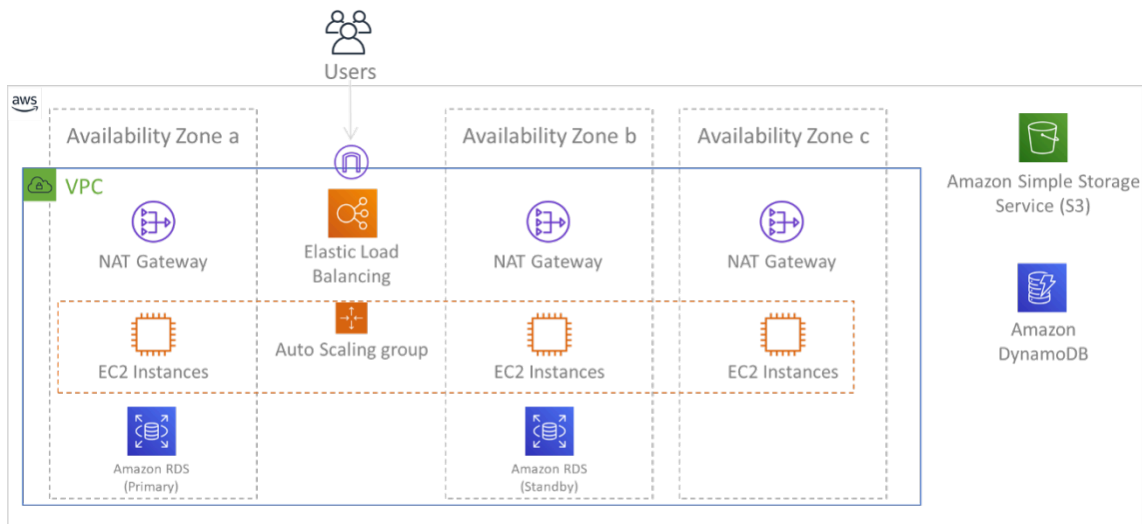
One of the bedrock principles for service design in AWS is the avoidance of single points of failure in underlying physical infrastructure. This motivates us to build software and systems that use multiple Availability Zones and are resilient to failure of a single zone. Similarly, systems are built to be resilient to failure of a single compute node, single storage volume, or single instance of a database. When building a system that relies on redundant components, it's important to ensure that the components operate independently, and in the case of AWS Regions, autonomously. The benefits achieved from theoretical availability calculations with redundant components are only valid if this holds true.

### Availability Zones (AZs)

AWS Regions are composed of multiple Availability Zones that are designed to be independent of each other. Each Availability Zone is separated by a meaningful physical distance from other zones to avoid correlated failure scenarios due to environmental hazards like fires, floods, and tornadoes. Each Availability Zone also has independent physical infrastructure: dedicated connections to utility power, standalone backup power sources, independent mechanical services, and independent network connectivity within and beyond the Availability Zone. This design limits faults in any of these systems to just the one affected AZ. Despite being geographically separated, Availability Zones are located in the same regional area which allows high-throughput, low-latency networking. The entire AWS Region (across all Availability Zones, consisting of multiple physically

independent data centers) can be treated as a single logical deployment target for your workload, including the ability to synchronously replicate data (for example, between databases). This allows you to use Availability Zones in an active/active or active/standby configuration.

Availability Zones are independent, and therefore workload availability is increased when the workload is architected to use multiple zones. Some AWS services (including the Amazon EC2 instance data plane) are deployed as strictly zonal services where they have shared fate with the Availability Zone they are in. Amazon EC2 instances in the other AZs will however be unaffected and continue to function. Similarly, if a failure in an Availability Zone causes an Amazon Aurora database to fail, a read-replica Aurora instance in an unaffected AZ can be automatically promoted to primary. Regional AWS services, such as Amazon DynamoDB on the other hand internally use multiple Availability Zones in an active/active configuration to achieve the availability design goals for that service, without you needing to configure AZ placement.



**Figure 9: Multi-tier architecture deployed across three Availability Zones. Note that Amazon S3 and Amazon DynamoDB are always Multi-AZ automatically. The ELB also is deployed to all three zones.**

While AWS control planes typically provide the ability to manage resources within the entire Region (multiple Availability Zones), certain control planes (including Amazon EC2 and Amazon EBS) have the ability to filter results to a single Availability Zone. When this is done, the request is processed only in the specified Availability Zone, reducing exposure to disruption in other Availability Zones. This AWS CLI example illustrates getting Amazon EC2 instance information from only the us-east-2c Availability Zone:

```
AWS ec2 describe-instances --filters Name=availability-zone,Values=us-east-2c
```

## AWS Local Zones

AWS Local Zones act similarly to Availability Zones within their respective AWS Region in that they can be selected as a placement location for zonal AWS resources such as subnets and EC2 instances. What makes them special is that they are located not in the associated AWS Region, but near large population, industry, and IT centers where no AWS Region exists today. Yet they still retain high-bandwidth, secure connection between local workloads in the local zone and those running in the AWS Region. You should use AWS Local Zones to deploy workloads closer to your users for low-latency requirements.

## Amazon Global Edge Network

Amazon Global Edge Network consists of edge locations in cities around the world. Amazon CloudFront uses this network to deliver content to end users with lower latency. AWS Global Accelerator allows you to create your workload endpoints in these edge locations to provide onboarding to the AWS global network close to your users. Amazon API Gateway allows edge-optimized API endpoints using a CloudFront distribution to facilitate client access through the closest edge location.

## AWS Regions

AWS Regions are designed to be autonomous, therefore, to use a multi-Region approach you would deploy dedicated copies of services to each Region.

A multi-Region approach is common for *disaster recovery* strategies to meet recovery objectives when one-off large-scale events occur. See [Plan for Disaster Recovery \(DR\)](#) for more information on these strategies. Here however, we focus instead on *availability*, which seeks to deliver a mean uptime objective over time. For high-availability objectives, a multi-region architecture will generally be designed to be active/active, where each service copy (in their respective regions) is active (serving requests).

### Recommendation

Availability goals for most workloads can be satisfied using a Multi-AZ strategy within a single AWS Region. Consider multi-Region architectures only when workloads have extreme availability requirements, or other business goals, that require a multi-Region architecture.

AWS provides you with the capabilities to operate services cross-region. For example, AWS provides continuous, asynchronous data replication of data using Amazon Simple Storage Service

(Amazon S3) Replication, Amazon RDS Read Replicas (including Aurora Read Replicas), and Amazon DynamoDB Global Tables. With continuous replication, versions of your data are available for near immediate use in each of your active Regions.

Using AWS CloudFormation, you can define your infrastructure and deploy it consistently across AWS accounts and across AWS Regions. And AWS CloudFormation StackSets extends this functionality by allowing you to create, update, or delete AWS CloudFormation stacks across multiple accounts and regions with a single operation. For Amazon EC2 instance deployments, an AMI (Amazon Machine Image) is used to supply information such as hardware configuration and installed software. You can implement an Amazon EC2 Image Builder pipeline that creates the AMIs you need and copy these to your active regions. This ensures that these *Golden AMIs* have everything you need to deploy and scale-out your workload in each new region.

To route traffic, both Amazon Route 53 and AWS Global Accelerator permit the definition of policies that determine which users go to which active regional endpoint. With Global Accelerator you set a traffic dial to control the percentage of traffic that is directed to each application endpoint. Route 53 supports this percentage approach, and also multiple other available policies including geoproximity and latency based ones. Global Accelerator automatically leverages the extensive network of AWS edge servers, to onboard traffic to the AWS network backbone as soon as possible, resulting in lower request latencies.

All of these capabilities operate so as to preserve each Region's autonomy. There are very few exceptions to this approach, including our services that provide global edge delivery (such as Amazon CloudFront and Amazon Route 53), along with the control plane for the AWS Identity and Access Management (IAM) service. Most services operate entirely within a single Region.

### **On-premises data center**

For workloads that run in an on-premises data center, architect a hybrid experience when possible. AWS Direct Connect provides a dedicated network connection from your premises to AWS allowing you to run in both.

Another option is to run AWS infrastructure and services on premises using AWS Outposts. AWS Outposts is a fully managed service that extends AWS infrastructure, AWS services, APIs, and tools to your data center. The same hardware infrastructure used in the AWS Cloud is installed in your data center. AWS Outposts are then connected to the nearest AWS Region. You can then use AWS Outposts to support your workloads that have low latency or local data processing requirements.

**Level of risk exposed if this best practice is not established: High**

## Implementation guidance

- Use multiple Availability Zones and AWS Regions. Distribute workload data and resources across multiple Availability Zones or, where necessary, across AWS Regions. These locations can be as diverse as required.
- Regional services are inherently deployed across Availability Zones.
  - This includes Amazon S3, Amazon DynamoDB, and AWS Lambda (when not connected to a VPC)
- Deploy your container, instance, and function-based workloads into multiple Availability Zones. Use multi-zone datastores, including caches. Use the features of Amazon EC2 Auto Scaling, Amazon ECS task placement, AWS Lambda function configuration when running in your VPC, and ElastiCache clusters.
  - Use subnets that are in separate Availability Zones when you deploy Auto Scaling groups.
    - [Example: Distributing instances across Availability Zones](#)
    - [Choosing Regions and Availability Zones](#)
  - Use ECS task placement parameters, specifying DB subnet groups.
    - [Amazon ECS task placement strategies](#)
  - Use subnets in multiple Availability Zones when you configure a function to run in your VPC.
    - [Configuring an AWS Lambda function to access resources in an Amazon VPC](#)
  - Use multiple Availability Zones with ElastiCache clusters.
    - [Choosing Regions and Availability Zones](#)
- If your workload must be deployed to multiple Regions, choose a multi-Region strategy. Most reliability needs can be met within a single AWS Region using a multi-Availability Zone strategy. Use a multi-Region strategy when necessary to meet your business needs.
  - [AWS re:Invent 2018: Architecture Patterns for Multi-Region Active-Active Applications \(ARC209-R2\)](#)
    - Backup to another AWS Region can add another layer of assurance that data will be available when needed.
    - Some workloads have regulatory requirements that require use of a multi-Region strategy.
- Evaluate AWS Outposts for your workload. If your workload requires low latency to your on-premises data center or has local data processing requirements. Then run AWS infrastructure and services on premises using AWS Outposts

- Determine if AWS Local Zones helps you provide service to your users. If you have low-latency requirements, see if AWS Local Zones is located near your users. If yes, then use it to deploy workloads closer to those users.
  - [AWS Local Zones FAQ](#)

## Resources

### Related documents:

- [AWS Global Infrastructure](#)
- [AWS Local Zones FAQ](#)
- [Amazon ECS task placement strategies](#)
- [Choosing Regions and Availability Zones](#)
- [Example: Distributing instances across Availability Zones](#)
- [Global Tables: Multi-Region Replication with DynamoDB](#)
- [Using Amazon Aurora global databases](#)
- [Creating a Multi-Region Application with AWS Services blog series](#)
- [What is AWS Outposts?](#)

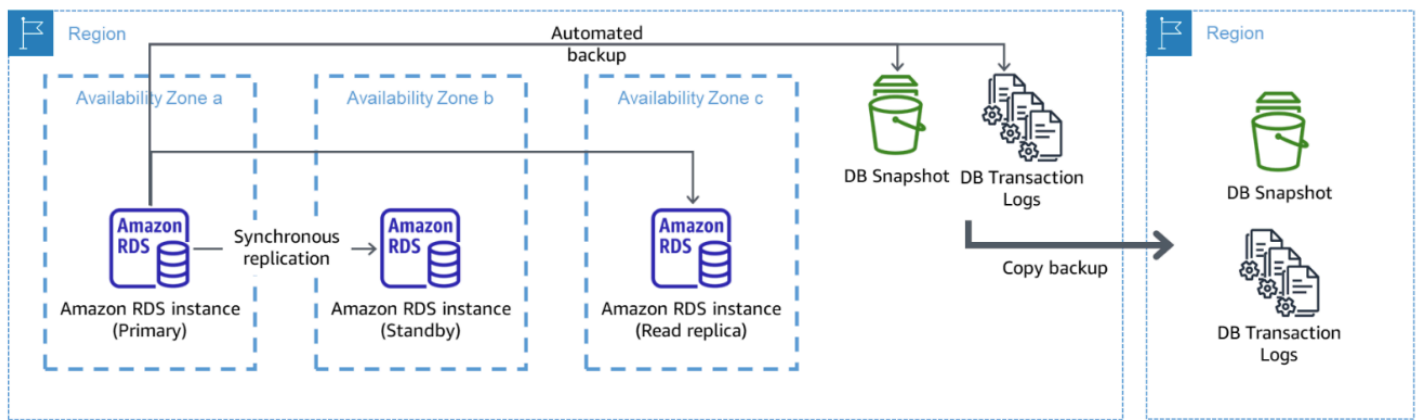
### Related videos:

- [AWS re:Invent 2018: Architecture Patterns for Multi-Region Active-Active Applications \(ARC209-R2\)](#)
- [AWS re:Invent 2019: Innovation and operation of the AWS global network infrastructure \(NET339\)](#)

## REL10-BP02 Select the appropriate locations for your multi-location deployment

**Desired outcome:** For high availability, always (when possible) deploy your workload components to multiple Availability Zones (AZs). For workloads with extreme resilience requirements, carefully evaluate the options for a multi-Region architecture.





### *A resilient multi-AZ database deployment with backup to another AWS Region*

#### **Common anti-patterns:**

- Choosing to design a multi-Region architecture when a multi-AZ architecture would satisfy requirements.
- Not accounting for dependencies between application components if resilience and multi-location requirements differ between those components.

**benefits of establishing this best practice:** For resilience, you should use an approach that builds layers of defense. One layer protects against smaller, more common, disruptions by building a highly available architecture using multiple AZs. Another layer of defense is meant to protect against rare events like widespread natural disasters and Region-level disruptions. This second layer involves architecting your application to span multiple AWS Regions.

- The difference between a 99.5% availability and 99.99% availability is over 3.5 hours per month. The expected availability of a workload can only reach “four nines” if it is in multiple AZs.
- By running your workload in multiple AZs, you can isolate faults in power, cooling, and networking, and most natural disasters like fire and flood.
- Implementing a multi-Region strategy for your workload helps protect it against widespread natural disasters that affect a large geographic region of a country, or technical failures of Region-wide scope. Be aware that implementing a multi-Region architecture can be significantly complex, and is usually not required for most workloads.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

For a disaster event based on disruption or partial loss of one Availability Zone, implementing a highly available workload in multiple Availability Zones within a single AWS Region helps mitigate against natural and technical disasters. Each AWS Region is comprised of multiple Availability Zones, each isolated from faults in the other zones and separated by a meaningful distance. However, for a disaster event that includes the risk of losing multiple Availability Zone components, which are a significant distance away from each other, you should implement disaster recovery options to mitigate against failures of a Region-wide scope. For workloads that require extreme resilience (critical infrastructure, health-related applications, financial system infrastructure, etc.), a multi-Region strategy may be required.

### Implementation Steps

1. Evaluate your workload and determine whether the resilience needs can be met by a multi-AZ approach (single AWS Region), or if they require a multi-Region approach. Implementing a multi-Region architecture to satisfy these requirements will introduce additional complexity, therefore carefully consider your use case and its requirements. Resilience requirements can almost always be met using a single AWS Region. Consider the following possible requirements when determining whether you need to use multiple Regions:
  - a. **Disaster recovery (DR):** For a disaster event based on disruption or partial loss of one Availability Zone, implementing a highly available workload in multiple Availability Zones within a single AWS Region helps mitigate against natural and technical disasters. For a disaster event that includes the risk of losing multiple Availability Zone components, which are a significant distance away from each other, you should implement disaster recovery across multiple Regions to mitigate against natural disasters or technical failures of a Region-wide scope.
  - b. **High availability (HA):** A multi-Region architecture (using multiple AZs in each Region) can be used to achieve greater than four 9's (> 99.99%) availability.
  - c. **Stack localization:** When deploying a workload to a global audience, you can deploy localized stacks in different AWS Regions to serve audiences in those Regions. Localization can include language, currency, and types of data stored.
  - d. **Proximity to users:** When deploying a workload to a global audience, you can reduce latency by deploying stacks in AWS Regions close to where the end users are.
  - e. **Data residency:** Some workloads are subject to data residency requirements, where data from certain users must remain within a specific country's borders. Based on the regulation in

question, you can choose to deploy an entire stack, or just the data, to the AWS Region within those borders.

2. Here are some examples of multi-AZ functionality provided by AWS services:

- a. To protect workloads using EC2 or ECS, deploy an Elastic Load Balancer in front of the compute resources. Elastic Load Balancing then provides the solution to detect instances in unhealthy zones and route traffic to the healthy ones.
  - i. [Getting started with Application Load Balancers](#)
  - ii. [Getting started with Network Load Balancers](#)
- b. In the case of EC2 instances running commercial off-the-shelf software that do not support load balancing, you can achieve a form of fault tolerance by implementing a multi-AZ disaster recovery methodology.
  - i. [the section called “REL13-BP02 Use defined recovery strategies to meet the recovery objectives”](#)
- c. For Amazon ECS tasks, deploy your service evenly across three AZs to achieve a balance of availability and cost.
  - i. [Amazon ECS availability best practices | Containers](#)
- d. For non-Aurora Amazon RDS, you can choose Multi-AZ as a configuration option. Upon failure of the primary database instance, Amazon RDS automatically promotes a standby database to receive traffic in another availability zone. Multi-Region read-replicas can also be created to improve resilience.
  - i. [Amazon RDS Multi AZ Deployments](#)
  - ii. [Creating a read replica in a different AWS Region](#)

3. Here are some examples of multi-Region functionality provided by AWS services:

- a. For Amazon S3 workloads, where multi-AZ availability is provided automatically by the service, consider Multi-Region Access Points if a multi-Region deployment is needed.
  - i. [Multi-Region Access Points in Amazon S3](#)
- b. For DynamoDB tables, where multi-AZ availability is provided automatically by the service, you can easily convert existing tables to global tables to take advantage of multiple regions.
  - i. [Convert Your Single-Region Amazon DynamoDB Tables to Global Tables](#)
- c. If your workload is fronted by Application Load Balancers or Network Load Balancers, use AWS Global Accelerator to improve the availability of your application by directing traffic to multiple regions that contain healthy endpoints.

- i. [Endpoints for standard accelerators in AWS Global Accelerator - AWS Global Accelerator \(amazon.com\)](#)
- d. For applications that leverage AWS EventBridge, consider cross-Region buses to forward events to other Regions you select.
  - i. [Sending and receiving Amazon EventBridge events between AWS Regions](#)
- e. For Amazon Aurora databases, consider Aurora global databases, which span multiple AWS regions. Existing clusters can be modified to add new Regions as well.
  - i. [Getting started with Amazon Aurora global databases](#)
- f. If your workload includes AWS Key Management Service (AWS KMS) encryption keys, consider whether multi-Region keys are appropriate for your application.
  - i. [Multi-Region keys in AWS KMS](#)
- g. For other AWS service features, see this blog series on [Creating a Multi-Region Application with AWS Services series](#)

**Level of effort for the Implementation Plan:** Moderate to High

## Resources

### Related documents:

- [Creating a Multi-Region Application with AWS Services series](#)
- [Disaster Recovery \(DR\) Architecture on AWS, Part IV: Multi-site Active/Active](#)
- [AWS Global Infrastructure](#)
- [AWS Local Zones FAQ](#)
- [Disaster Recovery \(DR\) Architecture on AWS, Part I: Strategies for Recovery in the Cloud](#)
- [Disaster recovery is different in the cloud](#)
- [Global Tables: Multi-Region Replication with DynamoDB](#)

### Related videos:

- [AWS re:Invent 2018: Architecture Patterns for Multi-Region Active-Active Applications \(ARC209-R2\)](#)
- [Auth0: Multi-Region High-Availability Architecture that Scales to 1.5B+ Logins a Month with automated failover](#)

## Related examples:

- [Disaster Recovery \(DR\) Architecture on AWS, Part I: Strategies for Recovery in the Cloud](#)
- [DTCC achieves resilience well beyond what they can do on premises](#)
- [Expedia Group uses a multi-Region, multi-Availability Zone architecture with a proprietary DNS service to add resilience to the applications](#)
- [Uber: Disaster Recovery for Multi-Region Kafka](#)
- [Netflix: Active-Active for Multi-Regional Resilience](#)
- [How we build Data Residency for Atlassian Cloud](#)
- [Intuit TurboTax runs across two Regions](#)

## REL10-BP03 Automate recovery for components constrained to a single location

If components of the workload can only run in a single Availability Zone or in an on-premises data center, implement the capability to do a complete rebuild of the workload within your defined recovery objectives.

**Level of risk exposed if this best practice is not established:** Medium

### Implementation guidance

If the best practice to deploy the workload to multiple locations is not possible due to technological constraints, you must implement an alternate path to resiliency. You must automate the ability to recreate necessary infrastructure, redeploy applications, and recreate necessary data for these cases.

For example, Amazon EMR launches all nodes for a given cluster in the same Availability Zone because running a cluster in the same zone improves performance of the jobs flows as it provides a higher data access rate. If this component is required for workload resilience, then you must have a way to redeploy the cluster and its data. Also for Amazon EMR, you should provision redundancy in ways other than using Multi-AZ. You can provision [multiple nodes](#). Using [EMR File System \(EMRFS\)](#), data in EMR can be stored in Amazon S3, which in turn can be replicated across multiple Availability Zones or AWS Regions.

Similarly, for Amazon Redshift, by default it provisions your cluster in a randomly selected Availability Zone within the AWS Region that you select. All the cluster nodes are provisioned in the same zone.

For stateful server-based workloads deployed to an on-premise data center, you can use AWS Elastic Disaster Recovery to protect your workloads in AWS. If you are already hosted in AWS, you can use Elastic Disaster Recovery to protect your workload to an alternative Availability Zone or Region. Elastic Disaster Recovery uses continual block-level replication to a lightweight staging area to provide fast, reliable recovery of on-premises and cloud-based applications.

## Implementation steps

1. Implement self-healing. Deploy your instances or containers using automatic scaling when possible. If you cannot use automatic scaling, use automatic recovery for EC2 instances or implement self-healing automation based on Amazon EC2 or ECS container lifecycle events.
  - Use [Amazon EC2 Auto Scaling groups](#) for instances and container workloads that have no requirements for a single instance IP address, private IP address, Elastic IP address, and instance metadata.
    - The launch template user data can be used to implement automation that can self-heal most workloads.
  - Use automatic [recovery of Amazon EC2 instances](#) for workloads that require a single instance ID address, private IP address, elastic IP address, and instance metadata.
    - Automatic Recovery will send recovery status alerts to a SNS topic as the instance failure is detected.
  - Use [Amazon EC2 instance lifecycle events](#) or [Amazon ECS events](#) to automate self-healing where automatic scaling or EC2 recovery cannot be used.
    - Use the events to invoke automation that will heal your component according to the process logic you require.
  - Protect stateful workloads that are limited to a single location using [AWS Elastic Disaster Recovery](#).

## Resources

### Related documents:

- [Amazon ECS events](#)

- [Amazon EC2 Auto Scaling lifecycle hooks](#)
- [Recover your instance.](#)
- [Service automatic scaling](#)
- [What Is Amazon EC2 Auto Scaling?](#)
- [AWS Elastic Disaster Recovery](#)

## REL10-BP04 Use bulkhead architectures to limit scope of impact

Implement bulkhead architectures (also known as cell-based architectures) to restrict the effect of failure within a workload to a limited number of components.

**Desired outcome:** A cell-based architecture uses multiple isolated instances of a workload, where each instance is known as a cell. Each cell is independent, does not share state with other cells, and handles a subset of the overall workload requests. This reduces the potential impact of a failure, such as a bad software update, to an individual cell and the requests it is processing. If a workload uses 10 cells to service 100 requests, when a failure occurs, 90% of the overall requests would be unaffected by the failure.

### Common anti-patterns:

- Allowing cells to grow without bounds.
- Applying code updates or deployments to all cells at the same time.
- Sharing state or components between cells (with the exception of the router layer).
- Adding complex business or routing logic to the router layer.
- Not minimizing cross-cell interactions.

**Benefits of establishing this best practice:** With cell-based architectures, many common types of failure are contained within the cell itself, providing additional fault isolation. These fault boundaries can provide resilience against failure types that otherwise are hard to contain, such as unsuccessful code deployments or requests that are corrupted or invoke a specific failure mode (also known as *poison pill requests*).

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

On a ship, bulkheads ensure that a hull breach is contained within one section of the hull. In complex systems, this pattern is often replicated to allow fault isolation. Fault isolated boundaries restrict the effect of a failure within a workload to a limited number of components. Components outside of the boundary are unaffected by the failure. Using multiple fault isolated boundaries, you can limit the impact on your workload. On AWS, customers can use multiple Availability Zones and Regions to provide fault isolation, but the concept of fault isolation can be extended to your workload's architecture as well.

The overall workload is partitioned cells by a partition key. This key needs to align with the *grain* of the service, or the natural way that a service's workload can be subdivided with minimal cross-cell interactions. Examples of partition keys are customer ID, resource ID, or any other parameter easily accessible in most API calls. A cell routing layer distributes requests to individual cells based on the partition key and presents a single endpoint to clients.

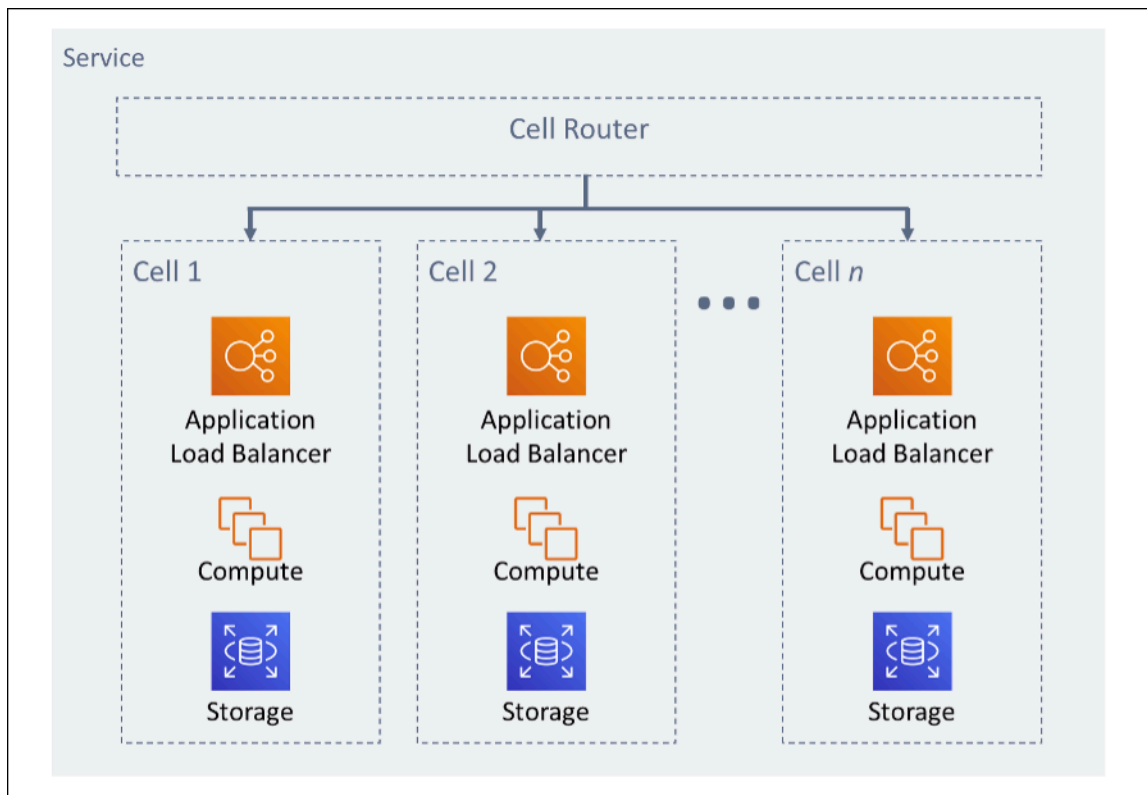


Figure 11: Cell-based architecture

## Implementation steps

When designing a cell-based architecture, there are several design considerations to consider:



1. **Partition key:** Special consideration should be taken while choosing the partition key.
  - It should align with the grain of the service, or the natural way that a service's workload can be subdivided with minimal cross-cell interactions. Examples are customer ID or resource ID.
  - The partition key must be available in all requests, either directly or in a way that could be easily inferred deterministically by other parameters.
2. **Persistent cell mapping:** Upstream services should only interact with a single cell for the lifecycle of their resources.
  - Depending on the workload, a cell migration strategy may be needed to migrate data from one cell to another. A possible scenario when a cell migration may be needed is if a particular user or resource in your workload becomes too big and requires it to have a dedicated cell.
  - Cells should not share state or components between cells.
  - Consequently, cross-cell interactions should be avoided or kept to a minimum, as those interactions create dependencies between cells and therefore diminish the fault isolation improvements.
3. **Router layer:** The router layer is a shared component between cells, and therefore cannot follow the same compartmentalization strategy as with cells.
  - It is recommended for the router layer to distribute requests to individual cells using a partition mapping algorithm in a computationally efficient manner, such as combining cryptographic hash functions and modular arithmetic to map partition keys to cells.
  - To avoid multi-cell impacts, the routing layer must remain as simple and horizontally scalable as possible, which necessitates avoiding complex business logic within this layer. This has the added benefit of making it easy to understand its expected behavior at all times, allowing for thorough testability. As explained by Colm MacCárthaigh in [Reliability, constant work, and a good cup of coffee](#), simple designs and constant work patterns produce reliable systems and reduce anti-fragility.
4. **Cell size:** Cells should have a maximum size and should not be allowed to grow beyond it.
  - The maximum size should be identified by performing thorough testing, until breaking points are reached and safe operating margins are established. For more detail on how to implement testing practices, see [REL07-BP04 Load test your workload](#)
  - The overall workload should grow by adding additional cells, allowing the workload to scale with increases in demand.
5. **Multi-AZ or Multi-Region strategies:** Multiple layers of resilience should be leveraged to protect against different failure domains.

- For resilience, you should use an approach that builds layers of defense. One layer protects against smaller, more common disruptions by building a highly available architecture using multiple AZs. Another layer of defense is meant to protect against rare events like widespread natural disasters and Region-level disruptions. This second layer involves architecting your application to span multiple AWS Regions. Implementing a multi-Region strategy for your workload helps protect it against widespread natural disasters that affect a large geographic region of a country, or technical failures of Region-wide scope. Be aware that implementing a multi-Region architecture can be significantly complex, and is usually not required for most workloads. For more detail, see [REL10-BP02 Select the appropriate locations for your multi-location deployment](#).
6. **Code deployment:** A staggered code deployment strategy should be preferred over deploying code changes to all cells at the same time.
- This helps minimize potential failure to multiple cells due to a bad deployment or human error. For more detail, see [Automating safe, hands-off deployment](#).

## Resources

### Related best practices:

- [REL07-BP04 Load test your workload](#)
- [REL10-BP02 Select the appropriate locations for your multi-location deployment](#)

### Related documents:

- [Reliability, constant work, and a good cup of coffee](#)
- [AWS and Compartmentalization](#)
- [Workload isolation using shuffle-sharding](#)
- [Automating safe, hands-off deployment](#)

### Related videos:

- [AWS re:Invent 2018: Close Loops and Opening Minds: How to Take Control of Systems, Big and Small](#)
- [AWS re:Invent 2018: How AWS Minimizes the Blast Radius of Failures \(ARC338\)](#)
- [Shuffle-sharding: AWS re:Invent 2019: Introducing The Amazon Builders' Library \(DOP328\)](#)

- [AWS Summit ANZ 2021 - Everything fails, all the time: Designing for resilience](#)

### Related examples:

- [Well-Architected Lab - Fault isolation with shuffle sharding](#)

## Design your workload to withstand component failures

Workloads with a requirement for high availability and low mean time to recovery (MTTR) must be architected for resiliency.

### Best practices

- [REL11-BP01 Monitor all components of the workload to detect failures](#)
- [REL11-BP02 Fail over to healthy resources](#)
- [REL11-BP03 Automate healing on all layers](#)
- [REL11-BP04 Rely on the data plane and not the control plane during recovery](#)
- [REL11-BP05 Use static stability to prevent bimodal behavior](#)
- [REL11-BP06 Send notifications when events impact availability](#)
- [REL11-BP07 Architect your product to meet availability targets and uptime service level agreements \(SLAs\)](#)

### REL11-BP01 Monitor all components of the workload to detect failures

Continually monitor the health of your workload so that you and your automated systems are aware of failures or degradations as soon as they occur. Monitor for key performance indicators (KPIs) based on business value.

All recovery and healing mechanisms must start with the ability to detect problems quickly. Technical failures should be detected first so that they can be resolved. However, availability is based on the ability of your workload to deliver business value, so key performance indicators (KPIs) that measure this need to be a part of your detection and remediation strategy.

**Desired outcome:** Essential components of a workload are monitored independently to detect and alert on failures when and where they happen.

### Common anti-patterns:

- No alarms have been configured, so outages occur without notification.
- Alarms exist, but at thresholds that don't provide adequate time to react.
- Metrics are not collected often enough to meet the recovery time objective (RTO).
- Only the customer facing interfaces of the workload are actively monitored.
- Only collecting technical metrics, no business function metrics.
- No metrics measuring the user experience of the workload.
- Too many monitors are created.

**Benefits of establishing this best practice:** Having appropriate monitoring at all layers allows you to reduce recovery time by reducing time to detection.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

Identify all workloads that will be reviewed for monitoring. Once you have identified all components of the workload that will need to be monitored, you will now need to determine the monitoring interval. The monitoring interval will have a direct impact on how fast recovery can be initiated based on the time it takes to detect a failure. The mean time to detection (MTTD) is the amount of time between a failure occurring and when repair operations begin. The list of services should be extensive and complete.

Monitoring must cover all layers of the application stack including application, platform, infrastructure, and network.

Your monitoring strategy should consider the impact of *gray failures*. For more detail on gray failures, see [Gray failures](#) in the Advanced Multi-AZ Resilience Patterns whitepaper.

## Implementation steps

- Your monitoring interval is dependent on how quickly you must recover. Your recovery time is driven by the time it takes to recover, so you must determine the frequency of collection by accounting for this time and your recovery time objective (RTO).
- Configure detailed monitoring for components and managed services.
  - Determine if [detailed monitoring for EC2 instances](#) and [Auto Scaling](#) is necessary. Detailed monitoring provides one minute interval metrics, and default monitoring provides five minute interval metrics.

- Determine if [enhanced monitoring](#) for RDS is necessary. Enhanced monitoring uses an agent on RDS instances to get useful information about different process or threads.
- Determine the monitoring requirements of critical serverless components for [Lambda](#), [API Gateway](#), [Amazon EKS](#), [Amazon ECS](#), and all types of [load balancers](#).
- Determine the monitoring requirements of storage components for [Amazon S3](#), [Amazon FSx](#), [Amazon EFS](#), and [Amazon EBS](#).
- Create [custom metrics](#) to measure business key performance indicators (KPIs). Workloads implement key business functions, which should be used as KPIs that help identify when an indirect problem happens.
- Monitor the user experience for failures using user canaries. [Synthetic transaction testing](#) (also known as canary testing, but not to be confused with canary deployments) that can run and simulate customer behavior is among the most important testing processes. Run these tests constantly against your workload endpoints from diverse remote locations.
- Create [custom metrics](#) that track the user's experience. If you can instrument the experience of the customer, you can determine when the consumer experience degrades.
- [Set alarms](#) to detect when any part of your workload is not working properly and to indicate when to automatically scale resources. Alarms can be visually displayed on dashboards, send alerts through Amazon SNS or email, and work with Auto Scaling to scale workload resources up or down.
- Create [dashboards](#) to visualize your metrics. Dashboards can be used to visually see trends, outliers, and other indicators of potential problems or to provide an indication of problems you may want to investigate.
- Create [distributed tracing monitoring](#) for your services. With distributed monitoring, you can understand how your application and its underlying services are performing to identify and troubleshoot the root cause of performance issues and errors.
- Create monitoring systems (using [CloudWatch](#) or [X-Ray](#)) dashboards and data collection in a separate Region and account.
- Create integration for [Amazon Health Aware](#) monitoring to allow for monitoring visibility to AWS resources that might have degradations. For business essential workloads, this solution provides access to proactive and real-time alerts for AWS services.

## Resources

### Related best practices:

- [Availability Definition](#)
- [REL11-BP06 Send Notifications when events impact availability](#)

**Related documents:**

- [Amazon CloudWatch Synthetics enables you to create user canaries](#)
- [Enable or Disable Detailed Monitoring for Your Instance](#)
- [Enhanced Monitoring](#)
- [Monitoring Your Auto Scaling Groups and Instances Using Amazon CloudWatch](#)
- [Publishing Custom Metrics](#)
- [Using Amazon CloudWatch Alarms](#)
- [Using CloudWatch Dashboards](#)
- [Using Cross Region Cross Account CloudWatch Dashboards](#)
- [Using Cross Region Cross Account X-Ray Tracing](#)
- [Understanding availability](#)
- [Implementing Amazon Health Aware \(AHA\)](#)

**Related videos:**

- [Mitigating gray failures](#)

**Related examples:**

- [Well-Architected Lab: Level 300: Implementing Health Checks and Managing Dependencies to Improve Reliability](#)
- [One Observability Workshop: Explore X-Ray](#)

**Related tools:**

- [CloudWatch](#)
- [CloudWatch X-Ray](#)

## REL11-BP02 Fail over to healthy resources

If a resource failure occurs, healthy resources should continue to serve requests. For location impairments (such as Availability Zone or AWS Region), ensure that you have systems in place to fail over to healthy resources in unimpaired locations.

When designing a service, distribute load across resources, Availability Zones, or Regions. Therefore, failure of an individual resource or impairment can be mitigated by shifting traffic to remaining healthy resources. Consider how services are discovered and routed to in the event of a failure.

Design your services with fault recovery in mind. At AWS, we design services to minimize the time to recover from failures and impact on data. Our services primarily use data stores that acknowledge requests only after they are durably stored across multiple replicas within a Region. They are constructed to use cell-based isolation and use the fault isolation provided by Availability Zones. We use automation extensively in our operational procedures. We also optimize our replace-and-restart functionality to recover quickly from interruptions.

The patterns and designs that allow for the failover vary for each AWS platform service. Many AWS native managed services are natively multiple Availability Zone (like Lambda or API Gateway). Other AWS services (like EC2 and EKS) require specific best practice designs to support failover of resources or data storage across AZs.

Monitoring should be set up to check that the failover resource is healthy, track the progress of the resources failing over, and monitor business process recovery.

**Desired outcome:** Systems are capable of automatically or manually using new resources to recover from degradation.

### **Common anti-patterns:**

- Planning for failure is not part of the planning and design phase.
- RTO and RPO are not established.
- Insufficient monitoring to detect failing resources.
- Proper isolation of failure domains.
- Multi-Region fail over is not considered.
- Detection for failure is too sensitive or aggressive when deciding to failover.
- Not testing or validating failover design.

- Performing auto healing automation, but not notifying that healing was needed.
- Lack of dampening period to avoid failing back too soon.

**Benefits of establishing this best practice:** You can build more resilient systems that maintain reliability when experiencing failures by degrading gracefully and recovering quickly.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

AWS services, such as [Elastic Load Balancing](#) and [Amazon EC2 Auto Scaling](#), help distribute load across resources and Availability Zones. Therefore, failure of an individual resource (such as an EC2 instance) or impairment of an Availability Zone can be mitigated by shifting traffic to remaining healthy resources.

For multi-Region workloads, designs are more complicated. For example, cross-Region read replicas allow you to deploy your data to multiple AWS Regions. However, failover is still required to promote the read replica to primary and then point your traffic to the new endpoint. Amazon Route 53, Route 53 Route 53 ARC, CloudFront, and AWS Global Accelerator can help route traffic across AWS Regions.

AWS services, such as Amazon S3, Lambda, API Gateway, Amazon SQS, Amazon SNS, Amazon SES, Amazon Pinpoint, Amazon ECR, AWS Certificate Manager, EventBridge, or Amazon DynamoDB, are automatically deployed to multiple Availability Zones by AWS. In case of failure, these AWS services automatically route traffic to healthy locations. Data is redundantly stored in multiple Availability Zones and remains available.

For Amazon RDS, Amazon Aurora, Amazon Redshift, Amazon EKS, or Amazon ECS, Multi-AZ is a configuration option. AWS can direct traffic to the healthy instance if failover is initiated. This failover action may be taken by AWS or as required by the customer

For Amazon EC2 instances, Amazon Redshift, Amazon ECS tasks, or Amazon EKS pods, you choose which Availability Zones to deploy to. For some designs, Elastic Load Balancing provides the solution to detect instances in unhealthy zones and route traffic to the healthy ones. Elastic Load Balancing can also route traffic to components in your on-premises data center.

For Multi-Region traffic failover, rerouting can leverage Amazon Route 53, Route 53 ARC, AWS Global Accelerator, Route 53 Private DNS for VPCs, or CloudFront to provide a way to define internet domains and assign routing policies, including health checks, to route traffic to healthy Regions. AWS Global Accelerator provides static IP addresses that act as a fixed entry point to



your application, then route to endpoints in AWS Regions of your choosing, using the AWS global network instead of the internet for better performance and reliability.

## Implementation steps

- Create failover designs for all appropriate applications and services. Isolate each architecture component and create failover designs meeting RTO and RPO for each component.
- Configure lower environments (like development or test) with all services that are required to have a failover plan. Deploy the solutions using infrastructure as code (IaC) to ensure repeatability.
- Configure a recovery site such as a second Region to implement and test the failover designs. If necessary, resources for testing can be configured temporarily to limit additional costs.
- Determine which failover plans are automated by AWS, which can be automated by a DevOps process, and which might be manual. Document and measure each service's RTO and RPO.
- Create a failover playbook and include all steps to failover each resource, application, and service.
- Create a failback playbook and include all steps to failback (with timing) each resource, application, and service
- Create a plan to initiate and rehearse the playbook. Use simulations and chaos testing to test the playbook steps and automation.
- For location impairment (such as Availability Zone or AWS Region), ensure you have systems in place to fail over to healthy resources in unimpaired locations. Check quota, autoscaling levels, and resources running before failover testing.

## Resources

### Related Well-Architected best practices:

- [REL13- Plan for DR](#)
- [REL10 - Use fault isolation to protect your workload](#)

### Related documents:

- [Setting RTO and RPO Targets](#)
- [Set up Route 53 ARC with application loadbalancers](#)
- [Failover using Route 53 Weighted routing](#)

- [DR with Route 53 ARC](#)
- [EC2 with autoscaling](#)
- [EC2 Deployments - Multi-AZ](#)
- [ECS Deployments - Multi-AZ](#)
- [Switch traffic using Route 53 ARC](#)
- [Lambda with an Application Load Balancer and Failover](#)
- [ACM Replication and Failover](#)
- [Parameter Store Replication and Failover](#)
- [ECR cross region replication and Failover](#)
- [Secrets manager cross region replication configuration](#)
- [Enable cross region replication for EFS and Failover](#)
- [EFS Cross Region Replication and Failover](#)
- [Networking Failover](#)
- [S3 Endpoint failover using MRAP](#)
- [Create cross region replication for S3](#)
- [Failover Regional API Gateway with Route 53 ARC](#)
- [Failover using multi-region global accelerator](#)
- [Failover with DRS](#)
- [Creating Disaster Recovery Mechanisms Using Amazon Route 53](#)

#### Related examples:

- [Disaster Recovery on AWS](#)
- [Elastic Disaster Recovery on AWS](#)

## REL11-BP03 Automate healing on all layers

Upon detection of a failure, use automated capabilities to perform actions to remediate. Degradations may be automatically healed through internal service mechanisms or require resources to be restarted or removed through remediation actions.

For self-managed applications and cross-Region healing, recovery designs and automated healing processes can be pulled from [existing best practices](#).

The ability to restart or remove a resource is an important tool to remediate failures. A best practice is to make services stateless where possible. This prevents loss of data or availability on resource restart. In the cloud, you can (and generally should) replace the entire resource (for example, a compute instance or serverless function) as part of the restart. The restart itself is a simple and reliable way to recover from failure. Many different types of failures occur in workloads. Failures can occur in hardware, software, communications, and operations.

Restarting or retrying also applies to network requests. Apply the same recovery approach to both a network timeout and a dependency failure where the dependency returns an error. Both events have a similar effect on the system, so rather than attempting to make either event a special case, apply a similar strategy of limited retry with exponential backoff and jitter. Ability to restart is a recovery mechanism featured in recovery-oriented computing and high availability cluster architectures.

**Desired outcome:** Automated actions are performed to remediate detection of a failure.

**Common anti-patterns:**

- Provisioning resources without autoscaling.
- Deploying applications in instances or containers individually.
- Deploying applications that cannot be deployed into multiple locations without using automatic recovery.
- Manually healing applications that automatic scaling and automatic recovery fail to heal.
- No automation to failover databases.
- Lack automated methods to reroute traffic to new endpoints.
- No storage replication.

**Benefits of establishing this best practice:** Automated healing can reduce your mean time to recovery and improve your availability.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

Designs for Amazon EKS or other Kubernetes services should include both minimum and maximum replica or stateful sets and the minimum cluster and node group sizing. These mechanisms provide

a minimum amount of continually-available processing resources while automatically remediating any failures using the Kubernetes control plane.

Design patterns that are accessed through a load balancer using compute clusters should leverage Auto Scaling groups. Elastic Load Balancing (ELB) automatically distributes incoming application traffic across multiple targets and virtual appliances in one or more Availability Zones (AZs).

Clustered compute-based designs that do not use load balancing should have their size designed for loss of at least one node. This will allow for the service to maintain itself running in potentially reduced capacity while it's recovering a new node. Example services are Mongo, DynamoDB Accelerator, Amazon Redshift, Amazon EMR, Cassandra, Kafka, MSK-EC2, Couchbase, ELK, and Amazon OpenSearch Service. Many of these services can be designed with additional auto healing features. Some cluster technologies must generate an alert upon the loss a node triggering an automated or manual workflow to recreate a new node. This workflow can be automated using AWS Systems Manager to remediate issues quickly.

Amazon EventBridge can be used to monitor and filter for events such as CloudWatch alarms or changes in state in other AWS services. Based on event information, it can then invoke AWS Lambda, Systems Manager Automation, or other targets to run custom remediation logic on your workload. Amazon EC2 Auto Scaling can be configured to check for EC2 instance health. If the instance is in any state other than running, or if the system status is impaired, Amazon EC2 Auto Scaling considers the instance to be unhealthy and launches a replacement instance. For large-scale replacements (such as the loss of an entire Availability Zone), static stability is preferred for high availability.

## Implementation steps

- Use Auto Scaling groups to deploy tiers in a workload. [Auto Scaling](#) can perform self-healing on stateless applications and add or remove capacity.
- For compute instances noted previously, use [load balancing](#) and choose the appropriate type of load balancer.
- Consider healing for Amazon RDS. With standby instances, configure for [auto failover](#) to the standby instance. For Amazon RDS Read Replica, automated workflow is required to make a read replica primary.
- Implement [automatic recovery on EC2 instances](#) that have applications deployed that cannot be deployed in multiple locations, and can tolerate rebooting upon failures. Automatic recovery can be used to replace failed hardware and restart the instance when the application is not capable of being deployed in multiple locations. The instance metadata and associated IP addresses are

kept, as well as the [EBS volumes](#) and mount points to [Amazon Elastic File System](#) or [File Systems for Lustre](#) and [Windows](#). Using [AWS OpsWorks](#), you can configure automatic healing of EC2 instances at the layer level.

- Implement automated recovery using [AWS Step Functions](#) and [AWS Lambda](#) when you cannot use automatic scaling or automatic recovery, or when automatic recovery fails. When you cannot use automatic scaling, and either cannot use automatic recovery or automatic recovery fails, you can automate the healing using AWS Step Functions and AWS Lambda.
- [Amazon EventBridge](#) can be used to monitor and filter for events such as [CloudWatch alarms](#) or changes in state in other AWS services. Based on event information, it can then invoke AWS Lambda (or other targets) to run custom remediation logic on your workload.

## Resources

### Related best practices:

- [Availability Definition](#)
- [REL11-BP01 Monitor all components of the workload to detect failures](#)

### Related documents:

- [How AWS Auto Scaling Works](#)
- [Amazon EC2 Automatic Recovery](#)
- [Amazon Elastic Block Store \(Amazon EBS\)](#)
- [Amazon Elastic File System \(Amazon EFS\)](#)
- [What is Amazon FSx for Lustre?](#)
- [What is Amazon FSx for Windows File Server?](#)
- [AWS OpsWorks: Using Auto Healing to Replace Failed Instances](#)
- [What is AWS Step Functions?](#)
- [What is AWS Lambda?](#)
- [What Is Amazon EventBridge?](#)
- [Using Amazon CloudWatch Alarms](#)
- [Amazon RDS Failover](#)
- [SSM - Systems Manager Automation](#)

- [Resilient Architecture Best Practices](#)

**Related videos:**

- [Automatically Provision and Scale OpenSearch Service](#)
- [Amazon RDS Failover Automatically](#)

**Related examples:**

- [Workshop on Auto Scaling](#)
- [Amazon RDS Failover Workshop](#)

**Related tools:**

- [CloudWatch](#)
- [CloudWatch X-Ray](#)

## REL11-BP04 Rely on the data plane and not the control plane during recovery

Control planes provide the administrative APIs used to create, read and describe, update, delete, and list (CRUDL) resources, while data planes handle day-to-day service traffic. When implementing recovery or mitigation responses to potentially resiliency-impacting events, focus on using a minimal number of control plane operations to recover, rescale, restore, heal, or failover the service. Data plane action should supersede any activity during these degradation events.

For example, the following are all control plane actions: launching a new compute instance, creating block storage, and describing queue services. When you launch compute instances, the control plane has to perform multiple tasks like finding a physical host with capacity, allocating network interfaces, preparing local block storage volumes, generating credentials, and adding security rules. Control planes tend to be complicated orchestration.

**Desired outcome:** When a resource enters an impaired state, the system is capable of automatically or manually recovering by shifting traffic from impaired to healthy resources.

**Common anti-patterns:**

- Dependence on changing DNS records to re-route traffic.
- Dependence on control-plane scaling operations to replace impaired components due to insufficiently provisioned resources.
- Relying on extensive, multi service, multi-API control plane actions to remediate any category of impairment.

**Benefits of establishing this best practice:** Increased success rate for automated remediation can reduce your mean time to recovery and improve availability of the workload.

**Level of risk exposed if this best practice is not established:** Medium: For certain types of service degradations, control planes are affected. Dependencies on extensive use of the control plane for remediation may increase recovery time (RTO) and mean time to recovery (MTTR).

## Implementation guidance

To limit data plane actions, assess each service for what actions are required to restore service.

Leverage Amazon Route 53 Application Recovery Controller to shift the DNS traffic. These features continually monitor your application's ability to recover from failures and allow you to control your application recovery across multiple AWS Regions, Availability Zones, and on premises.

Route 53 routing policies use the control plane, so do not rely on it for recovery. The Route 53 data planes answer DNS queries and perform and evaluate health checks. They are globally distributed and designed for a [100% availability service level agreement \(SLA\)](#).

The Route 53 management APIs and consoles where you create, update, and delete Route 53 resources run on control planes that are designed to prioritize the strong consistency and durability that you need when managing DNS. To achieve this, the control planes are located in a single Region: US East (N. Virginia). While both systems are built to be very reliable, the control planes are not included in the SLA. There could be rare events in which the data plane's resilient design allows it to maintain availability while the control planes do not. For disaster recovery and failover mechanisms, use data plane functions to provide the best possible reliability.

For Amazon EC2, use static stability designs to limit control plane actions. Control plane actions include the scaling up of resources individually or using Auto Scaling groups (ASG). For the highest levels of resilience, provision sufficient capacity in the cluster used for failover. If this capacity threshold must be limited, set throttles on the overall end-to-end system to safely limit the total traffic reaching the limited set of resources.

For services like Amazon DynamoDB, Amazon API Gateway, load balancers, and AWS Lambda serverless, using those services leverages the data plane. However, creating new functions, load balancers, API gateways, or DynamoDB tables is a control plane action and should be completed before the degradation as preparation for an event and rehearsal of failover actions. For Amazon RDS, data plane actions allow for access to data.

For more information about data planes, control planes, and how AWS builds services to meet high availability targets, see [Static stability using Availability Zones](#).

Understand which operations are on the data plane and which are on the control plane.

### Implementation steps

For each workload that needs to be restored after a degradation event, evaluate the failover runbook, high availability design, auto healing design, or HA resource restoration plan. Identity each action that might be considered a control plane action.

Consider changing the control action to a data plane action:

- Auto Scaling (control plane) compared to pre-scaled Amazon EC2 resources (data plane)
- Migrate to Lambda and its scaling methods (data plane) or Amazon EC2 and ASG (control plane)
- Assess any designs using Kubernetes and the nature of the control plane actions. Adding pods is a data plane action in Kubernetes. Actions should be limited to adding pods and not adding nodes. Using [over-provisioned nodes](#) is the preferred method to limit control plane actions

Consider alternate approaches that allow for data plane actions to affect the same remediation.

- Route 53 Record change (control plane) or Route 53 ARC (data plane)
- [Route 53 Health checks for more automated updates](#)

Consider some services in a secondary Region, if the service is mission critical, to allow for more control plane and data plane actions in an unaffected Region.

- Amazon EC2 Auto Scaling or Amazon EKS in a primary Region compared to Amazon EC2 Auto Scaling or Amazon EKS in a secondary Region and routing traffic to secondary Region (control plane action)
- Make read replica in secondary primary or attempting same action in primary Region (control plane action)



## Resources

### Related best practices:

- [Availability Definition](#)
- [REL11-BP01 Monitor all components of the workload to detect failures](#)

### Related documents:

- [APN Partner: partners that can help with automation of your fault tolerance](#)
- [AWS Marketplace: products that can be used for fault tolerance](#)
- [Amazon Builders' Library: Avoiding overload in distributed systems by putting the smaller service in control](#)
- [Amazon DynamoDB API \(control plane and data plane\)](#)
- [AWS Lambda Executions \(split into the control plane and the data plane\)](#)
- [AWS Elemental MediaStore Data Plane](#)
- [Building highly resilient applications using Amazon Route 53 Application Recovery Controller, Part 1: Single-Region stack](#)
- [Building highly resilient applications using Amazon Route 53 Application Recovery Controller, Part 2: Multi-Region stack](#)
- [Creating Disaster Recovery Mechanisms Using Amazon Route 53](#)
- [What is Route 53 Application Recovery Controller](#)
- [Kubernetes Control Plane and data plane](#)

### Related videos:

- [Back to Basics - Using Static Stability](#)
- [Building resilient multi-site workloads using AWS global services](#)

### Related examples:

- [Introducing Amazon Route 53 Application Recovery Controller](#)
- [Amazon Builders' Library: Avoiding overload in distributed systems by putting the smaller service in control](#)

- [Building highly resilient applications using Amazon Route 53 Application Recovery Controller, Part 1: Single-Region stack](#)
- [Building highly resilient applications using Amazon Route 53 Application Recovery Controller, Part 2: Multi-Region stack](#)
- [Static stability using Availability Zones](#)

**Related tools:**

- [Amazon CloudWatch](#)
- [AWS X-Ray](#)

## REL11-BP05 Use static stability to prevent bimodal behavior

Workloads should be statically stable and only operate in a single normal mode. Bimodal behavior is when your workload exhibits different behavior under normal and failure modes.

For example, you might try and recover from an Availability Zone failure by launching new instances in a different Availability Zone. This can result in a bimodal response during a failure mode. You should instead build workloads that are statically stable and operate within only one mode. In this example, those instances should have been provisioned in the second Availability Zone before the failure. This static stability design verifies that the workload only operates in a single mode.

**Desired outcome:** Workloads do not exhibit bimodal behavior during normal and failure modes.

**Common anti-patterns:**

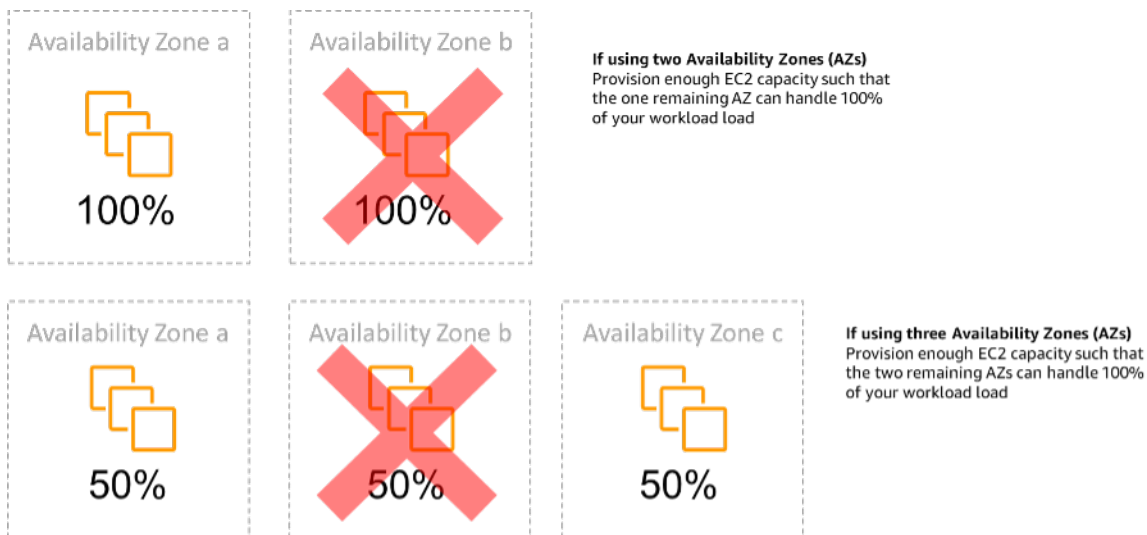
- Assuming resources can always be provisioned regardless of the failure scope.
- Trying to dynamically acquire resources during a failure.
- Not provisioning adequate resources across zones or Regions until a failure occurs.
- Considering static stable designs for compute resources only.

**Benefits of establishing this best practice:** Workloads running with statically stable designs are capable of having predictable outcomes during normal and failure events.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

Bimodal behavior occurs when your workload exhibits different behavior under normal and failure modes (for example, relying on launching new instances if an Availability Zone fails). An example of bimodal behavior is when stable Amazon EC2 designs provision enough instances in each Availability Zone to handle the workload load if one AZ were removed. Elastic Load Balancing or Amazon Route 53 health would check to shift a load away from the impaired instances. After traffic has shifted, use AWS Auto Scaling to asynchronously replace instances from the failed zone and launch them in the healthy zones. Static stability for compute deployment (such as EC2 instances or containers) results in the highest reliability.



### *Static stability of EC2 instances across Availability Zones*

This must be weighed against the cost for this model and the business value of maintaining the workload under all resilience cases. It's less expensive to provision less compute capacity and rely on launching new instances in the case of a failure, but for large-scale failures (such as an Availability Zone or Regional impairment), this approach is less effective because it relies on both an operational plane, and sufficient resources being available in the unaffected zones or Regions.

Your solution should also weigh reliability against the costs needs for your workload. Static stability architectures apply to a variety of architectures including compute instances spread across Availability Zones, database read replica designs, Kubernetes (Amazon EKS) cluster designs, and multi-Region failover architectures.

It is also possible to implement a more statically stable design by using more resources in each zone. By adding more zones, you reduce the amount of additional compute you need for static stability.

An example of bimodal behavior would be a network timeout that could cause a system to attempt to refresh the configuration state of the entire system. This would add an unexpected load to another component and might cause it to fail, resulting in other unexpected consequences. This negative feedback loop impacts the availability of your workload. Instead, you can build systems that are statically stable and operate in only one mode. A statically stable design would do constant work and always refresh the configuration state on a fixed cadence. When a call fails, the workload would use the previously cached value and initiate an alarm.

Another example of bimodal behavior is allowing clients to bypass your workload cache when failures occur. This might seem to be a solution that accommodates client needs but it can significantly change the demands on your workload and is likely to result in failures.

Assess critical workloads to determine what workloads require this type of resilience design. For those that are deemed critical, each application component must be reviewed. Example types of services that require static stability evaluations are:

- **Compute:** Amazon EC2, EKS-EC2, ECS-EC2, EMR-EC2
- **Databases:** Amazon Redshift, Amazon RDS, Amazon Aurora
- **Storage:** Amazon S3 (Single Zone), Amazon EFS (mounts), Amazon FSx (mounts)
- **Load balancers:** Under certain designs

## Implementation steps

- Build systems that are statically stable and operate in only one mode. In this case, provision enough instances in each Availability Zone or Region to handle the workload capacity if one Availability Zone or Region were removed. A variety of services can be used for routing to healthy resources, such as:
  - [Cross Region DNS Routing](#)
  - [MRAP Amazon S3 MultiRegion Routing](#)
  - [AWS Global Accelerator](#)
  - [Amazon Route 53 Application Recovery Controller](#)
- Configure [database read replicas](#) to account for the loss of a single primary instance or a read replica. If traffic is being served by read replicas, the quantity in each Availability Zone and each Region should equate to the overall need in case of the zone or Region failure.
- Configure critical data in Amazon S3 storage that is designed to be statically stable for data stored in case of an Availability Zone failure. If [Amazon S3 One Zone-IA](#) storage class is used, this

should not be considered statically stable, as the loss of that zone minimizes access to this stored data.

- [Load balancers](#) are sometimes configured incorrectly or by design to service a specific Availability Zone. In this case, the statically stable design might be to spread a workload across multiple AZs in a more complex design. The original design may be used to reduce interzone traffic for security, latency, or cost reasons.

## Resources

### Related Well-Architected best practices:

- [Availability Definition](#)
- [REL11-BP01 Monitor all components of the workload to detect failures](#)
- [REL11-BP04 Rely on the data plane and not the control plane during recovery](#)

### Related documents:

- [Minimizing Dependencies in a Disaster Recovery Plan](#)
- [The Amazon Builders' Library: Static stability using Availability Zones](#)
- [Fault Isolation Boundaries](#)
- [Static stability using Availability Zones](#)
- [Multi-Zone RDS](#)
- [Minimizing Dependencies in a Disaster Recovery Plan](#)
- [Cross Region DNS Routing](#)
- [MRAP Amazon S3 MultiRegion Routing](#)
- [AWS Global Accelerator](#)
- [Route 53 ARC](#)
- [Single Zone Amazon S3](#)
- [Cross Zone Load Balancing](#)

### Related videos:

- [Static stability in AWS: AWS re:Invent 2019: Introducing The Amazon Builders' Library \(DOP328\)](#)

## Related examples:

- [The Amazon Builders' Library: Static stability using Availability Zones](#)

## REL11-BP06 Send notifications when events impact availability

Notifications are sent upon the detection of thresholds breached, even if the event causing the issue was automatically resolved.

Automated healing allows your workload to be reliable. However, it can also obscure underlying problems that need to be addressed. Implement appropriate monitoring and events so that you can detect patterns of problems, including those addressed by auto healing, so that you can resolve root cause issues.

Resilient systems are designed so that degradation events are immediately communicated to the appropriate teams. These notifications should be sent through one or many communication channels.

**Desired outcome:** Alerts are immediately sent to operations teams when thresholds are breached, such as error rates, latency, or other critical key performance indicator (KPI) metrics, so that these issues are resolved as soon as possible and user impact is avoided or minimized.

### Common anti-patterns:

- Sending too many alarms.
- Sending alarms that are not actionable.
- Setting alarm thresholds too high (over sensitive) or too low (under sensitive).
- Not sending alarms for external dependencies.
- Not considering [gray failures](#) when designing monitoring and alarms.
- Performing healing automation, but not notifying the appropriate team that healing was needed.

**Benefits of establishing this best practice:** Notifications of recovery make operational and business teams aware of service degradations so that they can react immediately to minimize both mean time to detect (MTTD) and mean time to repair (MTTR). Notifications of recovery events also assure that you don't ignore problems that occur infrequently.

**Level of risk exposed if this best practice is not established:** Medium. Failure to implement appropriate monitoring and events notification mechanisms can result in failure to detect patterns of problems, including those addressed by auto healing. A team will only be made aware of system degradation when users contact customer service or by chance.

## Implementation guidance

When defining a monitoring strategy, a triggered alarm is a common event. This event would likely contain an identifier for the alarm, the alarm state (such as IN\_ALARM or OK), and details of what triggered it. In many cases, an alarm event should be detected and an email notification sent. This is an example of an action on an alarm. Alarm notification is critical in observability, as it informs the right people that there is an issue. However, when action on events mature in your observability solution, it can automatically remediate the issue without the need for human intervention.

Once KPI-monitoring alarms have been established, alerts should be sent to appropriate teams when thresholds are exceeded. Those alerts may also be used to trigger automated processes that will attempt to remediate the degradation.

For more complex threshold monitoring, composite alarms should be considered. Composite alarms use a number of KPI-monitoring alarms to create an alert based on operational business logic. CloudWatch Alarms can be configured to send emails, or to log incidents in third-party incident tracking systems using Amazon SNS integration or Amazon EventBridge.

## Implementation steps

Create various types of alarms based on how the workloads are monitored, such as:

- Application alarms are used to detect when any part of your workload is not working properly.
- [Infrastructure alarms](#) indicate when to scale resources. Alarms can be visually displayed on dashboards, send alerts through Amazon SNS or email, and work with Auto Scaling to scale workload resources in or out.
- Simple [static alarms](#) can be created to monitor when a metric breaches a static threshold for a specified number of evaluation periods.
- [Composite alarms](#) can account for complex alarms from multiple sources.
- Once the alarm has been created, create appropriate notification events. You can directly invoke an [Amazon SNS API](#) to send notifications and link any automation for remediation or communication.

- Integrate [Amazon Health Aware](#) monitoring to allow for monitoring visibility to AWS resources that might have degradations. For business essential workloads, this solution provides access to proactive and real-time alerts for AWS services.

## Resources

### Related Well-Architected best practices:

- [Availability Definition](#)

### Related documents:

- [Creating a CloudWatch Alarm Based on a Static Threshold](#)
- [What Is Amazon EventBridge?](#)
- [What is Amazon Simple Notification Service?](#)
- [Publishing Custom Metrics](#)
- [Using Amazon CloudWatch Alarms](#)
- [Amazon Health Aware \(AHA\)](#)
- [Setup CloudWatch Composite alarms](#)
- [What's new in AWS Observability at re:Invent 2022](#)

### Related tools:

- [CloudWatch](#)
- [CloudWatch X-Ray](#)

## REL11-BP07 Architect your product to meet availability targets and uptime service level agreements (SLAs)

Architect your product to meet availability targets and uptime service level agreements (SLAs). If you publish or privately agree to availability targets or uptime SLAs, verify that your architecture and operational processes are designed to support them.

**Desired outcome:** Each application has a defined target for availability and SLA for performance metrics, which can be monitored and maintained in order to meet business outcomes.



## Common anti-patterns:

- Designing and deploying workload's without setting any SLAs.
- SLA metrics are set too high without rationale or business requirements.
- Setting SLAs without taking into account for dependencies and their underlying SLA.
- Application designs are created without considering the Shared Responsibility Model for Resilience.

**Benefits of establishing this best practice:** Designing applications based on key resiliency targets helps you meet business objectives and customer expectations. These objectives help drive the application design process that evaluates different technologies and considers various tradeoffs.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

Application designs have to account for a diverse set of requirements that are derived from business, operational, and financial objectives. Within the operational requirements, workloads need to have specific resilience metric targets so they can be properly monitored and supported. Resilience metrics should not be set or derived after deploying the workload. They should be defined during the design phase and help guide various decisions and tradeoffs.

- Every workload should have its own set of resilience metrics. Those metrics may be different from other business applications.
- Reducing dependencies can have a positive impact on availability. Each workload should consider its dependencies and their SLAs. In general, select dependencies with availability goals equal to or greater than the goals of your workload.
- Consider loosely coupled designs so your workload can operate correctly despite dependency impairment, where possible.
- Reduce control plane dependencies, especially during recovery or a degradation. Evaluate designs that are statically stable for mission critical workloads. Use resource sparing to increase the availability of those dependencies in a workload.
- Observability and instrumentation are critical for achieving SLAs by reducing Mean Time to Detection (MTTD) and Mean Time to Repair (MTTR).

- Less frequent failure (longer MTBF), shorter failure detection times (shorter MTTD), and shorter repair times (shorter MTTR) are the three factors that are used to improve availability in distributed systems.
- Establishing and meeting resilience metrics for a workload is foundational to any effective design. Those designs must factor in tradeoffs of design complexity, service dependencies, performance, scaling, and costs.

## Implementation steps

- Review and document the workload design considering the following questions:
  - Where are control planes used in the workload?
  - How does the workload implement fault tolerance?
  - What are the design patterns for scaling, automatic scaling, redundancy, and highly available components?
  - What are the requirements for data consistency and availability?
  - Are there considerations for resource sparing or resource static stability?
  - What are the service dependencies?
- Define SLA metrics based on the workload architecture while working with stakeholders. Consider the SLAs of all dependencies used by the workload.
- Once the SLA target has been set, optimize the architecture to meet the SLA.
- Once the design is set that will meet the SLA, implement operational changes, process automation, and runbooks that also will have focus on reducing MTTD and MTTR.
- Once deployed, monitor and report on the SLA.

## Resources

### Related best practices:

- [REL03-BP01 Choose how to segment your workload](#)
- [REL10-BP01 Deploy the workload to multiple locations](#)
- [REL11-BP01 Monitor all components of the workload to detect failures](#)
- [REL11-BP03 Automate healing on all layers](#)
- [REL12-BP05 Test resiliency using chaos engineering](#)
- [REL13-BP01 Define recovery objectives for downtime and data loss](#)

- [Understanding workload health](#)

### Related documents:

- [Availability with redundancy](#)
- [Reliability pillar - Availability](#)
- [Measuring availability](#)
- [AWS Fault Isolation Boundaries](#)
- [Shared Responsibility Model for Resiliency](#)
- [Static stability using Availability Zones](#)
- [AWS Service Level Agreements \(SLAs\)](#)
- [Guidance for Cell-based Architecture on AWS](#)
- [AWS infrastructure](#)
- [Advanced Multi-AZ Resilience Patterns whitepaper](#)

### Related services:

- [Amazon CloudWatch](#)
- [AWS Config](#)
- [AWS Trusted Advisor](#)

## Test reliability

After you have designed your workload to be resilient to the stresses of production, testing is the only way to ensure that it will operate as designed, and deliver the resiliency you expect.

Test to validate that your workload meets functional and non-functional requirements, because bugs or performance bottlenecks can impact the reliability of your workload. Test the resiliency of your workload to help you find latent bugs that only surface in production. Exercise these tests regularly.

### Best practices

- [REL12-BP01 Use playbooks to investigate failures](#)
- [REL12-BP02 Perform post-incident analysis](#)

- [REL12-BP03 Test functional requirements](#)
- [REL12-BP04 Test scaling and performance requirements](#)
- [REL12-BP05 Test resiliency using chaos engineering](#)
- [REL12-BP06 Conduct game days regularly](#)

## REL12-BP01 Use playbooks to investigate failures

Permit consistent and prompt responses to failure scenarios that are not well understood, by documenting the investigation process in playbooks. Playbooks are the predefined steps performed to identify the factors contributing to a failure scenario. The results from any process step are used to determine the next steps to take until the issue is identified or escalated.

The playbook is proactive planning that you must do, to be able to take reactive actions effectively. When failure scenarios not covered by the playbook are encountered in production, first address the issue (put out the fire). Then go back and look at the steps you took to address the issue and use these to add a new entry in the playbook.

Note that playbooks are used in response to specific incidents, while runbooks are used to achieve specific outcomes. Often, runbooks are used for routine activities and playbooks are used to respond to non-routine events.

### Common anti-patterns:

- Planning to deploy a workload without knowing the processes to diagnose issues or respond to incidents.
- Unplanned decisions about which systems to gather logs and metrics from when investigating an event.
- Not retaining metrics and events long enough to be able to retrieve the data.

**Benefits of establishing this best practice:** Capturing playbooks ensures that processes can be consistently followed. Codifying your playbooks limits the introduction of errors from manual activity. Automating playbooks shortens the time to respond to an event by eliminating the requirement for team member intervention or providing them additional information when their intervention begins.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

- Use playbooks to identify issues. Playbooks are documented processes to investigate issues. Allow consistent and prompt responses to failure scenarios by documenting processes in playbooks. Playbooks must contain the information and guidance necessary for an adequately skilled person to gather applicable information, identify potential sources of failure, isolate faults, and determine contributing factors (perform post-incident analysis).
- Implement playbooks as code. Perform your operations as code by scripting your playbooks to ensure consistency and limit reduce errors caused by manual processes. Playbooks can be composed of multiple scripts representing the different steps that might be necessary to identify the contributing factors to an issue. Runbook activities can be invoked or performed as part of playbook activities, or might prompt to run a playbook in response to identified events.
  - [Automate your operational playbooks with AWS Systems Manager](#)
  - [AWS Systems Manager Run Command](#)
  - [AWS Systems Manager Automation](#)
  - [What is AWS Lambda?](#)
  - [What Is Amazon EventBridge?](#)
  - [Using Amazon CloudWatch Alarms](#)

## Resources

### Related documents:

- [AWS Systems Manager Automation](#)
- [AWS Systems Manager Run Command](#)
- [Automate your operational playbooks with AWS Systems Manager](#)
- [Using Amazon CloudWatch Alarms](#)
- [Using Canaries \(Amazon CloudWatch Synthetics\)](#)
- [What Is Amazon EventBridge?](#)
- [What is AWS Lambda?](#)

### Related examples:

- [Automating operations with Playbooks and Runbooks](#)

## REL12-BP02 Perform post-incident analysis

Review customer-impacting events, and identify the contributing factors and preventative action items. Use this information to develop mitigations to limit or prevent recurrence. Develop procedures for prompt and effective responses. Communicate contributing factors and corrective actions as appropriate, tailored to target audiences. Have a method to communicate these causes to others as needed.

Assess why existing testing did not find the issue. Add tests for this case if tests do not already exist.

**Desired outcome:** Your teams have a consistent and agreed upon approach to handling post-incident analysis. One mechanism is the [correction of error \(COE\) process](#). The COE process helps your teams identify, understand, and address the root causes for incidents, while also building mechanisms and guardrails to limit the probability of the same incident happening again.

### Common anti-patterns:

- Finding contributing factors, but not continuing to look deeper for other potential problems and approaches to mitigate.
- Only identifying human error causes, and not providing any training or automation that could prevent human errors.
- Focus on assigning blame rather than understanding the root cause, creating a culture of fear and hindering open communication
- Failure to share insights, which keeps incident analysis findings within a small group and prevents others from benefiting from the lessons learned
- No mechanism to capture institutional knowledge, thereby losing valuable insights by not preserving the lessons-learned in the form of updated best practices and resulting in repeat incidents with the same or similar root cause

**Benefits of establishing this best practice:** Conducting post-incident analysis and sharing the results permits other workloads to mitigate the risk if they have implemented the same contributing factors, and allows them to implement the mitigation or automated recovery before an incident occurs.

**Level of risk exposed if this best practice is not established: High**

## Implementation guidance

Good post-incident analysis provides opportunities to propose common solutions for problems with architecture patterns that are used in other places in your systems.

A cornerstone of the COE process is documenting and addressing issues. It is recommended to define a standardized way to document critical root causes, and ensure they are reviewed and addressed. Assign clear ownership for the post-incident analysis process. Designate a responsible team or individual who will oversee incident investigations and follow-ups.

Encourage a culture that focuses on learning and improvement rather than assigning blame. Emphasize that the goal is to prevent future incidents, not to penalize individuals.

Develop well-defined procedures for conducting post-incident analyses. These procedures should outline the steps to be taken, the information to be collected, and the key questions to be addressed during the analysis. Investigate incidents thoroughly, going beyond immediate causes to identify root causes and contributing factors. Use techniques like the [five whys](#) to delve deep into the underlying issues.

Maintain a repository of lessons learned from incident analyses. This institutional knowledge can serve as a reference for future incidents and prevention efforts. Share findings and insights from post-incident analyses, and consider holding open-invite post-incident review meetings to discuss lessons learned.

## Implementation steps

- While conducting post-incident analysis, ensure the process is blame-free. This allows people involved in the incident to be dispassionate about the proposed corrective actions and promote honest self-assessment and collaboration across teams.
- Define a standardized way to document critical issues. An example structure for such document is as follows:
  - What happened?
  - What was the impact on customers and your business?
  - What was the root cause?
  - What data do you have to support this?
    - For example, metrics and graphs
  - What were the critical pillar implications, especially security?

- When architecting workloads, you make trade-offs between pillars based upon your business context. These business decisions can drive your engineering priorities. You might optimize to reduce cost at the expense of reliability in development environments, or, for mission-critical solutions, you might optimize reliability with increased costs. Security is always job zero, as you have to protect your customers.
- What lessons did you learn?
- What corrective actions are you taking?
  - Action items
  - Related items
- Create well-defined standard operating procedures for conducting post-incident analyses.
- Set up a standardized incident reporting process. Document all incidents comprehensively, including the initial incident report, logs, communications, and actions taken during the incident.
- Remember that an incident does not require an outage. It could be a near-miss, or a system performing in an unexpected way while still fulfilling its business function.
- Continually improve your post-incident analysis process based on feedback and lessons learned.
- Capture key findings in a knowledge management system, and consider any patterns that should be added to developer guides or pre-deployment checklists.

## Resources

### Related documents:

- [Why you should develop a correction of error \(COE\)](#)

### Related videos:

- [Amazon's approach to failing successfully](#)
- [AWS re:Invent 2021 - Amazon Builders' Library: Operational Excellence at Amazon](#)

## REL12-BP03 Test functional requirements

Use techniques such as unit tests and integration tests that validate required functionality.

You achieve the best outcomes when these tests are run automatically as part of build and deployment actions. For instance, using AWS CodePipeline, developers commit changes to a source



repository where CodePipeline automatically detects the changes. Those changes are built, and tests are run. After the tests are complete, the built code is deployed to staging servers for testing. From the staging server, CodePipeline runs more tests, such as integration or load tests. Upon the successful completion of those tests, CodePipeline deploys the tested and approved code to production instances.

Additionally, experience shows that synthetic transaction testing (also known as *canary testing*, but not to be confused with canary deployments) that can run and simulate customer behavior is among the most important testing processes. Run these tests constantly against your workload endpoints from diverse remote locations. Amazon CloudWatch Synthetics allows you to [create canaries](#) to monitor your endpoints and APIs.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

- Test functional requirements. These include unit tests and integration tests that validate required functionality.
  - [Use CodePipeline with AWS CodeBuild to test code and run builds](#)
  - [AWS CodePipeline Adds Support for Unit and Custom Integration Testing with AWS CodeBuild](#)
  - [Continuous Delivery and Continuous Integration](#)
  - [Using Canaries \(Amazon CloudWatch Synthetics\)](#)
  - [Software test automation](#)

## Resources

### Related documents:

- [APN Partner: partners that can help with implementation of a continuous integration pipeline](#)
- [AWS CodePipeline Adds Support for Unit and Custom Integration Testing with AWS CodeBuild](#)
- [AWS Marketplace: products that can be used for continuous integration](#)
- [Continuous Delivery and Continuous Integration](#)
- [Software test automation](#)
- [Use CodePipeline with AWS CodeBuild to test code and run builds](#)
- [Using Canaries \(Amazon CloudWatch Synthetics\)](#)

## REL12-BP04 Test scaling and performance requirements

Use techniques such as load testing to validate that the workload meets scaling and performance requirements.

In the cloud, you can create a production-scale test environment on demand for your workload. If you run these tests on scaled down infrastructure, you must scale your observed results to what you think will happen in production. Load and performance testing can also be done in production if you are careful not to impact actual users, and tag your test data so it does not comingle with real user data and corrupt usage statistics or production reports.

With testing, ensure that your base resources, scaling settings, service quotas, and resiliency design operate as expected under load.

**Level of risk exposed if this best practice is not established:** High

### Implementation guidance

- Test scaling and performance requirements. Perform load testing to validate that the workload meets scaling and performance requirements.
  - [Distributed Load Testing on AWS: simulate thousands of connected users](#)
  - [Apache JMeter](#)
    - Deploy your application in an environment identical to your production environment and run a load test.
      - Use infrastructure as code concepts to create an environment as similar to your production environment as possible.

### Resources

#### Related documents:

- [Distributed Load Testing on AWS: simulate thousands of connected users](#)
- [Apache JMeter](#)

## REL12-BP05 Test resiliency using chaos engineering

Run chaos experiments regularly in environments that are in or as close to production as possible to understand how your system responds to adverse conditions.

**Desired outcome:**

The resilience of the workload is regularly verified by applying chaos engineering in the form of fault injection experiments or injection of unexpected load, in addition to resilience testing that validates known expected behavior of your workload during an event. Combine both chaos engineering and resilience testing to gain confidence that your workload can survive component failure and can recover from unexpected disruptions with minimal to no impact.

**Common anti-patterns:**

- Designing for resiliency, but not verifying how the workload functions as a whole when faults occur.
- Never experimenting under real-world conditions and expected load.
- Not treating your experiments as code or maintaining them through the development cycle.
- Not running chaos experiments both as part of your CI/CD pipeline, as well as outside of deployments.
- Neglecting to use past post-incident analyses when determining which faults to experiment with.

**Benefits of establishing this best practice:** Injecting faults to verify the resilience of your workload allows you to gain confidence that the recovery procedures of your resilient design will work in the case of a real fault.

**Level of risk exposed if this best practice is not established:** Medium

**Implementation guidance**

Chaos engineering provides your teams with capabilities to continually inject real world disruptions (simulations) in a controlled way at the service provider, infrastructure, workload, and component level, with minimal to no impact to your customers. It allows your teams to learn from faults and observe, measure, and improve the resilience of your workloads, as well as validate that alerts fire and teams get notified in the case of an event.

When performed continually, chaos engineering can highlight deficiencies in your workloads that, if left unaddressed, could negatively affect availability and operation.

**Note**

Chaos engineering is the discipline of experimenting on a system in order to build confidence in the system's capability to withstand turbulent conditions in production. – [Principles of Chaos Engineering](#)

If a system is able to withstand these disruptions, the chaos experiment should be maintained as an automated regression test. In this way, chaos experiments should be performed as part of your systems development lifecycle (SDLC) and as part of your CI/CD pipeline.

To ensure that your workload can survive component failure, inject real world events as part of your experiments. For example, experiment with the loss of Amazon EC2 instances or failover of the primary Amazon RDS database instance, and verify that your workload is not impacted (or only minimally impacted). Use a combination of component faults to simulate events that may be caused by a disruption in an Availability Zone.

For application-level faults (such as crashes), you can start with stressors such as memory and CPU exhaustion.

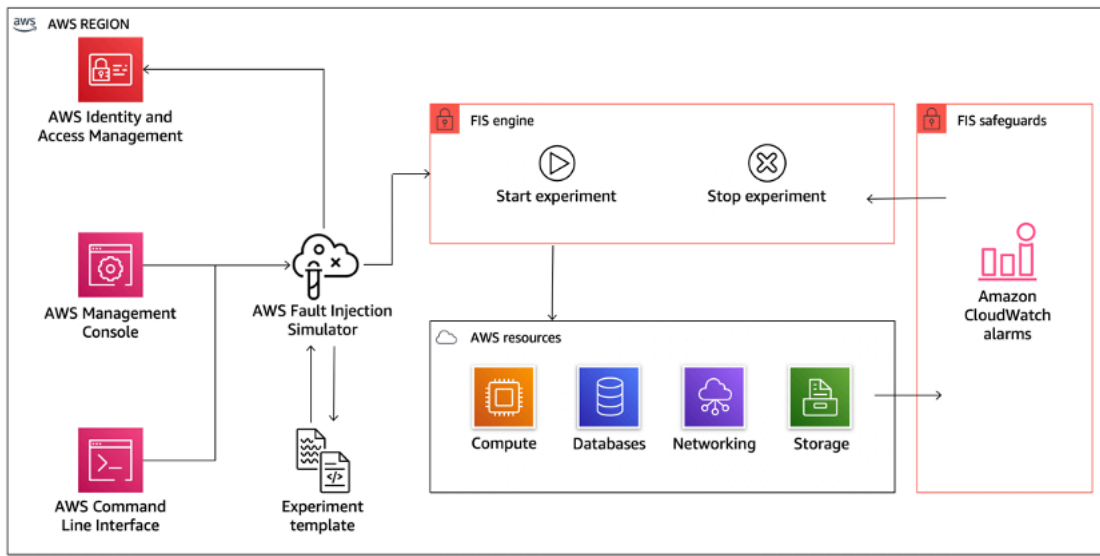
To validate [fallback or failover mechanisms](#) for external dependencies due to intermittent network disruptions, your components should simulate such an event by blocking access to the third-party providers for a specified duration that can last from seconds to hours.

Other modes of degradation might cause reduced functionality and slow responses, often resulting in a disruption of your services. Common sources of this degradation are increased latency on critical services and unreliable network communication (dropped packets). Experiments with these faults, including networking effects such as latency, dropped messages, and DNS failures, could include the inability to resolve a name, reach the DNS service, or establish connections to dependent services.

**Chaos engineering tools:**

AWS Fault Injection Service (AWS FIS) is a fully managed service for running fault injection experiments that can be used as part of your CD pipeline, or outside of the pipeline. AWS FIS is a good choice to use during chaos engineering game days. It supports simultaneously introducing faults across different types of resources including Amazon EC2, Amazon Elastic Container Service (Amazon ECS), Amazon Elastic Kubernetes Service (Amazon EKS), and Amazon RDS. These faults include termination of resources, forcing failovers, stressing CPU or memory, throttling, latency,

and packet loss. Since it is integrated with Amazon CloudWatch Alarms, you can set up stop conditions as guardrails to rollback an experiment if it causes unexpected impact.



*AWS Fault Injection Service integrates with AWS resources to allow you to run fault injection experiments for your workloads.*

There are also several third-party options for fault injection experiments. These include open-source tools such as [Chaos Toolkit](#), [Chaos Mesh](#), and [Litmus Chaos](#), as well as commercial options like Gremlin. To expand the scope of faults that can be injected on AWS, AWS FIS [integrates with Chaos Mesh and Litmus Chaos](#), allowing you to coordinate fault injection workflows among multiple tools. For example, you can run a stress test on a pod's CPU using Chaos Mesh or Litmus faults while terminating a randomly selected percentage of cluster nodes using AWS FIS fault actions.

## Implementation steps

### 1. Determine which faults to use for experiments.

Assess the design of your workload for resiliency. Such designs (created using the best practices of the [Well-Architected Framework](#)) account for risks based on critical dependencies, past events, known issues, and compliance requirements. List each element of the design intended to maintain resiliency and the faults it is designed to mitigate. For more information about creating such lists, see the [Operational Readiness Review whitepaper](#) which guides you on how to create a process to prevent recurrence of previous incidents. The Failure Modes and Effects Analysis (FMEA) process provides you with a framework for performing a component-level analysis of

failures and how they impact your workload. FMEA is outlined in more detail by Adrian Cockcroft in [Failure Modes and Continuous Resilience](#).

## 2. Assign a priority to each fault.

Start with a coarse categorization such as high, medium, or low. To assess priority, consider frequency of the fault and impact of failure to the overall workload.

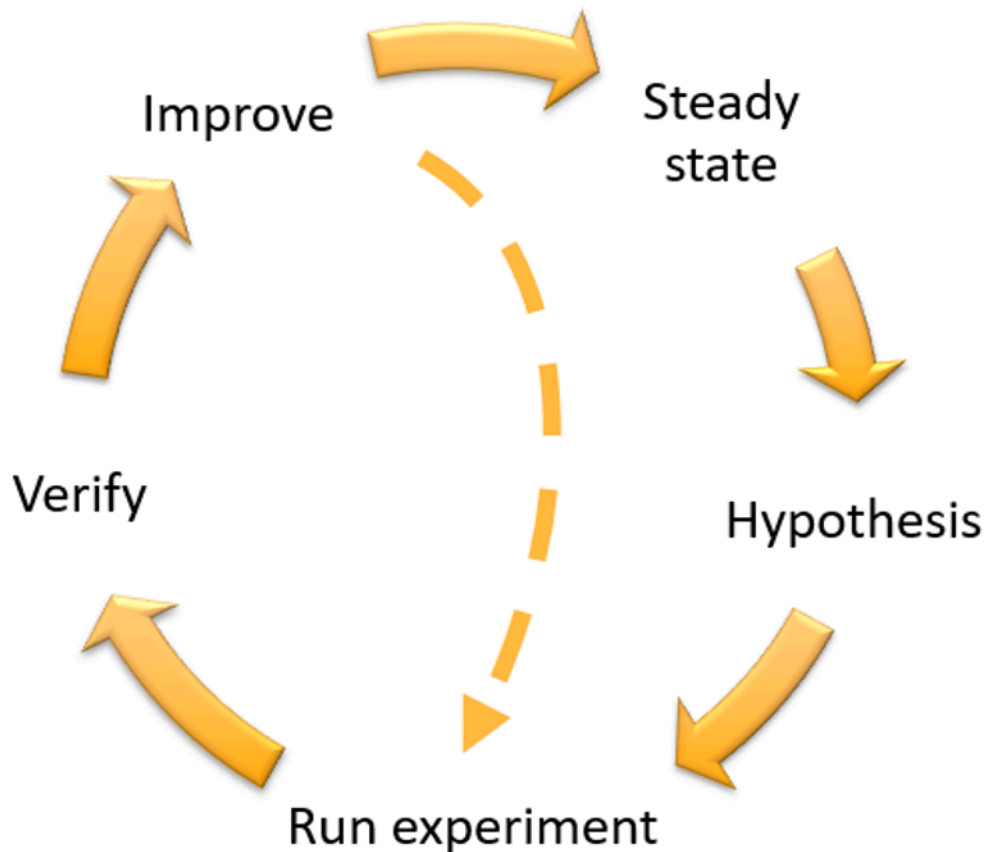
When considering frequency of a given fault, analyze past data for this workload when available. If not available, use data from other workloads running in a similar environment.

When considering impact of a given fault, the larger the scope of the fault, generally the larger the impact. Also consider the workload design and purpose. For example, the ability to access the source data stores is critical for a workload doing data transformation and analysis. In this case, you would prioritize experiments for access faults, as well as throttled access and latency insertion.

Post-incident analyses are a good source of data to understand both frequency and impact of failure modes.

Use the assigned priority to determine which faults to experiment with first and the order with which to develop new fault injection experiments.

## 3. For each experiment that you perform, follow the chaos engineering and continuous resilience flywheel in the following figure.



*Chaos engineering and continuous resilience flywheel, using the scientific method by Adrian Hornsby.*

- a. Define steady state as some measurable output of a workload that indicates normal behavior.

Your workload exhibits steady state if it is operating reliably and as expected. Therefore, validate that your workload is healthy before defining steady state. Steady state does not necessarily mean no impact to the workload when a fault occurs, as a certain percentage in faults could be within acceptable limits. The steady state is your baseline that you will observe during the experiment, which will highlight anomalies if your hypothesis defined in the next step does not turn out as expected.

For example, a steady state of a payments system can be defined as the processing of 300 TPS with a success rate of 99% and round-trip time of 500 ms.

- b. Form a hypothesis about how the workload will react to the fault.

A good hypothesis is based on how the workload is expected to mitigate the fault to maintain the steady state. The hypothesis states that given the fault of a specific type, the system or workload will continue steady state, because the workload was designed with specific mitigations. The specific type of fault and mitigations should be specified in the hypothesis.

The following template can be used for the hypothesis (but other wording is also acceptable):

**Note**

If *specific fault* occurs, the *workload name* workload will *describe mitigating controls* to maintain *business or technical metric impact*.

For example:

- If 20% of the nodes in the Amazon EKS node-group are taken down, the Transaction Create API continues to serve the 99th percentile of requests in under 100 ms (steady state). The Amazon EKS nodes will recover within five minutes, and pods will get scheduled and process traffic within eight minutes after the initiation of the experiment. Alerts will fire within three minutes.
- If a single Amazon EC2 instance failure occurs, the order system's Elastic Load Balancing health check will cause the Elastic Load Balancing to only send requests to the remaining healthy instances while the Amazon EC2 Auto Scaling replaces the failed instance, maintaining a less than 0.01% increase in server-side (5xx) errors (steady state).
- If the primary Amazon RDS database instance fails, the Supply Chain data collection workload will failover and connect to the standby Amazon RDS database instance to maintain less than 1 minute of database read or write errors (steady state).

c. Run the experiment by injecting the fault.

An experiment should by default be fail-safe and tolerated by the workload. If you know that the workload will fail, do not run the experiment. Chaos engineering should be used to find known-unknowns or unknown-unknowns. *Known-unknowns* are things you are aware of but don't fully understand, and *unknown-unknowns* are things you are neither aware of nor fully understand. Experimenting against a workload that you know is broken won't provide you with new insights. Your experiment should be carefully planned, have a clear scope of impact, and provide a rollback mechanism that can be applied in case of unexpected turbulence. If your due-diligence shows that your workload should survive the experiment, move forward



with the experiment. There are several options for injecting the faults. For workloads on AWS, [AWS FIS](#) provides many predefined fault simulations called [actions](#). You can also define custom actions that run in AWS FIS using [AWS Systems Manager documents](#).

We discourage the use of custom scripts for chaos experiments, unless the scripts have the capabilities to understand the current state of the workload, are able to emit logs, and provide mechanisms for rollbacks and stop conditions where possible.

An effective framework or toolset which supports chaos engineering should track the current state of an experiment, emit logs, and provide rollback mechanisms to support the controlled running of an experiment. Start with an established service like AWS FIS that allows you to perform experiments with a clearly defined scope and safety mechanisms that rollback the experiment if the experiment introduces unexpected turbulence. To learn about a wider variety of experiments using AWS FIS, also see the [Resilient and Well-Architected Apps with Chaos Engineering lab](#). Also, [AWS Resilience Hub](#) will analyze your workload and create experiments that you can choose to implement and run in AWS FIS.

 **Note**

For every experiment, clearly understand the scope and its impact. We recommend that faults should be simulated first on a non-production environment before being run in production.

Experiments should run in production under real-world load using [canary deployments](#) that spin up both a control and experimental system deployment, where feasible. Running experiments during off-peak times is a good practice to mitigate potential impact when first experimenting in production. Also, if using actual customer traffic poses too much risk, you can run experiments using synthetic traffic on production infrastructure against the control and experimental deployments. When using production is not possible, run experiments in pre-production environments that are as close to production as possible.

You must establish and monitor guardrails to ensure the experiment does not impact production traffic or other systems beyond acceptable limits. Establish stop conditions to stop an experiment if it reaches a threshold on a guardrail metric that you define. This should include the metrics for steady state for the workload, as well as the metric against the components into which you're injecting the fault. A [synthetic monitor](#) (also known as a user canary) is one metric you should usually include as a user proxy. [Stop conditions for AWS FIS](#)

are supported as part of the experiment template, allowing up to five stop-conditions per template.

One of the principles of chaos is minimize the scope of the experiment and its impact:

While there must be an allowance for some short-term negative impact, it is the responsibility and obligation of the Chaos Engineer to ensure the fallout from experiments are minimized and contained.

A method to verify the scope and potential impact is to perform the experiment in a non-production environment first, verifying that thresholds for stop conditions activate as expected during an experiment and observability is in place to catch an exception, instead of directly experimenting in production.

When running fault injection experiments, verify that all responsible parties are well-informed. Communicate with appropriate teams such as the operations teams, service reliability teams, and customer support to let them know when experiments will be run and what to expect. Give these teams communication tools to inform those running the experiment if they see any adverse effects.

You must restore the workload and its underlying systems back to the original known-good state. Often, the resilient design of the workload will self-heal. But some fault designs or failed experiments can leave your workload in an unexpected failed state. By the end of the experiment, you must be aware of this and restore the workload and systems. With AWS FIS you can set a rollback configuration (also called a post action) within the action parameters. A post action returns the target to the state that it was in before the action was run. Whether automated (such as using AWS FIS) or manual, these post actions should be part of a playbook that describes how to detect and handle failures.

d. Verify the hypothesis.

[Principles of Chaos Engineering](#) gives this guidance on how to verify steady state of your workload:

Focus on the measurable output of a system, rather than internal attributes of the system. Measurements of that output over a short period of time constitute a proxy for the system's steady state. The overall system's throughput, error rates, and latency percentiles could all be metrics of interest representing steady state behavior. By focusing on systemic behavior patterns during experiments, chaos engineering verifies that the system does work, rather than trying to validate how it works.

In our two previous examples, we include the steady state metrics of less than 0.01% increase in server-side (5xx) errors and less than one minute of database read and write errors.

The 5xx errors are a good metric because they are a consequence of the failure mode that a client of the workload will experience directly. The database errors measurement is good as a direct consequence of the fault, but should also be supplemented with a client impact measurement such as failed customer requests or errors surfaced to the client. Additionally, include a synthetic monitor (also known as a user canary) on any APIs or URIs directly accessed by the client of your workload.

e. Improve the workload design for resilience.

If steady state was not maintained, then investigate how the workload design can be improved to mitigate the fault, applying the best practices of the [AWS Well-Architected Reliability pillar](#). Additional guidance and resources can be found in the [AWS Builder's Library](#), which hosts articles about how to [improve your health checks](#) or [employ retries with backoff in your application code](#), among others.

After these changes have been implemented, run the experiment again (shown by the dotted line in the chaos engineering flywheel) to determine their effectiveness. If the verify step indicates the hypothesis holds true, then the workload will be in steady state, and the cycle continues.

4. Run experiments regularly.

A chaos experiment is a cycle, and experiments should be run regularly as part of chaos engineering. After a workload meets the experiment's hypothesis, the experiment should be automated to run continually as a regression part of your CI/CD pipeline. To learn how to do this, see this blog on [how to run AWS FIS experiments using AWS CodePipeline](#). This lab on recurrent [AWS FIS experiments in a CI/CD pipeline](#) allows you to work hands-on.

Fault injection experiments are also a part of game days (see [REL12-BP06 Conduct game days regularly](#)). Game days simulate a failure or event to verify systems, processes, and team responses. The purpose is to actually perform the actions the team would perform as if an exceptional event happened.

5. Capture and store experiment results.

Results for fault injection experiments must be captured and persisted. Include all necessary data (such as time, workload, and conditions) to be able to later analyze experiment results and

trends. Examples of results might include screenshots of dashboards, CSV dumps from your metric's database, or a hand-typed record of events and observations from the experiment. [Experiment logging with AWS FIS](#) can be part of this data capture.

## Resources

### Related best practices:

- [REL08-BP03 Integrate resiliency testing as part of your deployment](#)
- [REL13-BP03 Test disaster recovery implementation to validate the implementation](#)

### Related documents:

- [What is AWS Fault Injection Service?](#)
- [What is AWS Resilience Hub?](#)
- [Principles of Chaos Engineering](#)
- [Chaos Engineering: Planning your first experiment](#)
- [Resilience Engineering: Learning to Embrace Failure](#)
- [Chaos Engineering stories](#)
- [Avoiding fallback in distributed systems](#)
- [Canary Deployment for Chaos Experiments](#)

### Related videos:

- [AWS re:Invent 2020: Testing resiliency using chaos engineering \(ARC316\)](#)
- [AWS re:Invent 2019: Improving resiliency with chaos engineering \(DOP309-R1\)](#)
- [AWS re:Invent 2019: Performing chaos engineering in a serverless world \(CMY301\)](#)

### Related examples:

- [Well-Architected lab: Level 300: Testing for Resiliency of Amazon EC2, Amazon RDS, and Amazon S3](#)
- [Chaos Engineering on AWS lab](#)
- [Resilient and Well-Architected Apps with Chaos Engineering lab](#)

- [Serverless Chaos lab](#)
- [Measure and Improve Your Application Resilience with AWS Resilience Hub lab](#)

**Related tools:**

- [AWS Fault Injection Service](#)
- AWS Marketplace: [Gremlin Chaos Engineering Platform](#)
- [Chaos Toolkit](#)
- [Chaos Mesh](#)
- [Litmus](#)

## REL12-BP06 Conduct game days regularly

Use game days to regularly exercise your procedures for responding to events and failures as close to production as possible (including in production environments) with the people who will be involved in actual failure scenarios. Game days enforce measures to ensure that production events do not impact users.

Game days simulate a failure or event to test systems, processes, and team responses. The purpose is to actually perform the actions the team would perform as if an exceptional event happened. This will help you understand where improvements can be made and can help develop organizational experience in dealing with events. These should be conducted regularly so that your team builds *muscle memory* on how to respond.

After your design for resiliency is in place and has been tested in non-production environments, a game day is the way to ensure that everything works as planned in production. A game day, especially the first one, is an “all hands on deck” activity where engineers and operations are all informed when it will happen, and what will occur. Runbooks are in place. Simulated events are run, including possible failure events, in the production systems in the prescribed manner, and impact is assessed. If all systems operate as designed, detection and self-healing will occur with little to no impact. However, if negative impact is observed, the test is rolled back and the workload issues are remedied, manually if necessary (using the runbook). Since game days often take place in production, all precautions should be taken to ensure that there is no impact on availability to your customers.

**Common anti-patterns:**

- Documenting your procedures, but never exercising them.
- Not including business decision makers in the test exercises.

**Benefits of establishing this best practice:** Conducting game days regularly ensures that all staff follows the policies and procedures when an actual incident occurs, and validates that those policies and procedures are appropriate.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

- Schedule game days to regularly exercise your runbooks and playbooks. Game days should involve everyone who would be involved in a production event: business owner, development staff, operational staff, and incident response teams.
  - Run your load or performance tests and then run your failure injection.
  - Look for anomalies in your runbooks and opportunities to exercise your playbooks.
    - If you deviate from your runbooks, refine the runbook or correct the behavior. If you exercise your playbook, identify the runbook that should have been used, or create a new one.

## Resources

### Related documents:

- [What is AWS GameDay?](#)

### Related videos:

- [AWS re:Invent 2019: Improving resiliency with chaos engineering \(DOP309-R1\)](#)

### Related examples:

- [AWS Well-Architected Labs - Testing Resiliency](#)

## Plan for Disaster Recovery (DR)

Having backups and redundant workload components in place is the start of your DR strategy. [RTO and RPO are your objectives](#) for restoration of your workload. Set these based on business needs. Implement a strategy to meet these objectives, considering locations and function of workload resources and data. The probability of disruption and cost of recovery are also key factors that help to inform the business value of providing disaster recovery for a workload.

Both Availability and Disaster Recovery rely on the same best practices such as monitoring for failures, deploying to multiple locations, and automatic failover. However Availability focuses on components of the workload, while Disaster Recovery focuses on discrete copies of the entire workload. Disaster Recovery has different objectives from Availability, focusing on time to recovery after a disaster.

### Best practices

- [REL13-BP01 Define recovery objectives for downtime and data loss](#)
- [REL13-BP02 Use defined recovery strategies to meet the recovery objectives](#)
- [REL13-BP03 Test disaster recovery implementation to validate the implementation](#)
- [REL13-BP04 Manage configuration drift at the DR site or Region](#)
- [REL13-BP05 Automate recovery](#)

## REL13-BP01 Define recovery objectives for downtime and data loss

The workload has a recovery time objective (RTO) and recovery point objective (RPO).

*Recovery Time Objective (RTO)* is the maximum acceptable delay between the interruption of service and restoration of service. This determines what is considered an acceptable time window when service is unavailable.

*Recovery Point Objective (RPO)* is the maximum acceptable amount of time since the last data recovery point. This determines what is considered an acceptable loss of data between the last recovery point and the interruption of service.

RTO and RPO values are important considerations when selecting an appropriate Disaster Recovery (DR) strategy for your workload. These objectives are determined by the business, and then used by technical teams to select and implement a DR strategy.

### Desired Outcome:

Every workload has an assigned RTO and RPO, defined based on business impact. The workload is assigned to a predefined tier, defining service availability and acceptable loss of data, with an associated RTO and RPO. If such tiering is not possible then this can be assigned bespoke per workload, with the intent to create tiers later. RTO and RPO are used as one of the primary considerations for selection of a disaster recovery strategy implementation for the workload. Additional considerations in picking a DR strategy are cost constraints, workload dependencies, and operational requirements.

For RTO, understand impact based on duration of an outage. Is it linear, or are there nonlinear implications? (for example. after four hours, you shut down a manufacturing line until the start of the next shift).

A disaster recovery matrix, like the following, can help you understand how workload criticality relates to recovery objectives. (Note that the actual values for the X and Y axes should be customized to your organization needs).

		Disaster Recovery Matrix				
		Recovery Point Objective				
		< 1 Minute	< 1 Hour	< 6 Hours	< 1 Day	+ 1 Day
Recovery Time Objective	< 10 Minutes	Critical	Critical	High	Medium	Medium
	< 2 Hours	Critical	High	Medium	Medium	Low
	< 8 Hours	High	Medium	Medium	Low	Low
	< 24 Hours	Medium	Medium	Low	Low	Low
	24 + Hours	Medium	Low	Low	Low	Low

Figure 16: Disaster recovery matrix

### Common anti-patterns:

- No defined recovery objectives.
- Selecting arbitrary recovery objectives.
- Selecting recovery objectives that are too lenient and do not meet business objectives.
- Not understanding of the impact of downtime and data loss.
- Selecting unrealistic recovery objectives, such as zero time to recover and zero data loss, which may not be achievable for your workload configuration.



- Selecting recovery objectives more stringent than actual business objectives. This forces DR implementations that are costlier and more complicated than what the workload needs.
- Selecting recovery objectives incompatible with those of a dependent workload.
- Your recovery objectives do not consider regulatory compliance requirements.
- RTO and RPO defined for a workload, but never tested.

**Benefits of establishing this best practice:** Your recovery objectives for time and data loss are necessary to guide your DR implementation.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

For the given workload, you must understand the impact of downtime and lost data on your business. The impact generally grows larger with greater downtime or data loss, but the shape of this growth can differ based on the workload type. For example, you may be able to tolerate downtime for up to an hour with little impact, but after that impact quickly rises. Impact to business manifests in many forms including monetary cost (such as lost revenue), customer trust (and impact to reputation), operational issues (such as missing payroll or decreased productivity), and regulatory risk. Use the following steps to understand these impacts, and set RTO and RPO for your workload.

### Implementation Steps

1. Determine your business stakeholders for this workload, and engage with them to implement these steps. Recovery objectives for a workload are a business decision. Technical teams then work with business stakeholders to use these objectives to select a DR strategy.

#### Note

For steps 2 and 3, you can use the [the section called "Implementation worksheet"](#).

2. Gather the necessary information to make a decision by answering the questions below.
3. Do you have categories or tiers of criticality for workload impact in your organization?
  - a. If yes, assign this workload to a category
  - b. If no, then establish these categories. Create five or fewer categories and refine the range of your recovery time objective for each one. Example categories include: critical, high, medium,

- low. To understand how workloads map to categories, consider whether the workload is mission critical, business important, or non-business driving.
- c. Set workload RTO and RPO based on category. Always choose a category more strict (lower RTO and RPO) than the raw values calculated entering this step. If this results in an unsuitably large change in value, then consider creating a new category.
4. Based on these answers, assign RTO and RPO values to the workload. This can be done directly, or by assigning the workload to a predefined tier of service.
  5. Document the disaster recovery plan (DRP) for this workload, which is a part of your organization's [business continuity plan \(BCP\)](#), in a location accessible to the workload team and stakeholders
    - a. Record the RTO and RPO, and the information used to determine these values. Include the strategy used for evaluating workload impact to the business
    - b. Record other metrics besides RTO and RPO are you tracking or plan to track for disaster recovery objectives
    - c. You will add details of your DR strategy and runbook to this plan when you create these.
  6. By looking up the workload criticality in a matrix such as that in Figure 15, you can begin to establish predefined tiers of service defined for your organization.
  7. After you have implemented a DR strategy (or a proof of concept for a DR strategy) as per [the section called "REL13-BP02 Use defined recovery strategies to meet the recovery objectives"](#), test this strategy to determine workload actual RTC (Recovery Time Capability) and RPC (Recovery Point Capability). If these do not meet the target recovery objectives, then either work with your business stakeholders to adjust those objectives, or make changes to the DR strategy is possible to meet target objectives.

## Primary questions

1. What is the maximum time the workload can be down before severe impact to the business is incurred
  - a. Determine the monetary cost (direct financial impact) to the business per minute if workload is disrupted.
  - b. Consider that impact is not always linear. Impact can be limited at first, and then increase rapidly past a critical point in time.
2. What is the maximum amount of data that can be lost before severe impact to the business is incurred

- a. Consider this value for your most critical data store. Identify the respective criticality for other data stores.
  - b. Can workload data be recreated if lost? If this is operationally easier than backup and restore, then choose RPO based on the criticality of the source data used to recreate the workload data.
3. What are the recovery objectives and availability expectations of workloads that this one depends on (downstream), or workloads that depend on this one (upstream)?
- a. Choose recovery objectives that allow this workload to meet the requirements of upstream dependencies
  - b. Choose recovery objectives that are achievable given the recovery capabilities of downstream dependencies. Non-critical downstream dependencies (ones you can “work around”) can be excluded. Or, work with critical downstream dependencies to improve their recovery capabilities where necessary.

## Additional questions

Consider these questions, and how they may apply to this workload:

4. Do you have different RTO and RPO depending on the type of outage (Region vs. AZ, etc.)?
5. Is there a specific time (seasonality, sales events, product launches) when your RTO/RPO may change? If so, what is the different measurement and time boundary?
6. How many customers will be impacted if workload is disrupted?
7. What is the impact to reputation if workload is disrupted?
8. What other operational impacts may occur if workload is disrupted? For example, impact to employee productivity if email systems are unavailable, or if Payroll systems are unable to submit transactions.
9. How does workload RTO and RPO align with Line of Business and Organizational DR Strategy?
10. Are there internal contractual obligations for providing a service? Are there penalties for not meeting them?
11. What are the regulatory or compliance constraints with the data?

## Implementation worksheet

You can use this worksheet for implementation steps 2 and 3. You may adjust this worksheet to suit your specific needs, such as adding additional questions.

Step 2: Primary questions	Applies to workload?	workload RTO	workload RPO	RTO adjust.	RPO adjust.	Instructions
[1] maximum time the workload can be down						measured in time from start of outage to recovery
[2] maximum amount of data that can be lost						measured in time since last known good restorable dataset
[3a] upstream dependencies						enter the most strict upstream recovery objectives
[3b] downstream dependencies						enter the least strict downstream recovery objectives
[3a] reconciled upstream dependencies						if upstream value is less then current values and downstream value greater,
[3b] reconciled downstream dependencies						then work with dependencies to reconcile and enter reconciled values here
[3] dependencies						lower values to meet upstream dependencies or raise them based on downstream dependency capabilities
<b>Step 2: Additional questions</b>						Indicate if question applies. If it does not apply then skip it
Base RTO/RPO						Carry RTO and RPO values from above down to here
[4] type of outage	[ ] Y/[ ] N					Enter recovery objectives for event type with strictest requirements
[5] specific time-based objectives	[ ] Y/[ ] N					Enter recovery objectives for times with the strictest requirements
[6] customers disrupted	[ ] Y/[ ] N					Graph customers impacted as a function of time down or data lost. Use that to enter the maximum RTO and RPO permissible based on customer impact
[7] reputation impact	[ ] Y/[ ] N					Work with the business to determine maximum RTO and RPO based on impact to reputation
[8] operational impact	[ ] Y/[ ] N					Enter maximum RTO and RPO based on operational impact
[9] organizational alignment	[ ] Y/[ ] N					Enter maximum RTO and RPO for workloads of this type as per LOB and organizational requirements
[10] contractual obligations	[ ] Y/[ ] N					Enter maximum RTO and RPO based on contractual obligations
[11] regulatory compliance	[ ] Y/[ ] N					Enter maximum RTO and RPO based on applicable regulatory compliance
target based on additional questions						Take the minimum value (stricter value) from Q's 4-11 and enter it here
adjusted target						If the objectives on the above line cannot be accommodated, work with stakeholders to loosen constraints, and enter new minimum here
Adjusted RTO/RPO						Enter base RPO/RTO values, or adjusted target, whichever is lower
<b>Step 3</b>						
Map to predefined category or tier						Adjust both values to downward (more strict) to align to nearest defined tier

## Worksheet

### Level of effort for the Implementation Plan: Low

## Resources

### Related Best Practices:

- [the section called “REL09-BP04 Perform periodic recovery of the data to verify backup integrity and processes”](#)
- [the section called “REL13-BP02 Use defined recovery strategies to meet the recovery objectives”](#)
- [the section called “REL13-BP03 Test disaster recovery implementation to validate the implementation”](#)

### Related documents:

- [AWS Architecture Blog: Disaster Recovery Series](#)
- [Disaster Recovery of Workloads on AWS: Recovery in the Cloud \(AWS Whitepaper\)](#)
- [Managing resiliency policies with AWS Resilience Hub](#)

- [APN Partner: partners that can help with disaster recovery](#)
- [AWS Marketplace: products that can be used for disaster recovery](#)

**Related videos:**

- [AWS re:Invent 2018: Architecture Patterns for Multi-Region Active-Active Applications \(ARC209-R2\)](#)
- [Disaster Recovery of Workloads on AWS](#)

## REL13-BP02 Use defined recovery strategies to meet the recovery objectives

Define a disaster recovery (DR) strategy that meets your workload's recovery objectives. Choose a strategy such as backup and restore, standby (active/passive), or active/active.

**Desired outcome:** For each workload, there is a defined and implemented DR strategy that allows the workload to achieve DR objectives. DR strategies between workloads make use of reusable patterns (such as the strategies previously described),

**Common anti-patterns:**

- Implementing inconsistent recovery procedures for workloads with similar DR objectives.
- Leaving the DR strategy to be implemented ad-hoc when a disaster occurs.
- Having no plan for disaster recovery.
- Dependency on control plane operations during recovery.

**Benefits of establishing this best practice:**

- Using defined recovery strategies allows you to use common tooling and test procedures.
- Using defined recovery strategies improves knowledge sharing between teams and implementation of DR on the workloads they own.

**Level of risk exposed if this best practice is not established:** High. Without a planned, implemented, and tested DR strategy, you are unlikely to achieve recovery objectives in the event of a disaster.

## Implementation guidance

A DR strategy relies on the ability to stand up your workload in a recovery site if your primary location becomes unable to run the workload. The most common recovery objectives are RTO and RPO, as discussed in [REL13-BP01 Define recovery objectives for downtime and data loss](#).

A DR strategy across multiple Availability Zones (AZs) within a single AWS Region, can provide mitigation against disaster events like fires, floods, and major power outages. If it is a requirement to implement protection against an unlikely event that prevents your workload from being able to run in a given AWS Region, you can use a DR strategy that uses multiple Regions.

When architecting a DR strategy across multiple Regions, you should choose one of the following strategies. They are listed in increasing order of cost and complexity, and decreasing order of RTO and RPO. *Recovery Region* refers to an AWS Region other than the primary one used for your workload.

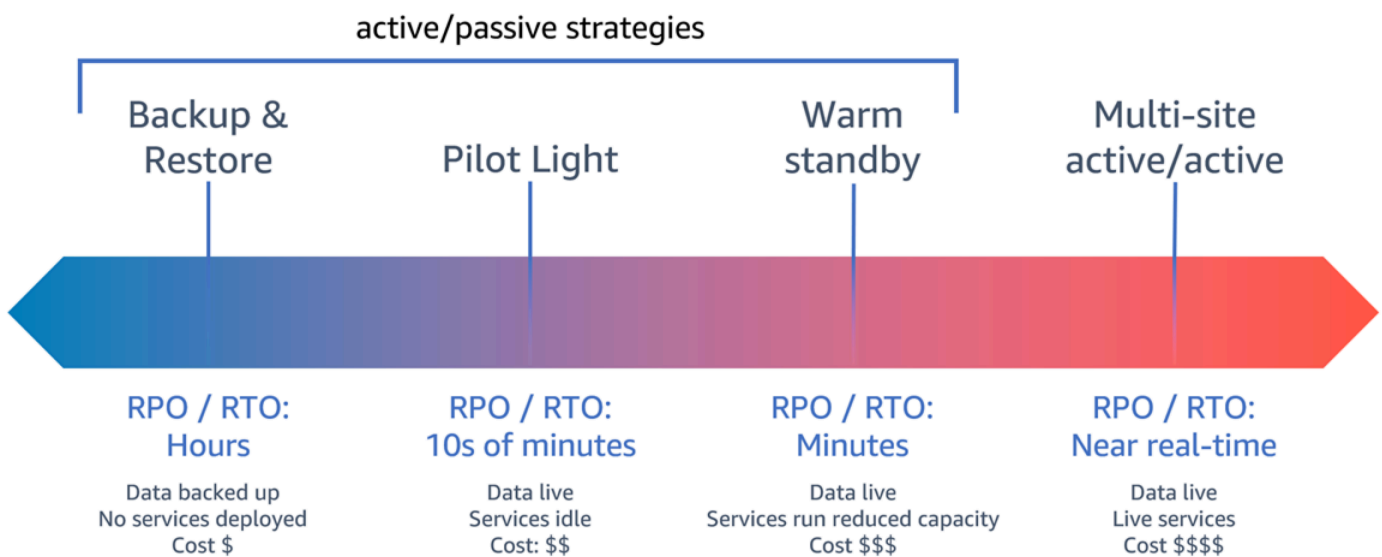


Figure 17: Disaster recovery (DR) strategies

- **Backup and restore** (RPO in hours, RTO in 24 hours or less): Back up your data and applications into the recovery Region. Using automated or continuous backups will permit point in time recovery (PITR), which can lower RPO to as low as 5 minutes in some cases. In the event of a disaster, you will deploy your infrastructure (using infrastructure as code to reduce RTO), deploy your code, and restore the backed-up data to recover from a disaster in the recovery Region.

- **Pilot light** (RPO in minutes, RTO in tens of minutes): Provision a copy of your core workload infrastructure in the recovery Region. Replicate your data into the recovery Region and create backups of it there. Resources required to support data replication and backup, such as databases and object storage, are always on. Other elements such as application servers or serverless compute are not deployed, but can be created when needed with the necessary configuration and application code.
- **Warm standby** (RPO in seconds, RTO in minutes): Maintain a scaled-down but fully functional version of your workload always running in the recovery Region. Business-critical systems are fully duplicated and are always on, but with a scaled down fleet. Data is replicated and live in the recovery Region. When the time comes for recovery, the system is scaled up quickly to handle the production load. The more scaled-up the warm standby is, the lower RTO and control plane reliance will be. When fully scales this is known as *hot standby*.
- **Multi-Region (multi-site) active-active** (RPO near zero, RTO potentially zero): Your workload is deployed to, and actively serving traffic from, multiple AWS Regions. This strategy requires you to synchronize data across Regions. Possible conflicts caused by writes to the same record in two different regional replicas must be avoided or handled, which can be complex. Data replication is useful for data synchronization and will protect you against some types of disaster, but it will not protect you against data corruption or destruction unless your solution also includes options for point-in-time recovery.

### Note

The difference between pilot light and warm standby can sometimes be difficult to understand. Both include an environment in your recovery Region with copies of your primary region assets. The distinction is that pilot light cannot process requests without additional action taken first, while warm standby can handle traffic (at reduced capacity levels) immediately. Pilot light will require you to turn on servers, possibly deploy additional (non-core) infrastructure, and scale up, while warm standby only requires you to scale up (everything is already deployed and running). Choose between these based on your RTO and RPO needs.

When cost is a concern, and you wish to achieve a similar RPO and RTO objectives as defined in the warm standby strategy, you could consider cloud native solutions, like AWS Elastic Disaster Recovery, that take the pilot light approach and offer improved RPO and RTO targets.

## Implementation steps

### 1. Determine a DR strategy that will satisfy recovery requirements for this workload.

Choosing a DR strategy is a trade-off between reducing downtime and data loss (RTO and RPO) and the cost and complexity of implementing the strategy. You should avoid implementing a strategy that is more stringent than it needs to be, as this incurs unnecessary costs.

For example, in the following diagram, the business has determined their maximum permissible RTO as well as the limit of what they can spend on their service restoration strategy. Given the business' objectives, the DR strategies pilot light or warm standby will satisfy both the RTO and the cost criteria.

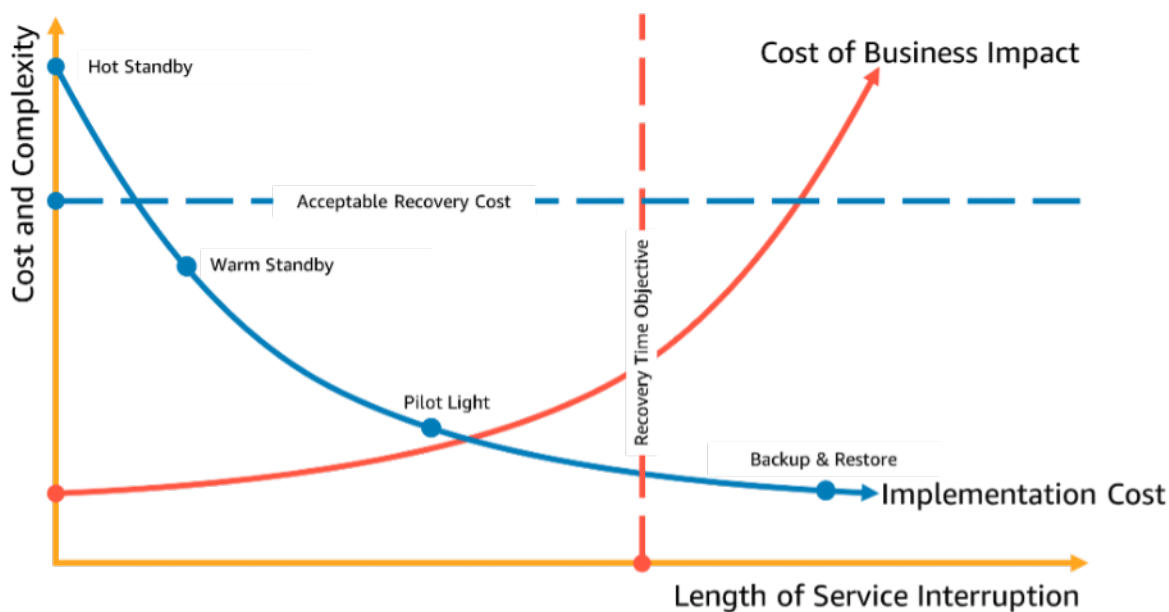


Figure 18: Choosing a DR strategy based on RTO and cost

To learn more, see [Business Continuity Plan \(BCP\)](#).

### 2. Review the patterns for how the selected DR strategy can be implemented.

This step is to understand how you will implement the selected strategy. The strategies are explained using AWS Regions as the primary and recovery sites. However, you can also choose to use Availability Zones within a single Region as your DR strategy, which makes use of elements of multiple of these strategies.

In the following steps, you can apply the strategy to your specific workload.



## Backup and restore

*Backup and restore* is the least complex strategy to implement, but will require more time and effort to restore the workload, leading to higher RTO and RPO. It is a good practice to always make backups of your data, and copy these to another site (such as another AWS Region).

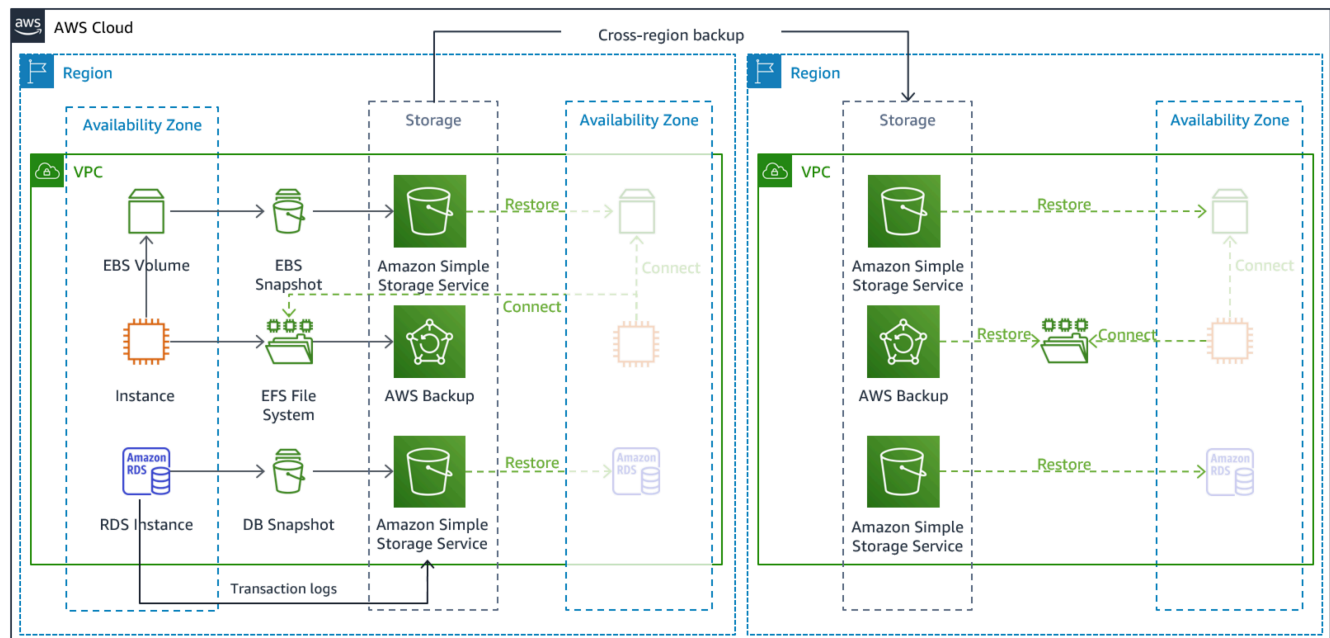


Figure 19: Backup and restore architecture

For more details on this strategy see [Disaster Recovery \(DR\) Architecture on AWS, Part II: Backup and Restore with Rapid Recovery](#).

## Pilot light

With the *pilot light* approach, you replicate your data from your primary Region to your recovery Region. Core resources used for the workload infrastructure are deployed in the recovery Region, however additional resources and any dependencies are still needed to make this a functional stack. For example, in Figure 20, no compute instances are deployed.

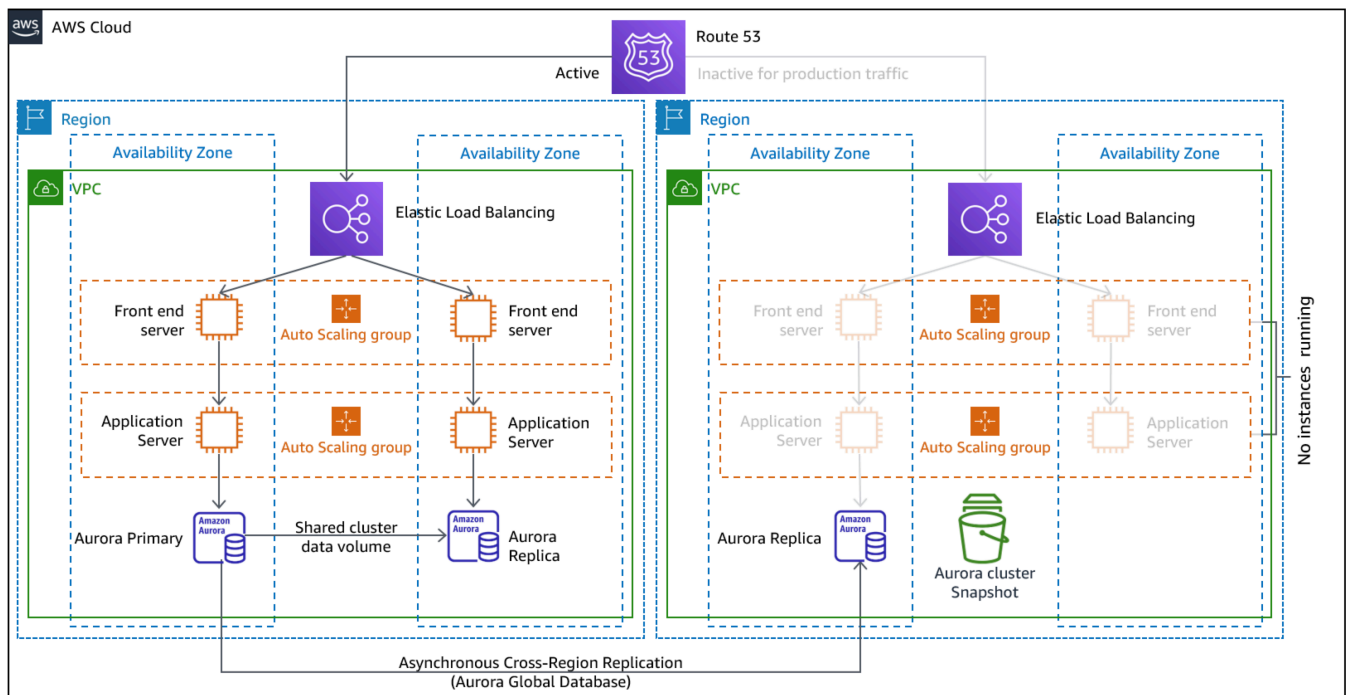


Figure 20: Pilot light architecture

For more details on this strategy, see [Disaster Recovery \(DR\) Architecture on AWS, Part III: Pilot Light and Warm Standby](#).

## Warm standby

The *warm standby* approach involves ensuring that there is a scaled down, but fully functional, copy of your production environment in another Region. This approach extends the pilot light concept and decreases the time to recovery because your workload is always-on in another Region. If the recovery Region is deployed at full capacity, then this is known as *hot standby*.

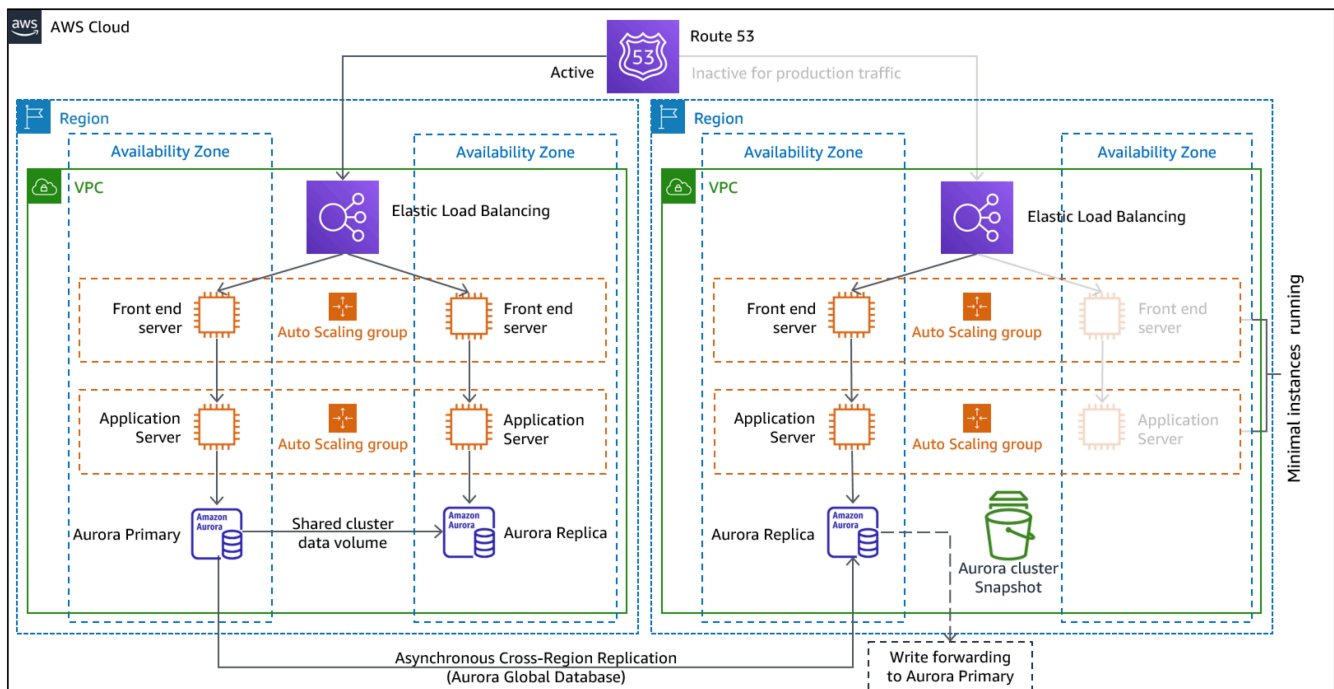


Figure 21: Warm standby architecture

Using warm standby or pilot light requires scaling up resources in the recovery Region. To verify capacity is available when needed, consider the use for [capacity reservations](#) for EC2 instances. If using AWS Lambda, then [provisioned concurrency](#) can provide runtime environments so that they are prepared to respond immediately to your function's invocations.

For more details on this strategy, see [Disaster Recovery \(DR\) Architecture on AWS, Part III: Pilot Light and Warm Standby](#).

### Multi-site active/active

You can run your workload simultaneously in multiple Regions as part of a *multi-site active/active* strategy. Multi-site active/active serves traffic from all regions to which it is deployed. Customers may select this strategy for reasons other than DR. It can be used to increase availability, or when deploying a workload to a global audience (to put the endpoint closer to users and/or to deploy stacks localized to the audience in that region). As a DR strategy, if the workload cannot be supported in one of the AWS Regions to which it is deployed, then that Region is evacuated, and the remaining Regions are used to maintain availability. Multi-site active/active is the most operationally complex of the DR strategies, and should only be selected when business requirements necessitate it.

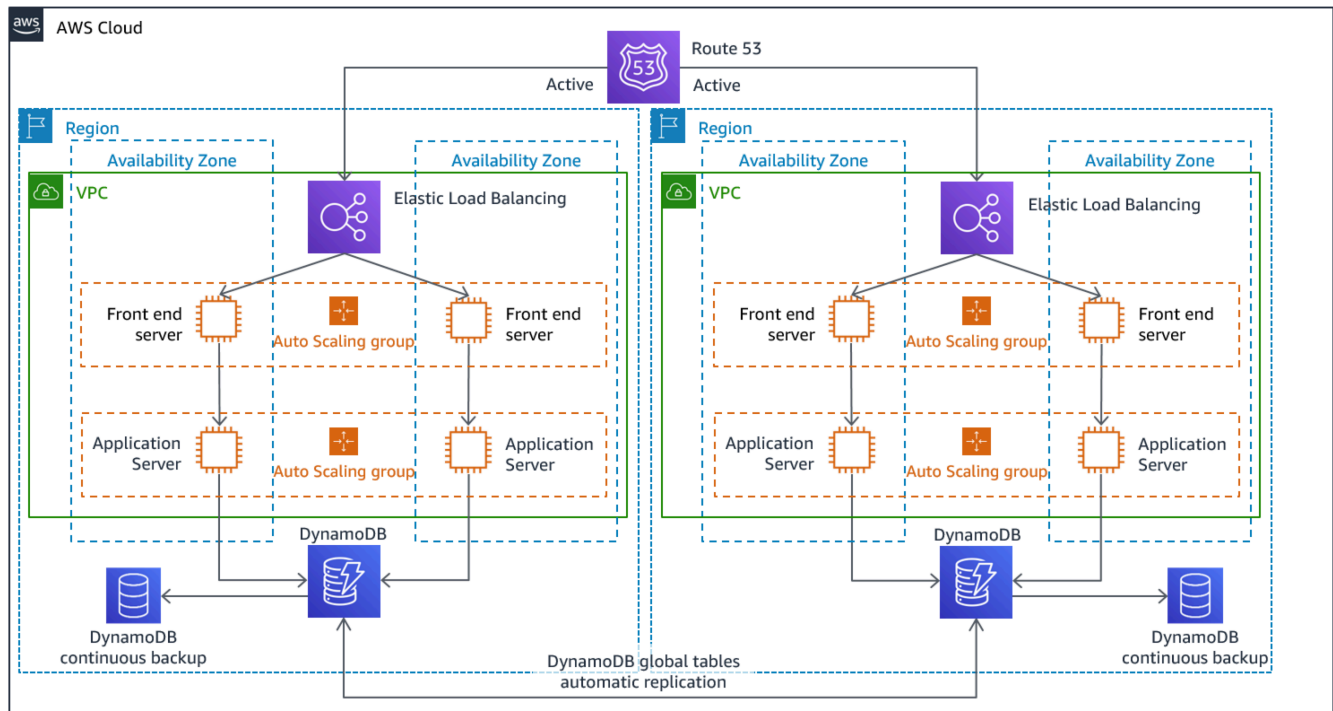


Figure 22: Multi-site active/active architecture

For more details on this strategy, see [Disaster Recovery \(DR\) Architecture on AWS, Part IV: Multi-site Active/Active](#).

## AWS Elastic Disaster Recovery

If you are considering the pilot light or warm standby strategy for disaster recovery, AWS Elastic Disaster Recovery could provide an alternative approach with improved benefits. Elastic Disaster Recovery can offer an RPO and RTO target similar to warm standby, but maintain the low-cost approach of pilot light. Elastic Disaster Recovery replicates your data from your primary region to your recovery Region, using continual data protection to achieve an RPO measured in seconds and an RTO that can be measured in minutes. Only the resources required to replicate the data are deployed in the recovery region, which keeps costs down, similar to the pilot light strategy. When using Elastic Disaster Recovery, the service coordinates and orchestrates the recovery of compute resources when initiated as part of failover or drill.

## AWS Elastic Disaster Recovery (AWS DRS) general architecture

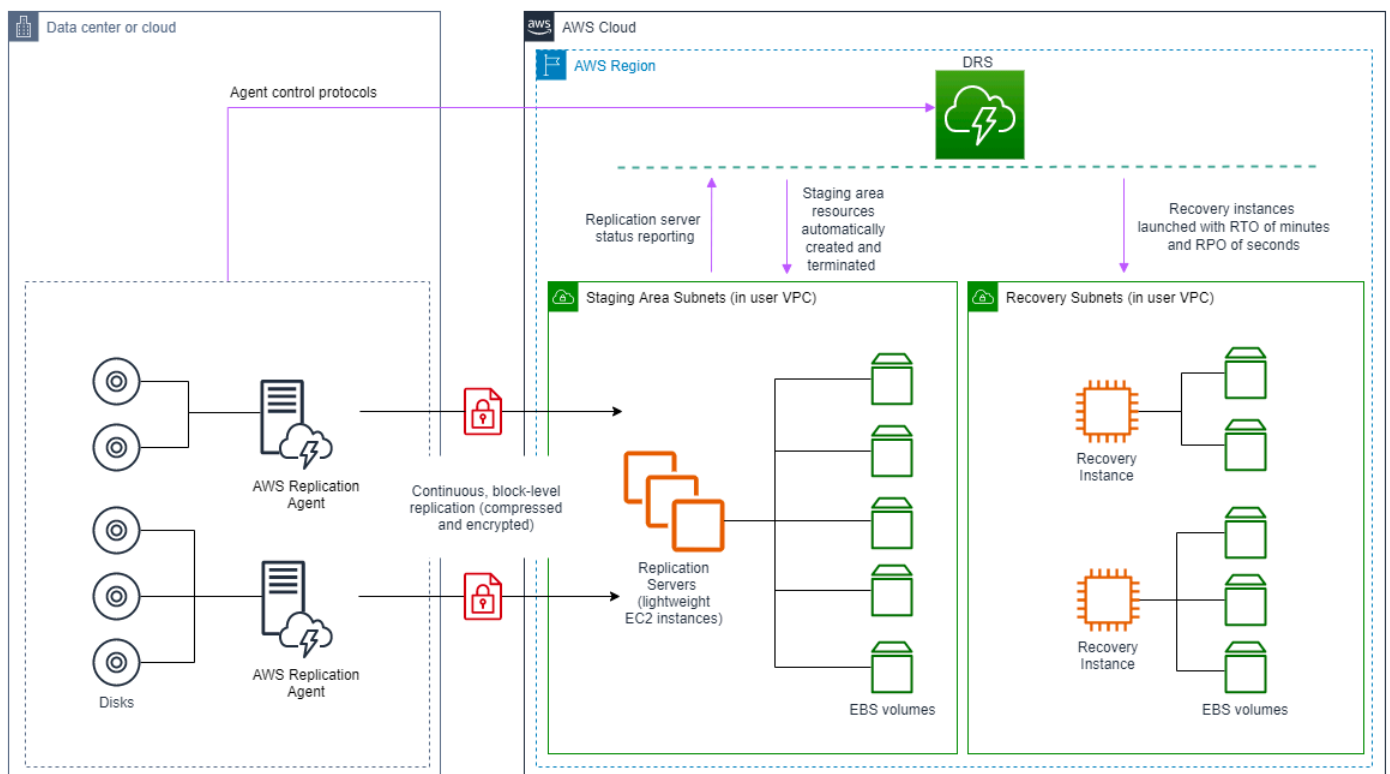


Figure 23: AWS Elastic Disaster Recovery architecture

### Additional practices for protecting data

With all strategies, you must also mitigate against a data disaster. Continuous data replication protects you against some types of disaster, but it may not protect you against data corruption or destruction unless your strategy also includes versioning of stored data or options for point-in-time recovery. You must also back up the replicated data in the recovery site to create point-in-time backups in addition to the replicas.

### Using multiple Availability Zones (AZs) within a single AWS Region

When using multiple AZs within a single Region, your DR implementation uses multiple elements of the above strategies. First you must create a high-availability (HA) architecture, using multiple AZs as shown in Figure 23. This architecture makes use of a multi-site active/active approach, as the [Amazon EC2 instances](#) and the [Elastic Load Balancer](#) have resources deployed in multiple AZs, actively handing requests. The architecture also demonstrates hot

standby, where if the primary [Amazon RDS](#) instance fails (or the AZ itself fails), then the standby instance is promoted to primary.

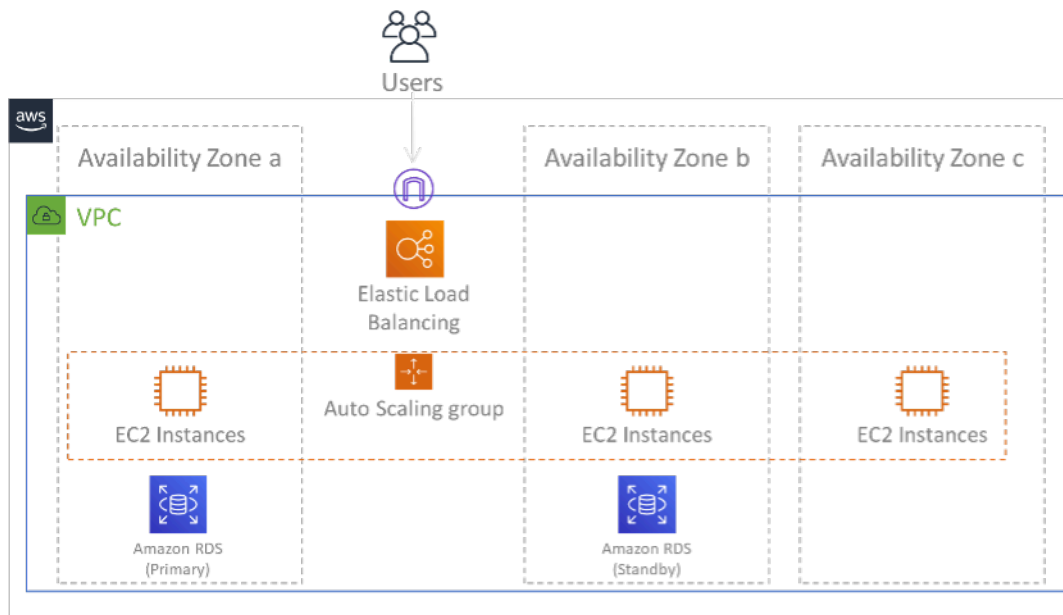


Figure 24: Multi-AZ architecture

In addition to this HA architecture, you need to add backups of all data required to run your workload. This is especially important for data that is constrained to a single zone such as [Amazon EBS volumes](#) or [Amazon Redshift clusters](#). If an AZ fails, you will need to restore this data to another AZ. Where possible, you should also copy data backups to another AWS Region as an additional layer of protection.

An less common alternative approach to single Region, multi-AZ DR is illustrated in the blog post, [Building highly resilient applications using Amazon Route 53 Application Recovery Controller, Part 1: Single-Region stack](#). Here, the strategy is to maintain as much isolation between the AZs as possible, like how Regions operate. Using this alternative strategy, you can choose an active/active or active/passive approach.

**Note**

Some workloads have regulatory data residency requirements. If this applies to your workload in a locality that currently has only one AWS Region, then multi-Region will not suit your business needs. Multi-AZ strategies provide good protection against most disasters.

### 3. Assess the resources of your workload, and what their configuration will be in the recovery Region prior to failover (during normal operation).

For infrastructure and AWS resources use infrastructure as code such as [AWS CloudFormation](#) or third-party tools like Hashicorp Terraform. To deploy across multiple accounts and Regions with a single operation you can use [AWS CloudFormation StackSets](#). For Multi-site active/active and Hot Standby strategies, the deployed infrastructure in your recovery Region has the same resources as your primary Region. For Pilot Light and Warm Standby strategies, the deployed infrastructure will require additional actions to become production ready. Using CloudFormation [parameters](#) and [conditional logic](#), you can control whether a deployed stack is active or standby with [a single template](#). When using Elastic Disaster Recovery, the service will replicate and orchestrate the restoration of application configurations and compute resources.

All DR strategies require that data sources are backed up within the AWS Region, and then those backups are copied to the recovery Region. [AWS Backup](#) provides a centralized view where you can configure, schedule, and monitor backups for these resources. For Pilot Light, Warm Standby, and Multi-site active/active, you should also replicate data from the primary Region to data resources in the recovery Region, such as [Amazon Relational Database Service \(Amazon RDS\)](#) DB instances or [Amazon DynamoDB](#) tables. These data resources are therefore live and ready to serve requests in the recovery Region.

To learn more about how AWS services operate across Regions, see this blog series on [Creating a Multi-Region Application with AWS Services](#).

### 4. Determine and implement how you will make your recovery Region ready for failover when needed (during a disaster event).

For multi-site active/active, failover means evacuating a Region, and relying on the remaining active Regions. In general, those Regions are ready to accept traffic. For Pilot Light and Warm Standby strategies, your recovery actions will need to deploy the missing resources, such as the EC2 instances in Figure 20, plus any other missing resources.

For all of the above strategies you may need to promote read-only instances of databases to become the primary read/write instance.

For backup and restore, restoring data from backup creates resources for that data such as EBS volumes, RDS DB instances, and DynamoDB tables. You also need to restore the infrastructure and deploy code. You can use AWS Backup to restore data in the recovery Region. See [REL09-BP01 Identify and back up all data that needs to be backed up, or reproduce the data from](#)

[sources](#) for more details. Rebuilding the infrastructure includes creating resources like EC2 instances in addition to the [Amazon Virtual Private Cloud \(Amazon VPC\)](#), subnets, and security groups needed. You can automate much of the restoration process. To learn how, see [this blog post](#).

## 5. Determine and implement how you will reroute traffic to failover when needed (during a disaster event).

This failover operation can be initiated either automatically or manually. Automatically initiated failover based on health checks or alarms should be used with caution since an unnecessary failover (false alarm) incurs costs such as non-availability and data loss. Manually initiated failover is therefore often used. In this case, you should still automate the steps for failover, so that the manual initiation is like the push of a button.

There are several traffic management options to consider when using AWS services. One option is to use [Amazon Route 53](#). Using Amazon Route 53, you can associate multiple IP endpoints in one or more AWS Regions with a Route 53 domain name. To implement manually initiated failover you can use [Amazon Route 53 Application Recovery Controller](#), which provides a highly available data plane API to reroute traffic to the recovery Region. When implementing failover, use data plane operations and avoid control plane ones as described in [REL11-BP04 Rely on the data plane and not the control plane during recovery](#).

To learn more about this and other options see [this section of the Disaster Recovery Whitepaper](#).

## 6. Design a plan for how your workload will fail back.

Failback is when you return workload operation to the primary Region, after a disaster event has abated. Provisioning infrastructure and code to the primary Region generally follows the same steps as were initially used, relying on infrastructure as code and code deployment pipelines. The challenge with failback is restoring data stores, and ensuring their consistency with the recovery Region in operation.

In the failed over state, the databases in the recovery Region are live and have the up-to-date data. The goal then is to re-synchronize from the recovery Region to the primary Region, ensuring it is up-to-date.

Some AWS services will do this automatically. If using [Amazon DynamoDB global tables](#), even if the table in the primary Region had become not available, when it comes back online, DynamoDB resumes propagating any pending writes. If using [Amazon Aurora Global Database](#) and using [managed planned failover](#), then Aurora global database's existing replication topology



is maintained. Therefore, the former read/write instance in the primary Region will become a replica and receive updates from the recovery Region.

In cases where this is not automatic, you will need to re-establish the database in the primary Region as a replica of the database in the recovery Region. In many cases this will involve deleting the old primary database, and creating new replicas.

After a failover, if you can continue running in your recovery Region, consider making this the new primary Region. You would still do all the above steps to make the former primary Region into a recovery Region. Some organizations do a scheduled rotation, swapping their primary and recovery Regions periodically (for example every three months).

All of the steps required to fail over and fail back should be maintained in a playbook that is available to all members of the team, and is periodically reviewed.

When using Elastic Disaster Recovery, the service will assist in orchestrating and automating the failback process. For more details, see [Performing a failback](#).

**Level of effort for the Implementation Plan: High**

## Resources

### Related best practices:

- [the section called “REL09-BP01 Identify and back up all data that needs to be backed up, or reproduce the data from sources”](#)
- [the section called “REL11-BP04 Rely on the data plane and not the control plane during recovery”](#)
- [the section called “REL13-BP01 Define recovery objectives for downtime and data loss”](#)

### Related documents:

- [AWS Architecture Blog: Disaster Recovery Series](#)
- [Disaster Recovery of Workloads on AWS: Recovery in the Cloud \(AWS Whitepaper\)](#)
- [Disaster recovery options in the cloud](#)
- [Build a serverless multi-region, active-active backend solution in an hour](#)
- [Multi-region serverless backend — reloaded](#)

- [RDS: Replicating a Read Replica Across Regions](#)
- [Route 53: Configuring DNS Failover](#)
- [S3: Cross-Region Replication](#)
- [What Is AWS Backup?](#)
- [What is Route 53 Application Recovery Controller?](#)
- [AWS Elastic Disaster Recovery](#)
- [HashiCorp Terraform: Get Started - AWS](#)
- [APN Partner: partners that can help with disaster recovery](#)
- [AWS Marketplace: products that can be used for disaster recovery](#)

#### Related videos:

- [Disaster Recovery of Workloads on AWS](#)
- [AWS re:Invent 2018: Architecture Patterns for Multi-Region Active-Active Applications \(ARC209-R2\)](#)
- [Get Started with AWS Elastic Disaster Recovery | Amazon Web Services](#)

#### Related examples:

- [Well-Architected Lab - Disaster Recovery](#) - Series of workshops illustrating DR strategies

## REL13-BP03 Test disaster recovery implementation to validate the implementation

Regularly test failover to your recovery site to verify that it operates properly and that RTO and RPO are met.

#### Common anti-patterns:

- Never exercise failovers in production.

**Benefits of establishing this best practice:** Regularly testing your disaster recovery plan verifies that it will work when it needs to, and that your team knows how to perform the strategy.

**Level of risk exposed if this best practice is not established:** High

## Implementation guidance

A pattern to avoid is developing recovery paths that are rarely exercised. For example, you might have a secondary data store that is used for read-only queries. When you write to a data store and the primary fails, you might want to fail over to the secondary data store. If you don't frequently test this failover, you might find that your assumptions about the capabilities of the secondary data store are incorrect. The capacity of the secondary, which might have been sufficient when you last tested, might be no longer be able to tolerate the load under this scenario. Our experience has shown that the only error recovery that works is the path you test frequently. This is why having a small number of recovery paths is best. You can establish recovery patterns and regularly test them. If you have a complex or critical recovery path, you still need to regularly exercise that failure in production to convince yourself that the recovery path works. In the example we just discussed, you should fail over to the standby regularly, regardless of need.

### Implementation steps

1. Engineer your workloads for recovery. Regularly test your recovery paths. Recovery-oriented computing identifies the characteristics in systems that enhance recovery: isolation and redundancy, system-wide ability to roll back changes, ability to monitor and determine health, ability to provide diagnostics, automated recovery, modular design, and ability to restart. Exercise the recovery path to verify that you can accomplish the recovery in the specified time to the specified state. Use your runbooks during this recovery to document problems and find solutions for them before the next test.
2. For Amazon EC2-based workloads, use [AWS Elastic Disaster Recovery](#) to implement and launch drill instances for your DR strategy. AWS Elastic Disaster Recovery provides the ability to efficiently run drills, which helps you prepare for a failover event. You can also frequently launch of your instances using Elastic Disaster Recovery for test and drill purposes without redirecting the traffic.

## Resources

### Related documents:

- [APN Partner: partners that can help with disaster recovery](#)
- [AWS Architecture Blog: Disaster Recovery Series](#)
- [AWS Marketplace: products that can be used for disaster recovery](#)
- [AWS Elastic Disaster Recovery](#)

- [Disaster Recovery of Workloads on AWS: Recovery in the Cloud \(AWS Whitepaper\)](#)
- [AWS Elastic Disaster Recovery Preparing for Failover](#)
- [The Berkeley/Stanford recovery-oriented computing project](#)
- [What is AWS Fault Injection Simulator?](#)

**Related videos:**

- [AWS re:Invent 2018: Architecture Patterns for Multi-Region Active-Active Applications](#)
- [AWS re:Invent 2019: Backup-and-restore and disaster-recovery solutions with AWS](#)

**Related examples:**

- [Well-Architected Lab - Testing for Resiliency](#)

## REL13-BP04 Manage configuration drift at the DR site or Region

Ensure that the infrastructure, data, and configuration are as needed at the DR site or Region. For example, check that AMIs and service quotas are up to date.

AWS Config continuously monitors and records your AWS resource configurations. It can detect drift and invoke [AWS Systems Manager Automation](#) to fix it and raise alarms. AWS CloudFormation can additionally detect drift in stacks you have deployed.

**Common anti-patterns:**

- Failing to make updates in your recovery locations, when you make configuration or infrastructure changes in your primary locations.
- Not considering potential limitations (like service differences) in your primary and recovery locations.

**Benefits of establishing this best practice:** Ensuring that your DR environment is consistent with your existing environment guarantees complete recovery.

**Level of risk exposed if this best practice is not established:** Medium

## Implementation guidance

- Ensure that your delivery pipelines deliver to both your primary and backup sites. Delivery pipelines for deploying applications into production must distribute to all the specified disaster recovery strategy locations, including dev and test environments.
- Permit AWS Config to track potential drift locations. Use AWS Config rules to create systems that enforce your disaster recovery strategies and generate alerts when they detect drift.
  - [Remediating Noncompliant AWS Resources by AWS Config Rules](#)
  - [AWS Systems Manager Automation](#)
- Use AWS CloudFormation to deploy your infrastructure. AWS CloudFormation can detect drift between what your CloudFormation templates specify and what is actually deployed.
  - [AWS CloudFormation: Detect Drift on an Entire CloudFormation Stack](#)

## Resources

### Related documents:

- [APN Partner: partners that can help with disaster recovery](#)
- [AWS Architecture Blog: Disaster Recovery Series](#)
- [AWS CloudFormation: Detect Drift on an Entire CloudFormation Stack](#)
- [AWS Marketplace: products that can be used for disaster recovery](#)
- [AWS Systems Manager Automation](#)
- [Disaster Recovery of Workloads on AWS: Recovery in the Cloud \(AWS Whitepaper\)](#)
- [How do I implement an Infrastructure Configuration Management solution on AWS?](#)
- [Remediating Noncompliant AWS Resources by AWS Config Rules](#)

### Related videos:

- [AWS re:Invent 2018: Architecture Patterns for Multi-Region Active-Active Applications \(ARC209-R2\)](#)

## REL13-BP05 Automate recovery

Use AWS or third-party tools to automate system recovery and route traffic to the DR site or Region.

Based on configured health checks, AWS services, such as Elastic Load Balancing and AWS Auto Scaling, can distribute load to healthy Availability Zones while services, such as Amazon Route 53 and AWS Global Accelerator, can route load to healthy AWS Regions. Amazon Route 53 Application Recovery Controller helps you manage and coordinate failover using readiness check and routing control features. These features continually monitor your application's ability to recover from failures, so you can control application recovery across multiple AWS Regions, Availability Zones, and on premises.

For workloads on existing physical or virtual data centers or private clouds, [AWS Elastic Disaster Recovery](#) allows organizations to set up an automated disaster recovery strategy in AWS. Elastic Disaster Recovery also supports cross-Region and cross-Availability Zone disaster recovery in AWS.

### Common anti-patterns:

- Implementing identical automated failover and failback can cause flapping when a failure occurs.

**Benefits of establishing this best practice:** Automated recovery reduces your recovery time by eliminating the opportunity for manual errors.

**Level of risk exposed if this best practice is not established:** Medium

### Implementation guidance

- Automate recovery paths. For short recovery times, follow your [disaster recovery plan](#) to get your IT systems back online quickly in the case of a disruption.
- Use Elastic Disaster Recovery for automated Failover and Failback. Elastic Disaster Recovery continuously replicates your machines (including operating system, system state configuration, databases, applications, and files) into a low-cost staging area in your target AWS account and preferred Region. In the case of a disaster, after choosing to recover using Elastic Disaster Recovery, Elastic Disaster Recovery automates the conversion of your replicated servers into fully provisioned workloads in your recovery Region on AWS.
  - [Using Elastic Disaster Recovery for Failover and Failback](#)
  - [AWS Elastic Disaster Recovery resources](#)

## Resources

### Related documents:

- [APN Partner: partners that can help with disaster recovery](#)
- [AWS Architecture Blog: Disaster Recovery Series](#)
- [AWS Marketplace: products that can be used for disaster recovery](#)
- [AWS Systems Manager Automation](#)
- [AWS Elastic Disaster Recovery](#)
- [Disaster Recovery of Workloads on AWS: Recovery in the Cloud \(AWS Whitepaper\)](#)

### Related videos:

- [AWS re:Invent 2018: Architecture Patterns for Multi-Region Active-Active Applications \(ARC209-R2\)](#)

## Example implementations for availability goals

### Note

The example scenarios presented in this section do not represent actual availability for real-world workloads on AWS. These sections are intended to illustrate architectural considerations and guide high-level thinking when designing for different availability goals. Actual workload availability depends on specific business requirements, workload design, and operational constraints that extend beyond AWS services and infrastructure. Tailor your architecture to the unique demands of your workload and thoroughly assess availability requirements for your environment.

In this section, we'll review workload designs using the deployment of a typical web application that consists of a reverse proxy, static content on Amazon S3, an application server, and a SQL database for persistent storage of data. For each availability target, we provide an example implementation. This workload could instead use containers or AWS Lambda for compute and NoSQL (such as Amazon DynamoDB) for the database, but the approaches are similar. In each scenario, we demonstrate how to meet availability goals through workload design for these topics:

Topic	For more information, see this section
Monitor resources	<a href="#">Monitor workload resources</a>
Adapt to changes in demand	<a href="#">Design your workload to adapt to changes in demand</a>
Implement change	<a href="#">Implement change</a>
Back up data	<a href="#">Back up data</a>
Architect for resiliency	<a href="#">Use fault isolation to protect your workload</a> <a href="#">Design your workload to withstand component failures</a>
Test reliability	<a href="#">Test reliability</a>



Topic	For more information, see this section
Plan for disaster recovery (DR)	<a href="#">Plan for Disaster Recovery (DR)</a>

## Dependency selection

We have chosen to use Amazon EC2 for our applications. We will show how using Amazon RDS and multiple Availability Zones improves the availability of our applications. We will use Amazon Route 53 for DNS. When we use multiple Availability Zones, we will use Elastic Load Balancing. Amazon S3 is used for backups and static content. As we design for higher reliability, we must use services with higher availability themselves.

## Single-Region scenarios

### Topics

- [2 9s \(99%\) scenario](#)
- [3 9s \(99.9%\) scenario](#)
- [4 9s \(99.99%\) scenario](#)

### 2 9s (99%) scenario

These workloads are helpful to the business, but it's only an *inconvenience* if they are unavailable. This type of workload can be internal tooling, internal knowledge management, or project tracking. Or these can be actual customer-facing workloads but served from an experimental service, with a feature toggle that can hide the service if needed.

These workloads can be deployed with one Region and one Availability Zone.

### Monitor resources

We will have simple monitoring, indicating whether the service home page is returning an HTTP 200 OK status. When problems occur, our playbook will indicate that logging from the instance will be used to establish root cause.

## **Adapt to changes in demand**

We will have playbooks for common hardware failures, urgent software updates, and other disruptive changes.

## **Implement change**

We will use AWS CloudFormation to define our infrastructure as code, and specifically to speed up reconstruction in the event of a failure.

Software updates are manually performed using a runbook, with downtime required for the installation and restart of the service. If a problem happens during deployment, the runbook describes how to roll back to the previous version.

Any corrections of the error are done using analysis of logs by the operations and development teams, and the correction is deployed after the fix is prioritized and completed.

## **Back up data**

We will use a vendor or purpose built backup solution to send encrypted backup data to Amazon S3 using a runbook. We will test that the backups work by restoring the data and ensuring the ability to use it on a regular basis using a runbook. We configure versioning on our Amazon S3 objects and remove permissions for deletion of the backups. We use an Amazon S3 bucket lifecycle policy to archive or permanently delete according to our requirements.

## **Architect for resiliency**

Workloads are deployed with one Region and one Availability Zone. We deploy the application, including the database, to a single instance.

## **Test resiliency**

The deployment pipeline of new software is scheduled, with some unit testing, but mostly white-box/black-box testing of the assembled workload.

## **Plan for disaster recovery (DR)**

During failures we wait for the failure to finish, optionally routing requests to a static website using DNS modification via a runbook. The recovery time for this will be determined by the speed at which the infrastructure can be deployed and the database restored to the most recent backup. This deployment can either be into the same Availability Zone, or into a different Availability Zone, in the event of an Availability Zone failure, using a runbook.

## Availability design goal

We take 30 minutes to understand and decide to invoke recovery, deploy the whole stack in AWS CloudFormation in 10 minutes, assume that we deploy to a new Availability Zone, and assume that the database can be restored in 30 minutes. This implies that it takes about 70 minutes to recover from a failure. Assuming one failure per quarter, our estimated impact time for the year is 280 minutes, or four hours and 40 minutes.

This means that the upper limit on availability is 99.9%. The actual availability also depends on the real rate of failure, the duration of failure, and how quickly each failure actually recovers. For this architecture, we require the application to be offline for updates (estimating 24 hours per year: four hours per change, six times per year), plus actual events. So referring to the table on application availability earlier in the whitepaper we see that our **availability design goal** is 99%.

## Summary

Topic	Implementation
Monitor resources	Site health check only; no alerting.
Adapt to changes in demand	Vertical scaling via re-deployment.
Implement change	Runbook for deploy and rollback.
Back up data	Runbook for backup and restore.
Architect for resiliency	Complete rebuild; restore from backup.
Test resiliency	Complete rebuild; restore from backup.
Plan for disaster recovery (DR)	Encrypted backups, restore to different Availability Zone if needed.

## 3 9s (99.9%) scenario

The next availability goal is for applications for which it's important to be highly available, but they can tolerate short periods of unavailability. This type of workload is typically used for internal operations that have an effect on employees when they are down. This type of workload can also be customer-facing, but are not high revenue for the business and can tolerate a longer

recovery time or recovery point. Such workloads include administrative applications for account or information management.

We can improve availability for workloads by using two Availability Zones for our deployment and by separating the applications to separate tiers.

## **Monitor resources**

Monitoring will be expanded to alert on the availability of the website over all by checking for an HTTP 200 OK status on the home page. In addition, there will be alerting on every replacement of a web server and when the database fails over. We will also monitor the static content on Amazon S3 for availability and alert if it becomes unavailable. Logging will be aggregated for ease of management and to help in root cause analysis.

## **Adapt to changes in demand**

Automatic scaling is configured to monitor CPU utilization on EC2 instances, and add or remove instances to maintain the CPU target at 70%, but with no fewer than one EC2 instance per Availability Zone. If load patterns on our RDS instance indicate that scale up is needed, we will change the instance type during a maintenance window.

## **Implement change**

The infrastructure deployment technologies remain the same as the previous scenario.

Delivery of new software is on a fixed schedule of every two to four weeks. Software updates will be automated, not using canary or blue/green deployment patterns, but rather, using replace in place. The decision to roll back will be made using the runbook.

We will have playbooks for establishing root cause of problems. After the root cause has been identified, the correction for the error will be identified by a combination of the operations and development teams. The correction will be deployed after the fix is developed.

## **Back up data**

Backup and restore can be done using Amazon RDS. It will be run regularly using a runbook to ensure that we can meet recovery requirements.

## **Architect for resiliency**

We can improve availability for applications by using two Availability Zones for our deployment and by separating the applications to separate tiers. We will use services that work across multiple

Availability Zones, such as Elastic Load Balancing, Auto Scaling and Amazon RDS Multi-AZ with encrypted storage via AWS Key Management Service. This will ensure tolerance to failures on the resource level and on the Availability Zone level.

The load balancer will only route traffic to healthy application instances. The health check needs to be at the data plane/application layer indicating the capability of the application on the instance. This check should not be against the control plane. A health check URL for the web application will be present and configured for use by the load balancer and Auto Scaling, so that instances that fail are removed and replaced. Amazon RDS will manage the active database engine to be available in the second Availability Zone if the instance fails in the primary Availability Zone, then repair to restore to the same resiliency.

After we have separated the tiers, we can use distributed system resiliency patterns to increase the reliability of the application so that it can still be available even when the database is temporarily unavailable during an Availability Zone failover.

## Test resiliency

We do functional testing, same as in the previous scenario. We do not test the self-healing capabilities of ELB, automatic scaling, or RDS failover.

We will have playbooks for common database problems, security-related incidents, and failed deployments.

## Plan for disaster recovery (DR)

Runbooks exist for total workload recovery and common reporting. Recovery uses backups stored in the same region as the workload.

## Availability design goal

We assume that at least some failures will require a manual decision to run recovery. However with the greater automation in this scenario, we assume that only two events per year will require this decision. We take 30 minutes to decide to run recovery, and assume that recovery is completed within 30 minutes. This implies 60 minutes to recover from failure. Assuming two incidents per year, our estimated impact time for the year is 120 minutes.

This means that the upper limit on availability is 99.95%. The actual availability also depends on the real rate of failure, the duration of the failure, and how quickly each failure actually recovers. For this architecture, we require the application to be briefly offline for updates, but these updates are automated. We estimate 150 minutes per year for this: 15 minutes per change, 10 times per

year. This adds up to 270 minutes per year when the service is not available, so our **availability design goal** is 99.9%.

## Summary

Topic	Implementation
Monitor resources	Site health check only; alerts sent when down.
Adapt to changes in demand	ELB for web and automatic scaling application tier; resizing Multi-AZ RDS.
Implement change	Automated deploy in place and runbook for rollback.
Back up data	Automated backups via RDS to meet RPO and runbook for restoring.
Architect for resiliency	Automatic scaling to provide self-healing web and application tier; RDS is Multi-AZ.
Test resiliency	ELB and application are self-healing; RDS is Multi-AZ; no explicit testing.
Plan for disaster recovery (DR)	Encrypted backups via RDS to same AWS Region.

## 4 9s (99.99%) scenario

This availability goal for applications requires the application to be highly available and tolerant to component failures. The application must be able to absorb failures without needing to get additional resources. This availability goal is for mission critical applications that are main or significant revenue drivers for a corporation, such as an ecommerce site, a business to business web service, or a high traffic content/media site.

We can improve availability further by using an architecture that will be *statically stable* within the Region. This availability goal doesn't require a control plane change in behavior of our workload to tolerate failure. For example, there should be enough capacity to withstand the loss of one

Availability Zone. We should not require updates to Amazon Route 53 DNS. We should not need to create any new infrastructure, whether it's creating or modifying an S3 bucket, creating new IAM policies (or modifications of policies), or modifying Amazon ECS task configurations.

## Monitor resources

Monitoring will include success metrics as well as alerting when problems occur. In addition, there will be alerting on every replacement of a failed web server, when the database fails over, and when an AZ fails.

## Adapt to changes in demand

We will use Amazon Aurora as our RDS, which allows automatic scaling of read replicas. For these applications, engineering for read availability over write availability of primary content is also a key architecture decision. Aurora can also automatically grow storage as needed, in 10 GB increments up to 128 TB.

## Implement change

We will deploy updates using canary or blue/green deployments into each isolation zone separately. The deployments are fully automated, including a roll back if KPIs indicate a problem.

Runbooks will exist for rigorous reporting requirements and performance tracking. If successful operations are trending toward failure to meet performance or availability goals, a playbook will be used to establish what is causing the trend. Playbooks will exist for undiscovered failure modes and security incidents. Playbooks will also exist for establishing the root cause of failures. We will also engage with AWS Support for Infrastructure Event Management offering.

The team that builds and operates the website will identify the correction of error of any unexpected failure and prioritize the fix to be deployed after it is implemented.

## Back up data

Backup and restore can be done using Amazon RDS. It will be run regularly using a runbook to ensure that we can meet recovery requirements.

## Architect for resiliency

We recommend three Availability Zones for this approach. Using a three Availability Zone deployment, each AZ has static capacity of 50% of peak. Two Availability Zones could be used, but the cost of the statically stable capacity would be more because both zones would have to have

100% of peak capacity. We will add Amazon CloudFront to provide geographic caching, as well as request reduction on our application's data plane.

We will use Amazon Aurora as our RDS and deploy read replicas in all three zones.

The application will be built using the software/application resiliency patterns in all layers.

## Test resiliency

The deployment pipeline will have a full test suite, including performance, load, and failure injection testing.

We will practice our failure recovery procedures constantly through game days, using runbooks to ensure that we can perform the tasks and not deviate from the procedures. The team that builds the website also operates the website.

## Plan for disaster recovery (DR)

Runbooks exist for total workload recovery and common reporting. Recovery uses backups stored in the same region as the workload. Restore procedures are regularly exercised as part of game days.

## Availability design goal

We assume that at least some failures will require a manual decision to perform recovery, however with greater automation in this scenario we assume that only two events per year will require this decision and the recovery actions will be rapid. We take 10 minutes to decide to run recovery, and assume that recovery is completed within five minutes. This implies 15 minutes to recover from failure. Assuming two failures per year, our estimated impact time for the year is 30 minutes.

This means that the upper limit on availability is 99.99%. The actual availability will also depend on the real rate of failure, the duration of the failure, and how quickly each failure actually recovers. For this architecture, we assume that the application is online continuously through updates. Based on this, our **availability design goal** is 99.99%.

## Summary

Topic	Implementation
Monitor resources	Health checks at all layers and on KPIs; alerts sent when configured alarms are tripped;



Topic	Implementation
	alerting on all failures. Operational meetings are rigorous to detect trends and manage to design goals.
Adapt to changes in demand	ELB for web and automatic scaling applicati on tier; automatic scaling storage and read replicas in multiple zones for Aurora RDS.
Implement change	Automated deploy via canary or blue/green and automated rollback when KPIs or alerts indicate undetected problems in application. Deployments are made by isolation zone.
Back up data	Automated backups via RDS to meet RPO and automated restoration that is practiced regularly in a game day.
Architect for resiliency	Implemented fault isolation zones for the application; auto scaling to provide self-heal ing web and application tier; RDS is Multi-AZ.
Test resiliency	Component and isolation zone fault testing is in pipeline and practiced with operational staff regularly in a game day; playbooks exist for diagnosing unknown problems; and a Root Cause Analysis process exists.
Plan for disaster recovery (DR)	Encrypted backups via RDS to same AWS Region that is practiced in a game day.

## Multi-Region scenarios

Implementing our application in multiple AWS Regions will increase the cost of operation, partly because we isolate regions to maintain their autonomy. It should be a very thoughtful decision to pursue this path. That said, regions provide a strong isolation boundary and we take great pains to avoid correlated failures across regions. Using multiple regions will give you greater control over

your recovery time in the event of a hard dependency failure on a regional AWS service. In this section, we'll discuss various implementation patterns and their typical availability.

## Topics

- [3½ 9s \(99.95%\) with a Recovery Time between 5 and 30 Minutes](#)
- [5 9s \(99.999%\) or higher scenario with a recovery time under one minute](#)

## 3½ 9s (99.95%) with a Recovery Time between 5 and 30 Minutes

This availability goal for applications requires extremely short downtime and very little data loss during specific times. Applications with this availability goal include applications in the areas of: banking, investing, emergency services, and data capture. These applications have very short recovery times and recovery points.

We can improve recovery time further by using a *Warm Standby* approach across two AWS Regions. We will deploy the entire workload to both Regions, with our passive site scaled down and all data kept eventually consistent. Both deployments will be *statically stable* within their respective regions. The applications should be built using the distributed system resiliency patterns. We'll need to create a lightweight *routing* component that monitors for workload health, and can be configured to route traffic to the passive region if necessary.

### Monitor resources

There will be alerting on every replacement of a web server, when the database fails over, and when the Region fails over. We will also monitor the static content on Amazon S3 for availability and alert if it becomes unavailable. Logging will be aggregated for ease of management and to help in root cause analysis in each Region.

The routing component monitors both our application health and any regional hard dependencies we have.

### Adapt to changes in demand

Same as the 4 9s scenario.

### Implement change

Delivery of new software is on a fixed schedule of every two to four weeks. Software updates will be automated using canary or blue/green deployment patterns.

Runbooks exist for when Region failover occurs, for common customer issues that occur during those events, and for common reporting.

We will have playbooks for common database problems, security-related incidents, failed deployments, unexpected customer issues on Region failover, and establishing root cause of problems. After the root cause has been identified, the correction of error will be identified by a combination of the operations and development teams and deployed when the fix is developed.

We will also engage with AWS Support for Infrastructure Event Management.

## Back up data

Like the 4 9s scenario, we use automatic RDS backups and use S3 versioning. Data is automatically and asynchronously replicated from the Aurora RDS cluster in the active region to cross-region read replicas in the passive region. S3 cross-region replication is used to automatically and asynchronously move data from the active to the passive region.

## Architect for resiliency

Same as the 4 9s scenario, plus regional failover is possible. This is managed manually. During failover, we will route requests to a static website using DNS failover until recovery in the second Region.

## Test resiliency

Same as the 4 9s scenario plus we will validate the architecture through game days using runbooks. Also RCA correction is prioritized above feature releases for immediate implementation and deployment

## Plan for disaster recovery (DR)

Regional failover is manually managed. All data is asynchronously replicated. Infrastructure in the *warm standby* is scaled out. This can be automated using a workflow invoked on AWS Step Functions. AWS Systems Manager (SSM) can also help with this automation, as you can create SSM documents that update Auto Scaling groups and resize instances.

## Availability design goal

We assume that at least some failures will require a manual decision to run recovery, however with good automation in this scenario we assume that only two events per year will require this decision. We take 20 minutes to decide to run recovery, and assume that recovery is completed

within 10 minutes. This implies that it takes 30 minutes to recover from failure. Assuming two failures per year, our estimated impact time for the year is 60 minutes.

This means that the upper limit on availability is 99.95%. The actual availability will also depend on the real rate of failure, the duration of the failure, and how quickly each failure actually recovers. For this architecture, we assume that the application is online continuously through updates. Based on this, our **availability design goal** is 99.95%.

## Summary

Topic	Implementation
Monitor resources	Health checks at all layers, including DNS health at AWS Region level, and on KPIs; alerts sent when configured alarms are tripped; alerting on all failures. Operational meetings are rigorous to detect trends and manage to design goals.
Adapt to changes in demand	ELB for web and automatic scaling applicati on tier; automatic scaling storage and read replicas in multiple zones in the active and passive regions for Aurora RDS. Data and infrastructure synchronized between AWS Regions for static stability.
Implement change	Automated deploy via canary or blue/green and automated rollback when KPIs or alerts indicate undetected problems in application, deployments are made to one isolation zone in one AWS Region at a time.
Back up data	Automated backups in each AWS Region via RDS to meet RPO and automated restorati on that is practiced regularly in a game day. Aurora RDS and S3 data is automatically and asynchronously replicated from active to passive region.

Topic	Implementation
Architect for resiliency	Automatic scaling to provide self-healing web and application tier; RDS is Multi-AZ; regional failover is managed manually with static site presented while failing over.
Test resiliency	Component and isolation zone fault testing is in pipeline and practiced with operational staff regularly in a game day; playbooks exist for diagnosing unknown problems; and a Root Cause Analysis process exists, with communication paths for what the problem was, and how it was corrected or prevented. RCA correction is prioritized above feature releases for immediate implementation and deployment.
Plan for disaster recovery (DR)	Warm Standby deployed in another region. Infrastructure is scaled out using workflows invoked using AWS Step Functions or AWS Systems Manager Documents. Encrypted backups via RDS. Cross-region read replicas between two AWS Regions. Cross-region replication of static assets in Amazon S3. Restoration is to the current active AWS Region, is practiced in a game day, and is coordinated with AWS.

## 5 9s (99.999%) or higher scenario with a recovery time under one minute

This availability goal for applications requires almost no downtime or data loss for specific times. Applications that could have this availability goal include, for example certain banking, investing, finance, government, and critical business applications that are the core business of an extremely large-revenue generating business. The desire is to have strongly consistent data stores and complete redundancy at all layers. We have selected a SQL-based data store. However, in some

scenarios, we will find it difficult to achieve a very small RPO. If you can partition your data, it's possible to have no data loss. This might require you to add application logic and latency to ensure that you have consistent data between geographic locations, as well as the capability to move or copy data between partitions. Performing this partitioning might be easier if you use a NoSQL database.

We can improve availability further by using an *Active-Active* approach across multiple AWS Regions. The workload will be deployed in all desired Regions that are *statically stable* across regions (so the remaining regions can handle load with the loss of one region). A *routing* layer directs traffic to geographic locations that are healthy and automatically changes the destination when a location is unhealthy, as well as temporarily stopping the data replication layers. Amazon Route 53 offers 10-second interval health checks and also offers TTL on your record sets as low as one second.

## Monitor resources

Same as the 3½ 9s scenario, plus alerting when a Region is detected as unhealthy, and traffic is routed away from it.

## Adapt to changes in demand

Same as the 3½ 9s scenario.

## Implement change

The deployment pipeline will have a full test suite, including performance, load, and failure injection testing. We will deploy updates using canary or blue/green deployments to one isolation zone at a time, in one Region before starting at the other. During the deployment, the old versions will still be kept running on instances to facilitate a faster rollback. These are fully automated, including a rollback if KPIs indicate a problem. Monitoring will include success metrics as well as alerting when problems occur.

Runbooks will exist for rigorous reporting requirements and performance tracking. If successful operations are trending towards failure to meet performance or availability goals, a playbook will be used to establish what is causing the trend. Playbooks will exist for undiscovered failure modes and security incidents. Playbooks will also exist for establishing root cause of failures.

The team that builds the website also operates the website. That team will identify the correction of error of any unexpected failure and prioritize the fix to be deployed after it's implemented. We will also engage with AWS Support for Infrastructure Event Management.

## Back up data

Same as the 3½ 9s scenario.

## Architect for resiliency

The applications should be built using the software/application resiliency patterns. It's possible that many other routing layers may be required to implement the needed availability. The complexity of this additional implementation should not be underestimated. The application will be implemented in deployment fault isolation zones, and partitioned and deployed such that even a Region wide-event will not affect all customers.

## Test resiliency

We will validate the architecture through game days using runbooks to ensure that we can perform the tasks and not deviate from the procedures.

## Plan for disaster recovery (DR)

*Active-Active* multi-region deployment with complete workload infrastructure and data in multiple regions. Using a read local, write global strategy, one region is the primary database for all writes, and data is replicated for reads to other regions. If the primary DB region fails, a new DB will need to be promoted. Read local, write global has users assigned to a home region where DB writes are handled. This lets users read or write from any region, but requires complex logic to manage potential data conflicts across writes in different regions.

When a region is detected as unhealthy, the routing layer automatically routes traffic to the remaining healthy regions. No manual intervention is required.

Data stores must be replicated between the Regions in a manner that can resolve potential conflicts. Tools and automated processes will need to be created to copy or move data between the partitions for latency reasons and to balance requests or amounts of data in each partition. Remediation of the data conflict resolution will also require additional operational runbooks.

## Availability design goal

We assume that heavy investments are made to automate all recovery, and that recovery can be completed within one minute. We assume no manually invoke recoveries, but up to one automated recovery action per quarter. This implies four minutes per year to recover. We assume that the

application is online continuously through updates. Based on this, our **availability design goal** is 99.999%.

## Summary

Topic	Implementation
Monitor resources	Health checks at all layers, including DNS health at AWS Region level, and on KPIs; alerts sent when configured alarms are tripped; alerting on all failures. Operational meetings are rigorous to detect trends and manage to design goals.
Adapt to changes in demand	ELB for web and automatic scaling application tier; automatic scaling storage and read replicas in multiple zones in the active and passive regions for Aurora RDS. Data and infrastructure synchronized between AWS Regions for static stability.
Implement change	Automated deploy via canary or blue/green and automated rollback when KPIs or alerts indicate undetected problems in application, deployments are made to one isolation zone in one AWS Region at a time.
Back up data	Automated backups in each AWS Region via RDS to meet RPO and automated restoration that is practiced regularly in a game day. Aurora RDS and S3 data is automatically and asynchronously replicated from active to passive region.
Architect for resiliency	Implemented fault isolation zones for the application; auto scaling to provide self-healing web and application tier; RDS is Multi-AZ; regional failover automated.



Topic	Implementation
Test resiliency	Component and isolation zone fault testing is in pipeline and practiced with operational staff regularly in a game day; playbooks exist for diagnosing unknown problems; and a Root Cause Analysis process exists with communication paths for what the problem was, and how it was corrected or prevented. RCA correction is prioritized above feature releases for immediate implementation and deployment.
Plan for disaster recovery (DR)	Active-Active deployed across at least two regions. Infrastructure is fully scaled and statically stable across regions. Data is partitioned and synchronized across regions. Encrypted backups via RDS. Region failure is practiced in a game day, and is coordinated with AWS. During restoration a new database primary may need to be promoted.

## Resources

### Documentation

- [The Amazon Builders' Library](#) - How Amazon builds and operates software
- [AWS Architecture Center](#)
- [Resilience analysis framework](#)

### Labs

- [AWS Well-Architected Reliability Labs](#)

## External Links

- Adaptive Queuing Pattern: [Fail at Scale](#)
- [Availability and Beyond: Understanding and Improving the Resilience of Distributed Systems on AWS](#)

## Books

- Robert S. Hammer "[Patterns for Fault Tolerant Software](#)"
- Andrew Tanenbaum and Marten van Steen "[Distributed Systems: Principles and Paradigms](#)"

## Conclusion

Whether you are new to the topics of availability and reliability, or a seasoned veteran seeking insights to maximize your mission critical workload's availability, we hope this whitepaper has challenged your thinking, offered a new idea, or introduced a new line of questioning. We hope this leads to a deeper understanding of the right level of availability based on the needs of your business, and how to design the reliability to achieve it. We encourage you to take advantage of the design, operational, and recovery-oriented recommendations offered here as well as the knowledge and experience of our AWS Solution Architects. We'd love to hear from you—especially about your success stories achieving high levels of availability on AWS. Contact your account team or use [Contact US on our website](#).

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## Further reading

For additional information, see:

- [AWS Well-Architected Framework](#)
- [AWS Architecture Center](#)

# Document revisions

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Change	Description	Date
<a href="#">Updated best practice guidance</a>	Small updates to best practices in REL 2, 4, 5, 6, 7, and 8.	June 27, 2024
<a href="#">Updated best practice guidance</a>	Best practices were updated with new guidance in the following areas: <a href="#">Design interactions in a distributed system to prevent failures</a> , <a href="#">Design interactions in a distributed system to mitigate or withstand failures</a> , <a href="#">Monitor workload resources</a> , <a href="#">Design your workload to adapt to changes in demand</a> , <a href="#">Implement change</a> , and <a href="#">Test reliability</a> .	December 6, 2023
<a href="#">Updated best practice guidance</a>	Best practices were updated with new guidance in the following areas: <a href="#">Monitor workload resources</a> and <a href="#">Design your workload to withstand component failures</a> .	October 3, 2023
<a href="#">Updated best practice guidance</a>	Best practices were updated with new guidance in the following areas: <a href="#">Design your workload service architecture</a> , <a href="#">Design interactions in a</a>	July 13, 2023

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	<a href="#">distributed system to mitigate or withstand failures, and Monitor workload resources.</a>	
<a href="#">Minor update</a>	Remove non-inclusive language.	April 13, 2023
<a href="#">Updates for new Framework</a>	Best practices updated with prescriptive guidance and new best practices added.	April 10, 2023
<a href="#">Whitepaper updated</a>	Best practices updated with new implementation guidance.	December 15, 2022
<a href="#">Minor updates</a>	Corrected figure numbers and minor changes throughout.	November 17, 2022
<a href="#">Whitepaper updated</a>	Best practices expanded and improvement plans added.	October 20, 2022
<a href="#">Whitepaper updated</a>	Added two new best practices to Reliability Pillar in sections <b>Use Fault Isolation to Protect Your Workload</b> and <b>Design your Workload to Withstand Component Failures.</b>	May 5, 2022
<a href="#">Minor update</a>	Added Sustainability Pillar to introduction.	December 2, 2021
<a href="#">Whitepaper updated</a>	Update Disaster Recovery guidance to include Route 53 Application Recovery Controller. Add references to DevOps Guru. Update several Resource links, and other minor editorial changes.	October 26, 2021

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<a href="#">Minor update</a>	Added information about AWS Fault Injection Service (AWS FIS).	March 15, 2021
<a href="#">Minor update</a>	Minor text update.	January 4, 2021
<a href="#">Whitepaper updated</a>	Updated Appendix A to update the Availability Design Goal for Amazon SQS, Amazon SNS, and Amazon MQ; Re-order rows in table for easier lookup; Improve explanation of differences between availability and disaster recovery and how they both contribute to resiliency; Expand coverage of multi-region architectures (for availability) and multi-region strategies (for disaster recovery); Update reference book to latest version; Expand availability calculations to include request-based calculation, and shortcut calculations; Improve description for Game Days	December 7, 2020
<a href="#">Minor update</a>	Updated Appendix A to update the Availability Design Goal for AWS Lambda	October 27, 2020
<a href="#">Minor update</a>	Updated Appendix A to add the Availability Design Goal for AWS Global Accelerator	July 24, 2020



[Updates for new Framework](#)

Substantial updates and new/ revised content, including: Added “Workload Architecture” best practices section, re-organized best practices into Change Management and Failure Management sections, updated Resources, updated to include latest AWS resources and services such as AWS Global Accelerator, AWS Service Quotas, and AWS Transit Gateway, added/updated definitions for Reliability, Availability, Resiliency, better aligned whitepaper to the AWS Well-Architected Tool (questions and best practices) used for Well-Architected Reviews, re-order design principles, moving **Automatically recover from failure** before **Test recovery procedures**, updated diagrams and formats for equations, removed Key Services sections and instead integrated references to key AWS services into the best practices.

July 8, 2020

[Minor update](#)

Fixed broken link

October 1, 2019

[Whitepaper updated](#)

Appendix A updated

April 1, 2019

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<a href="#">Whitepaper updated</a>	Added specific AWS Direct Connect networking recommendations and additional service design goals	September 1, 2018
<a href="#">Whitepaper updated</a>	Added Design Principles and Limit Management sections. Updated links, removed ambiguity of upstream/downstream terminology, and added explicit references to the remaining Reliability Pillar topics in the availability scenarios.	June 1, 2018
<a href="#">Whitepaper updated</a>	Changed DynamoDB Cross Region solution to DynamoDB Global Tables. Added service design goals	March 1, 2018
<a href="#">Minor updates</a>	Minor correction to availability calculation to include application availability	December 1, 2017
<a href="#">Whitepaper updated</a>	Updated to provide guidance on high availability designs, including concepts, best practice and example implementations.	November 1, 2017
<a href="#">Initial publication</a>	Reliability Pillar - AWS Well-Architected Framework published.	November 1, 2016

## Notices

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# AWS Glossary

For the latest AWS terminology, see the [AWS glossary](#) in the *AWS Glossary Reference*.