Technical Report

Storage Subsystem Resiliency Guide

Jay White, NetApp

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ABSTRACT

This document provides technical recommendations and best practices as they relate to data availability and resiliency in the NetApp® storage subsystem. The topics addressed in this document are important to understand when planning and architecting a NetApp storage environment that will meet customer needs and expectations.

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1 INTRODUCTION

The predecessor to this document approached storage resiliency with a focus on key features and options that allow you to configure your storage system for maximum storage resiliency within the scope of a predefined set of data-availability tiers. This document builds on that foundation. It is not always possible or even necessary to configure systems for maximum resiliency depending on the purpose and requirements of a given storage configuration. Furthermore, the end objective of any storage configuration is not necessarily to make sure of storage resiliency, but rather to make sure of data availability. How resilient is a system that experiences a failure that results in a performance impact on the system as a whole such that applications depending upon the storage system stop functioning, even if the system technically still responds for foreground I/O?

As a result of situations such as the one just described, simply focusing on resiliency is not enough. Resiliency must be approached with data availability in mind and how it affects the system as a whole.

1.1 DATA AVAILABILITY

A core measurement of a NetApp storage system is data availability. For the purposes of this document, data availability is assessed based on three factors:

- **Performance:** Performance can be broken into two key perspectives from a data-availability point of view. The first is that customers will have specific performance requirements that are necessary to meet in order to satisfy applications that depend on storage system data being readily available. A data-availability outage from this perspective means that the storage system may still respond to foreground I/O, but fell below the requirements of the dependent applications' ability to function. The second is that if a system's performance suffers to the extent that the system stops responding to foreground I/O, then a data-availability outage situation has been encountered.
- **Resiliency:** Resiliency from the point of view of data availability is the system's ability to suffer a single failure or multiple failures while continuing to respond to foreground I/O in the degraded state. There are multiple options and features that contribute to a system's ability to suffer failures; they are discussed throughout this document.
- **Recoverability:** Recoverability defines the system's ability to both automatically recover from failures and continue to respond to foreground I/O while conducting recovery operations on the storage system.

These three factors are further applied to the three layers of data availability:

- **Storage subsystem:** The storage subsystem layer addresses all hardware components and software features that relate to the storage system's internals. Primarily this can be considered to be from the HBA down through the attached storage arrays from a physical perspective, or around the storage and RAID software layers that are part of Data ONTAP®: in short, the system's ability to communicate internally from the controller to the attached storage arrays.
- **System:** The system layer addresses the ability of a storage system to suffer failures. This is primarily focused on controller-level failures that affect the ability of a system to continue external communication. This applies to single controller and HA pair configurations and the components that contribute to external controller communication such as network interfaces.
- **Site:** The site layer addresses the ability of a group of collocated storage systems to suffer failures. This is primarily focused on the features related to distributed storage system architecture that allow an entire storage system failure, which would likely be related to a site-level incident, such as a natural disaster or an act of terrorism**.**

To further quantify best practices and recommendations, this information must be applied to a set of defined tiers of data availability. This is necessary because, for example, you are not able to accomplish maximum resiliency and recoverability without sacrificing performance to a certain extent.

Depending on the requirements of each tier of data availability, the balance between the three factors outlined above changes, which results in different best practices and recommendations between the defined tiers of data availability. The tiers of data availability and the recommendations for each are covered in section 6, "Data Availability Tiers," in this document.

1.2 SCOPE

The primary scope of this document is to address the storage subsystem layer of data availability while taking into account the three factors (performance, resiliency, and recoverability) outlined in section 1.1, “Data Availability.”

2 RELIABILITY

The most common measure of reliability that is publicly stated in the industry today is mean time between failures (MTBF). The problem is that MTBF is not as accurate a measure of reliability as average return rate (ARR) or average failure rate (AFR), both of which are tracked by companies but in most cases are not made publicly available.

NetApp does track ARR and AFR for critical storage components. Although ARR and AFR are better than MTBF, they are not perfect. In the case of the statistical math used for reliability measures, the math only gains meaning when applied to very large populations of devices.

2.1 MEASURING RELIABILITY

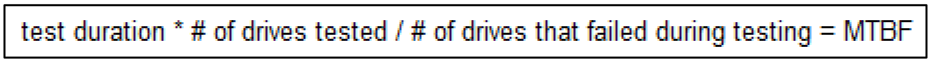
There are generally three reliability measures available for hardware components today. They are mean time between failures, average return rate, and average failure rate. These measures are discussed in detail below, but here is a summary of the key points to take away from this section:

- The expected operating life of an enterprise drive is five years. NetApp highly recommends replacing drives that are older than five years. This also aligns with the five-year warranty offered with drives.
- The more drives you have in your configuration, the more likely you are to encounter drive failures within the service life of the drives.
- MTBF is the least accurate measure of reliability.
- AFR is the best measure of reliability but it takes time to establish an accurate dataset.

This section primarily focuses on drives, but the same methods and information are applied to the other devices present in the storage subsystem and beyond.

MEAN TIME BETWEEN FAILURES

MTBF is the least accurate measure of reliability. MTBF is commonly misunderstood to be the useful life of a hardware device. Since hardware manufacturers can’t reasonably test devices for their entire expected life before release, they test many devices in an attempt to extract what the failure rate should be during the expected life of the device. The formula most commonly used is as follows:



test duration * # of drives tested / # of drives that failed during testing = MTBF

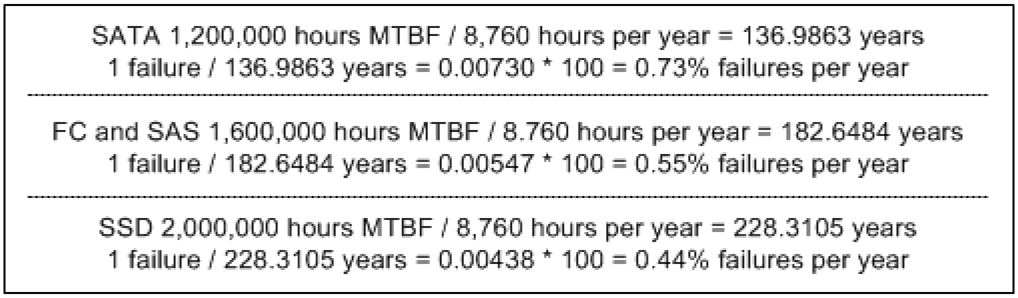
Figure 1) MTBF formula.

The most commonly referenced MTBF values for storage subsystem devices are for drives. SSD, SATA, SAS, and FC drives have different MTBF values, as follows:

- SSD (SLC) drives are 2.0 million hours
- SAS and FC drives are 1.6 million hours
- SATA drives are 1.2 million hours

The drive warranty is five years (43,800 hours), which is far short of 1.6 million or even 1.2 million hours. Again, MTBF is a measure not of the usable life of the drive but rather of the error rate within the useful drive life.

Purely based on MTBF, the math suggests that for SATA drives (1.2 million hours MTBF) ~0.73% of your deployed drives should fail each year. For FC and SAS drives (1.6 million hours MTBF) ~0.55% of your deployed drives should fail each year. For SSD drives (2.0 million hours MTBF) ~.44% of your deployed drives should fail each year.



SATA 1,200,000 hours MTBF / 8,760 hours per year = 136.9863 years
1 failure / 136.9863 years = 0.00730 * 100 = 0.73% failures per year

FC and SAS 1,600,000 hours MTBF / 8.760 hours per year = 182.6484 years
1 failure / 182.6484 years = 0.00547 * 100 = 0.55% failures per year

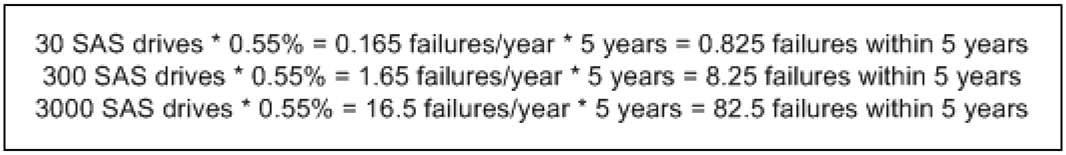
SSD 2,000,000 hours MTBF / 8,760 hours per year = 228.3105 years
1 failure / 228.3105 years = 0.00438 * 100 = 0.44% failures per year

Figure 2) Calculating drive failure rate based on MTBF.

To apply this further, let’s consider the following two example configurations:

- 30 SAS drives with an expected use of 5 years
- 300 SAS drives with an expected use of 5 years
- 3,000 SAS drives with an expected use of 5 years

Math can now be applied to determine how many failures would be expected to occur over the operating life of these configurations:



30 SAS drives * 0.55% = 0.165 failures/year * 5 years = 0.825 failures within 5 years
300 SAS drives * 0.55% = 1.65 failures/year * 5 years = 8.25 failures within 5 years
3000 SAS drives * 0.55% = 16.5 failures/year * 5 years = 82.5 failures within 5 years

Figure 3) Expected failures within 5 year operating life based on MTBF and number of drives.

The primary point to take from all this is that the more drives you have, the more likely it is that one of those drives will fail within the time it is in use. Based on the five-year warranty (three year standard with two year extended) that is applied to enterprise drives today, it is safe to state that the expected reliable life of a drive is five years, after which the likelihood that it will fail increases significantly the longer the drive stays in use.

AVERAGE RETURN RATE

The ARR of a device is a better measure of reliability than MTBF because it is based on the actual return rate of a device from systems that are in service and using the device. Unfortunately this is still not the best measure of reliability because it does not distinguish between devices that have been returned for reasons that are not associated with failures. Some examples of returns unrelated to failures include drives that are returned due to false positives, as a precautionary measure, or because of a mistaken shipment. Although not the best method for determining reliability, ARR is useful for companies to track this to understand if there are issues with operational efficiency, usability, or other business-related reasons.

AVERAGE FAILURE RATE

This is the most accurate measure of device reliability because it is based on devices that have been returned and verified to have failed. Unfortunately it takes time to establish AFR because it is based on an average over time. As a result, AFR becomes more accurate as time progresses. Devices can fail for a multitude of reasons, some of which are discussed later in this document.

The purpose of this document is not to address what the ARR or AFR is for the various devices shipped by NetApp (because that is not public information) but rather to explain and put in context the measures that are either publically available or potentially available as a NetApp customer.

2.2 SYSTEM RELIABILITY

Many ask what the MTBF is for a controller or storage shelf. There are several reasons why MTBF is not published for collections of devices:

- The MTBF calculation is based on the usage of a single device or group of integrated devices. Controllers and storage shelves contain several components that are optional (expansion cards, shelf modules, and more) and components that are collections of smaller devices themselves. As such, these configurations are highly variable in terms of the components involved in the system as a whole.
- An MTBF value has to take into account all components in use, but with controllers and storage shelves not all components are critical. For example, if an LED fails on a storage shelf, the shelf will continue to operate in its primary role of providing access to drives.
- As stated in section 2.1, “Measuring Reliability,” MTBF is the least accurate measure of reliability. Adding additional devices further dilutes an already abstracted calculation and result. More importantly, companies track ARR and AFR, which eliminates the need to understand MTBF.

Between storage shelves, shelf modules, and drives, the least reliable components of the storage subsystem are generally considered to be the drives. This does not mean that storage shelves and shelf modules are more reliable than drives. The logic behind this is as follows:

- There are many more drives present in a storage shelf than any other device. For example, a DS4243 has 2 to 4 PSUs, 2 IOM3 shelf modules, 1 shelf enclosure, and 24 drives.
- Drives contain just as many electronics and just as much sophistication as the other components, with the added factor that they contain moving parts, with the exception of SSD.

As a result of this thinking, when storage subsystem reliability is discussed, it normally revolves around drives.

2.3 RELIABILITY BEST PRACTICES

Some key best practices to follow when attempting to maximize storage subsystem component reliability are as follows:

- Remove failed hardware components quickly so that failures don’t propagate to healthy components in the system.
- Replace or retire hardware components that have exceeded their warranty period.
- Follow safe practices when handling hardware components to protect against physical damage and electrostatic discharge (ESD) damage.
- Understand that failures are a fact of life with technology and make sure that spares for critical components are readily available. This means following best practices for hot and cold spares and understanding the parts turnaround for your site(s).
- The use of cold spares does not replace the need for hot spares. The longer hardware components sit on a shelf, the more likely it is that they might suffer physical damage or simply not work. A drive installed and working in a storage system (hot spare) is in a state that results in high reliability because it is ready to fulfill its role as a drive replacement.

3 ERRORS AND FAILURES

This section provides additional details regarding some key errors and failures that can occur in the storage subsystem. It does not include every possible error for failure that can occur; rather, the focus is on conditions that affect system resiliency operations such as RAID reconstruction. Single points of failure (SPOFs) are also discussed because they affect system resiliency.

NetApp highly recommends removing failed hardware components from an active system as soon as possible to reduce the risk of the failure propagating to healthy components within the system.

3.1 SINGLE POINTS OF FAILURE

Some potential SPOFs are eliminated by native system configurations. For example, every NetApp storage shelf uses more than a single shelf module, power supply unit, and drive. Other SPOFs might exist depending on the system configuration selected:

- **Controller:** NetApp supports single-controller configurations, in which the controller itself is a SPOF. Using an HA pair storage configuration that includes two controllers eliminates the controller as a SPOF.
- **Host bus adapter (HBA):** This includes on-board ports and separate HBAs, which are referred to as port groups. A port group is any set of interconnected ports. For example, on-board ports A and B might use a different ASIC than ports C and D, but they both depend upon the system motherboard to be able to function. A single quad-port HBA generally has two ASICs as well, but the HBA itself is a SPOF. As a result NetApp generally recommends connecting your storage loops (FC-AL) and stacks (SAS) to more than one port group. For example, this could be two HBAs or a combination of on-board ports and one or more HBAs. NetApp always recommends at a minimum that connections are split across ASICs.
- **Cables:** There are many types of cables used to connect a storage system. Some cables are more resilient to physical damage than others; for example, optical cables are much more susceptible to physical damage than Ethernet cables. To avoid cables as a SPOF in your storage configuration, NetApp recommends (and in many cases now requires) the use of multipath high-availability (MPHA) cabling. MPHA provides secondary path connections to all storage shelves attached to the system.
- **Shelf enclosure:** Although complete shelf enclosure failures are very rare, they are a possibility. An approach used in the field to protect against this situation has been to make sure that no more than two drives from any RAID group are located on a single shelf (assuming RAID-DP®). This approach is not a shelf resiliency solution. The resulting system degradation after losing a shelf (without mirroring in place) would be crippling to the ability of the system to continue operating. The recommended method for protecting against shelf failures is to use local SyncMirror® or other mirroring methods to quickly make data available in a failure situation. Mirroring solutions also account for multiple failure situations. Note that Data ONTAP 8.1 Cluster-Mode systems do not currently support SyncMirror.

3.2 DRIVES

Errors and failures associated with drives are very complex. As a result, many misconceptions exist concerning the types of failures that occur and how they are resolved.

Under some circumstances the perception could be that NetApp storage systems aggressively fail drives for reasons that are not always perceived to be critical. For example, after a single bad block is detected, NetApp could fail a drive, which might seem extreme. The term *bad block* is generic. In reality the drive is returning an error code that is associated with an unsuccessful drive operation, and that error can indicate that there is a serious problem. Depending on the significance of the error returned from the drive, it could indicate that other blocks on the drive are also likely compromised. In this situation it is safer to fail the drive and remove it from the active file system so data is not compromised further.

The following five conditions generally result in a drive being failed by the system and corrective action being initiated:

- The drive itself returns a fatal error.
- The storage layer of Data ONTAP reports that the drive is inaccessible.
- The drive returns a recommendation to Data ONTAP that the drive should be failed.
- The storage and RAID layer of Data ONTAP recommends that a drive should be failed based on various error thresholds being exceeded by the drive.
- Lost write protection (LWP) occurs.

4 CORRECTIVE ACTIONS AND PREVENTIVE FEATURES

When issues are encountered, Data ONTAP checks the current RAID state and error condition. This results in one of three possible actions:

- Initiate a RAID reconstruction.
- Initiate a Rapid RAID Recovery (could also result in the use of Maintenance Center).
- Ignore the error.

RAID reconstruction and Rapid RAID Recovery are discussed in more detail later. Errors are only potentially ignored for RAID groups that are already in a degraded state. This is because Data ONTAP already understands that there are issues present and it is likely in the process of resolving the degraded state.

Errors not associated with drive failures normally detected by preventive actions such as RAID scrubs can result in one of the following actions:

- Rewrite the suspect data block to a new block (data block repair).
- Rewrite parity data for the block (parity repair).

Knowing that Data ONTAP conducts data block repair and parity repair is sufficient for the scope of this document, because these operations are not specific to drive failures but rather are issues with individual data blocks in the file system. The key point is that Data ONTAP takes several steps to enable data integrity, and those steps do not always result in drives being failed.

4.1 RAID RECONSTRUCTIONS

When a drive is failed and a RAID reconstruction initiated, several factors determine how long the reconstruction process will take and how the system's performance will be affected as a result. Some of the factors that contribute to system performance while operating in a degraded mode are:

- System workload profile (random/sequential and read/write mixes)
- Current CPU and I/O bandwidth utilization
- RAID group size
- Storage shelf and shelf module technology in use
- Type of drives (SSD, SATA, FC, or SAS)
- RAID option settings
- Drive path assignments
- Distribution of drives across stacks/loops
- Single or double drive failure and reconstruction

Because of these factors, it is very difficult to accurately predict the impact on a storage system.

Once a drive is failed, all I/O that would normally be directed at the drive is redirected to the replacement drive. Reconstruction traffic will affect all drives in the degraded RAID group because reads will be occurring on all data drives in the RAID group. Additional bandwidth is needed on stacks/loops containing the degraded RAID group and the replacement drive. RAID reconstruction I/O will compete with foreground I/O within the confines of current system utilization and RAID options settings. This is discussed in greater depth in section 5.2, “RAID Options,” in this document.

SINGLE-DRIVE RECONSTRUCTION

A single drive reconstruction occurring in a RAID-DP RAID group results in data being reconstructed much like any single-parity drive RAID group (double-parity information is not needed). A reconstruction involves reads from all remaining drives in the RAID group and the parity drive (unless you are reconstructing the parity drive).

A single reconstruction effectively doubles the I/O occurring on the stack/loop, because for each foreground I/O directed toward the RAID group the data needs to be reconstructed on demand for the failed drive. This traffic is in addition to the reconstruction traffic associated with parity calculations and writes to the replacement drive.

DOUBLE-DRIVE RECONSTRUCTION

A double-drive reconstruction occurring in a RAID-DP group results in data being reconstructed from both single-parity and double-parity data. This type of reconstruction involves reads from all remaining data drives in the RAID group in addition to the single- and double-parity drives. Stack bandwidth requirements for foreground I/O triple in this case. Data ONTAP is intelligent enough not to require multiple reads in order to conduct both parity and double-parity data reconstruction calculations; a single read operation is sufficient to do both calculations.

A double reconstruction effectively triples the I/O occurring on the stack/loop, because for each foreground I/O directed toward the RAID group the data needs to be reconstructed on demand for the two failed drives.

This traffic is in addition to the reconstruction traffic associated with parity calculations and writes to the replacement drive.

4.2 RAPID RAID RECOVERY

A Rapid RAID Recovery is similar to a RAID reconstruction but without the need to reconstruct data from parity because the drive is still accessible. Some blocks on the drive might need to be reconstructed from parity data, but the majority of the drives will be copied at block level to the replacement drive. Because this is a block-level copy, all blocks are copied regardless of how full (or empty) the drive might be.

A Rapid RAID Recovery does increase the I/O occurring on the stack/loop due to the read and write traffic occurring between the failing drive and the replacement drive. However, the impact on the remaining drives in the RAID group is far less than with reconstruction, because parity calculations are not needed for most if not all of the data on the failing drive. A Rapid RAID Recovery will also complete in a shorter time than a full RAID reconstruction.

4.3 MAINTENANCE CENTER

When enabled on a system, Maintenance Center works in conjunction with Rapid RAID Recovery to assess the condition of failed drives prior to them being returned to NetApp. When a drive enters Maintenance Center, a Rapid RAID Recovery is initiated, failing the drive out of the RAID group. The failed drive is then assessed by Data ONTAP by running drive diagnostics. If the drive is deemed to be functional, it is returned to the systems spare pool. If the drive is not functional, it remains failed and needs to be replaced.

Maintenance Center requires a minimum of two hot spares available on the system, and Rapid RAID Recovery (`raid.disk.copy.auto.enable`) must be enabled. NetApp recommends setting the option `raid.min_spare_count` to a minimum of 2 in order to allow the system to notify the administrator when Maintenance Center spares requirements are not being met.

4.4 LOST WRITE PROTECTION

Lost write protection is a feature of Data ONTAP that occurs on each WAFL® read. Data is checked against block checksum information (WAFL context) and RAID parity data. If an issue is detected, there are two possible outcomes:

- The drive containing the data is failed.
- The aggregate containing the data is marked inconsistent.

If an aggregate is marked inconsistent, it will require the use of WAFL iron to be able to return the aggregate to a consistent state. If a drive is failed, it is subject to the same corrective actions as any failed drive in the system.

It is a rare occurrence for lost write protection to find an issue. Its primary purpose is to detect what are generally the most complex or edge case problems that might occur and determine the best course of action to take in order to protect data integrity.

4.5 BACKGROUND MEDIA SCANS

Background media scans are a drive diagnostic feature that is run continuously on all RAID group drives. This type of scrub (media scrub) is used to detect media errors. The purpose is not to make sure the data block is integral from the point of view of the file system but rather to make sure blocks on the drive are accessible.

System performance is affected by less than 4% on average. This is primarily because the drive internals conduct the actual scans, which do not require CPU or I/O bandwidth from the system.

4.6 RAID PARITY SCRUBS

RAID parity scrubs are used to check the integrity of data at rest. For very active datasets, the benefit of RAID parity scrubs is limited because the data is read often, and thus Data ONTAP is enabling data integrity through other means. The most common data that is at rest is archive data. RAID parity scrubs offer the best return when used with this type of data.

This process traverses data at rest and triggers reads on that data. As a result of triggering the read, the data is checked against parity to determine if it is correct. If a block is found to be incorrect, the block is marked as bad, and the data is recreated from parity and written to a new block. RAID scrubs minimally affect foreground I/O, and data suggests that this impact is less than 10% on average. For large archival datasets, NetApp recommends increasing the frequency and/or duration of RAID parity scrubs.

RAID parity scrubs are enabled by default, and by default a scrub will run for 360 minutes (6 hours). The performance impact is set to low by default, which results in the process only using idle system resources.

5 ADDITIONAL CONSIDERATIONS

In addition to specific resiliency features and corrective actions, there are considerations that are important to understand when configuring your storage system. This section focuses on specific configuration factors such as RAID group size, RAID options, and best practices for mixed configurations.

5.1 SHELF-LEVEL RESILIENCY

Many administrators in the past took an approach to shelf-level resiliency that involves ensuring that no more than two drives from any RAID group are located on a single shelf, the logic being that with RAID-DP, if the shelf were to fail, no single RAID group on the system would be more than doubly degraded. This is not a realistic shelf-level resiliency approach. Consider the following:

- With DS14 (14 drives) you are looking at seven degraded RAID groups resulting from a shelf failure. DS4243 or DS2246 leaves you with 12 degraded RAID groups if a shelf fails.
- By default, Data ONTAP will only conduct RAID reconstructions in two RAID groups at a time. This leaves you with either 5 (DS14) or 10 (DS4243/DS2246) degraded RAID groups that are at a high risk of data loss while waiting for the reconstructing RAID groups to complete both reconstructions.
- The large amount of reconstruction traffic combined with the severely degraded state of so many RAID groups essentially cripples the system’s ability to respond to foreground I/O.

NetApp’s shelf-level resiliency feature is called SyncMirror. SyncMirror protects NetApp storage configurations from shelf-level failure events, which are very rare but not impossible. Not only does SyncMirror offer shelf-level resiliency but it can also increase read performance in drive-bound configurations by up to 80%. Note that Data ONTAP 8.1 Cluster-Mode systems do not currently support SyncMirror.

5.2 RAID GROUPS

RAID group configuration can greatly affect a storage system’s resiliency. NetApp highly recommends using RAID-DP for all storage configurations, because it offers the best resiliency features and enables nondisruptive background firmware updates for drives. The best practices and points discussed in this section assume the use of RAID-DP.

It is tempting to always create the largest RAID groups in an aggregate to minimize parity tax and maximize performance, but the results of doing so are:

- **Larger failure domains:** The more drives you have in a RAID group, the more likely it is that one or more of those drives will fail in the course of the operational lifetime of the storage system. Drive reliability is a primary factor in attempting to understand the risk of encountering multiple drive failures (MDFs) within a single RAID group. Ultimately any calculation is a guess because there is no guarantee that drives will fail all at the same time, in the same RAID group, or fail at all (within the five-year warranty period).
- **Increased drive reconstruction times:** The more data drives that are present in the RAID group, the greater the calculation overhead for reconstructing data from parity. Each data drive contributes a data point that needs to be considered in the parity calculations. The more data points, the larger the parity calculation is, and, as a result, the reconstruction times increase. In RAID group sizes from 12 to 20, data suggests that this increase is as little as 6%.

SATA VERSUS FC/SAS

Many consider SATA drives (1.2 million hours MTBF) to be less reliable that FC and SAS drives (1.6 million hours MTBF). NetApp's AFR and ARR data suggests that enterprise SATA drives are as reliable in actual deployments as FC and SAS drives, which leads to the question, "Then why is the maximum SATA RAID group size less than SSD, FC, or SAS?"

Although the reliability might be similar, the capacity and speed differences cannot be overlooked. SATA drives are of larger capacity and slower than FC/SAS drives, which means they take a significantly longer time to reconstruct than FC/SAS drives. In Data ONTAP 8.0.1 the maximum SATA RAID group size has been increased from 16 to 20. This change was decided on after analyzing field data and based on SATA reliability data tracked by NetApp (among other factors). After RAID group size 20, however (size 21 to 28), an inflection point was seen in the risk of multiple drive failures occurring at the same time, creating the potential for a perpetual drive reconstruction situation.

Perpetual drive reconstructions occur when the reconstruction time for the drive is so long that it greatly increases the probability of encountering another drive failure before completing the current reconstruction activity. This is normally only a risk with large (>1TB) SATA drives. The risk is currently increasing as larger and larger SATA drives (3TB, 4TB, and larger) come to market.

SOLID-STATE DRIVES

Given the small capacity points of SSD and the significantly better drive-level performance, the use of larger SSD-based RAID groups is less risky. Data shows that RAID reconstruction of a 100GB SSD is <20 minutes on a loaded system. Given this fast reconstruction time, it is reasonable to expect sufficient system resiliency even at the largest RAID group size of 28 (assuming RAID-DP).

5.3 RAID OPTIONS

Within the scope of data availability, it is important to understand how you can tune a storage configuration in order to make sure data availability requirements are met. For example, in an archival storage configuration, it is better to tune the system to allow reconstruction I/O to compete efficiently with foreground I/O, whereas in an Exchange configuration it might be necessary to make sure the foreground I/O competes for system resources more effectively than reconstruction I/O.

RAID options are the primary user-configurable method for telling Data ONTAP how foreground I/O and corrective I/O (RAID reconstruction I/O and Rapid RAID Recovery I/O) should compete for system resources.

The option `raid.reconstruct.perf_impact` can be set to low, medium, or high. By default it is set to medium. Changing this option results in the following behavior:

- **Low:** This allows corrective I/O and foreground I/O to compete with 0% of system resources during peak controller performance. This effectively guarantees that foreground I/O can consume 100% of system resources when capable of doing so. Corrective I/O will only use idle system resources.
- **Medium:** This allows corrective I/O and foreground I/O to compete with 40% of system resources during peak controller performance. This effectively guarantees that foreground I/O can consume 60% of system resources without interference from corrective I/O.
- **High:** This allows corrective I/O and foreground I/O to compete with 90% of system resources during peak controller performance. This effectively guarantees that foreground I/O can consume 10% of system resources without interference from corrective I/O.

For the purposes of corrective I/O the term "system resources" refers to:

- CPU
- I/O bandwidth
- Drive utilization

There is no limit on the amount of idle CPU and I/O bandwidth that corrective I/O can consume; hence, 0% means that only background processing will be allocated when the system is under load. This also means that this option makes very little difference on idle systems because there is no foreground I/O with which to compete.

The percentages listed do not guarantee that corrective I/O will consume that much, rather, that foreground I/O and corrective I/O will compete for system resources within those percentages. A setting of high does not mean you will see a 90% impact on foreground I/O, because both foreground and corrective I/O are still occurring within that percentage. Additionally, corrective actions might be able to compete with foreground I/O up to those percentages, but that does not mean the corrective actions are demanding that percentage of system resources.

5.4 SPARES POLICY

Spares recommendations vary by configuration and situation. In the past NetApp has based spares recommendations purely on the number of drives attached to a system. This is certainly an important factor but not the only consideration. NetApp storage systems are deployed in a wide breadth of configurations. This warrants defining more than a single approach to determining the appropriate number of spares to maintain in your storage configuration.

Depending on the requirements of your storage configuration, you can choose to tune your spares policy toward:

- **Minimum spares:** In configurations in which drive capacity utilization is a key concern, the desire might be to use only the minimum number of spares. This option allows you to survive the most basic failures. If multiple failures occur, it might be necessary to manually intervene to make sure of continued data integrity.
- **Balanced spares:** This configuration approach is the middle ground between minimum and maximum. This assumes you will not encounter the worst-case scenario and will provide sufficient spares to handle most failure scenarios.
- **Maximum spares:** This option makes sure that enough spares are on hand to handle a failure situation that would demand the maximum number of spares that could be consumed by a system at a single time. Using the term “maximum” is not stating that the system might not operate with more than this recommended number of spares. You can always add additional hot spares within spindle limits as you deem appropriate.

Selecting any one of these approaches is the best practice within the scope of your system requirements. The majority of storage architects will likely choose the balanced approach, although customers who are extremely sensitive to data integrity might warrant taking a maximum spares approach. Given that entry platforms use small numbers of disks, a minimum spares approach would be reasonable for those configurations. For RAID-DP configurations, consult Table 1 for the recommended number of spares.

Table 1) Determining recommended spares.

Recommended Spares		
Minimum	**Balanced**	**Maximum**
Two per Controller	**Four per Controller**	**Six per Controller**
Special Considerations		
Entry Platforms	Entry-level platforms using only internal drives can be reduced to using a minimum of one hot spare.	
RAID Groups	Systems containing only a single RAID group do not warrant maintaining more than two hot spares for the system.	
Maintenance Center	Maintenance Center requires a minimum of two spares to be present in the system.	
>48-Hour Lead Time	For remotely located systems there is an increased chance they might encounter multiple failures and completed reconstructions before manual intervention can occur. Spares recommendations should be doubled for these systems.	
>1,200 Drives	For systems using greater than 1,200 drives an additional two hot spares should be added to the recommendations for all three approaches.	
<300 Drives	For systems using less than 300 drives you can reduce spares recommendations for a balanced and maximum approach by two.	

Additional notes regarding hot spares:

- Spares recommendations are for each drive type installed in the system. See section 5.4, “Mixed Configurations,” for more information.
- Larger-capacity drives can serve as spares for smaller-capacity drives (they will be downsized).
- Slower drives replacing faster drives of the same type will affect RAID group and aggregate performance. For example, if a 10k rpm SAS drive (DS2246) replaces a 15k rpm SAS drive (DS4243), this results in a nonoptimal configuration.
- Although FC and SAS drives are equivalent from a performance perspective, the resiliency features of the storage shelves in which they are offered are very different. By default Data ONTAP uses FC and SAS drives interchangeably. This can be prevented by setting the RAID option `raid.disk.type.enable` to `on`. See section 5.4, “Mixed Configurations,” for more information.

HOT AND COLD SPARES

NetApp does not discourage administrators from keeping cold spares on hand. NetApp recommends removing a failed drive from a system as soon as possible, and keeping cold spares on hand can speed the replacement process for those failed drives. However, cold spares are not a replacement for keeping hot spares installed in a system.

Hot spares are also present to replace failed drives, but in a different way. Cold spares can replace a failed part (speeding the return/replace process), but hot spares serve a different purpose: to respond in real time to drive failures by providing a target drive for RAID reconstruction or Rapid RAID Recovery actions. It is hard to imagine an administrator running into a lab to plug in a cold spare when a drive fails. Cold spares are also at greater risk of being “dead on replacement” because drives are subjected to the increased possibility of physical damage when not installed in a system. For example, handling damage from electrostatic discharge is a form of physical damage that can occur when retrieving a drive to install in a system.

Given the different purpose of cold spares versus hot spares, you should never consider cold spares as a substitute for maintaining hot spares in your storage configuration.

ENFORCING MINIMUM SPARES

The RAID option `raid.min_spare_count` can be used to specify the minimum number of spares that should be available in the system. This is effective for Maintenance Center users because when set to the value of 2 it effectively notifies the administrator if the system falls out of Maintenance Center compliance. NetApp recommends setting this value to the resulting number of spares that you should maintain for your system (based on this spares policy) so the system will notify you when you have fallen below the recommended number of spares.

5.5 MIXED CONFIGURATIONS

The ability to create mixed configurations with NetApp storage solutions is a significant benefit for many customers. The purpose of this section is not to dissuade the use of mixed configurations but to show that as technology changes or is introduced, there is a need to assess and reassess mixed configurations to determine that resiliency and/or performance have not been unintentionally compromised. This is not to say that simply by creating a mixed configuration you have compromised resiliency, because there are several mixed configurations supported today that offer the same resiliency level as the equivalent segregated configurations.

SHELF TECHNOLOGY

As NetApp makes the transition from the DS14 storage shelf family to the SAS storage shelf family (DS4243 and DS2246), it is common to see both shelf technologies attached to the same system. The SAS storage shelf family has new and unique resiliency features that are not available with the DS14 storage shelf family. For example, Alternate Control Path (ACP) is a feature only available with the SAS storage shelf family.

NetApp recommends segregating logical system configurations between DS14 and SAS storage shelf technologies.

FC AND SAS EQUIVALENCY

The option `raid.disktype.enable` is off by default. This means that for the purposes of aggregate creation and spares selection, Data ONTAP treats FC and SAS drives the same. For example, a SAS drive can serve as a replacement for a failed FC drive and vice versa. Although from a performance perspective FC and SAS drives are equivalent, they are different from a resiliency perspective, because the storage shelves in which those drives are available are very different. FC is available in DS14mk2 and Ds14mk4 shelves using ESH2 and ESH4 shelf modules. SAS is available in DS4243 using IOM3 shelf modules and DS2246 using IOM6 shelf modules. The SAS shelf family has improved resiliency features compared to the DS14 family. For example, if a DS14-based drive replaces a drive that was part of a RAID group contained completely within a SAS shelf, the resiliency level of that RAID group has effectively dropped when considered as a whole.

NetApp recommends setting the option `raid.disktype.enable` to `on` in order to enforce the separation of FC and SAS drives.

DRIVE SPEED

With the introduction of the DS2246 storage shelf, we see the availability of 10k rpm 2.5” SAS drives at a time when DS4243 is offering 15k 3.5” SAS drives. 10k rpm FC drives are still around in customer configurations even though they are no longer available from NetApp. Mixing 10k rpm drives with 15k rpm drives in the same aggregate effectively throttles all drives down to 10k rpm. This results in longer times for corrective actions such as RAID reconstructions.

NetApp recommends that you do not mix 10k rpm and 15k rpm drives within the same aggregate.

5.6 MY AUTOSUPPORT SYSTEM RISKS

For customers who use My AutoSupport™, there is a newly expanded Health Summary section that includes a feature known as System Risk Details (SRD). The SRD section proactively identifies risks in deployed NetApp storage configurations that can negatively affect system performance, availability, and resiliency. Each risk entry contains information about the specific risk to the system, potential negative effects, and links to risk mitigation plans. By addressing identified risks proactively, you can significantly reduce the possibility of unplanned downtime for your NetApp storage system.

NetApp recommends using the SRD section to increase system resiliency by addressing system risks before they lead to unplanned downtime. More information can be found on the NetApp Support (formerly NOW™) site on the main My AutoSupport page, located at https://now.netapp.com/NOW/asuphome.

6 DATA-AVAILABILITY TIERS

This section covers resiliency requirements and recommendations as they relate to the data-availability tiers defined within this document. The majority of this document can be considered general best practices that are applicable to all data-availability tiers.

DEFAULT VALUES

It is important to note that default values do not always equate to best practices. The reality of default values is that they are normally subject to one of the following factors:

- They represent the average or middle ground, neither optimized nor not optimized.
- Their values might have been determined years ago and might have not been reassessed for currency with today’s solutions and features.
- They can be determined to be generically applicable settings or recommendations for the majority of known configurations.

Given the breadth and depth of the storage solutions offered by NetApp, it is almost impossible to make sure that all default values align with best practices. There is no single answer in many circumstances, which means due diligence must be exercised in order to appropriately optimize your storage configuration for your customers.

6.1 TIER 1: MISSION CRITICAL

These types of environments enable services that are in high demand and cost the customer significant loss of revenue when an outage occurs. Online transaction processing (OLTP), batch transaction processing, and some virtualization/cloud environments are examples of environments that fit into this tier of data availability. This tier of data availability is tuned toward prioritizing I/O response to foreground (client application) traffic to make sure dependent applications remain functional. By prioritizing foreground I/O over corrective I/O in degraded situations, you increase the time necessary to complete corrective actions. This increases the risk of encountering additional failures in the system before completing a corrective action; for example, encountering an additional drive failure before an existing reconstruction operation can complete.

Table 2) Recommendations and best practices for mission-critical data availability.

Mission-Critical Recommendations	
Flash Cache	Use Flash Cache to improve system performance and minimize the impact to foreground I/O while in degraded mode situations.
SyncMirror	Use local SyncMirror to make sure of shelf-level resiliency and to improve performance in degraded mode situations. Note that Data ONTAP 8.1 Cluster-Mode systems do not currently support SyncMirror.
Spares	Use a maximum hot spares approach to make sure sufficient disks are available for corrective actions. Set the RAID option raid.min_spares_count to the recommended number of spares to make sure the administrator will be notified when spare counts are reduced below recommendations.
Drive Type	Use performance drives (SAS, FC, or SSD) instead of capacity drives (SATA). Smaller-capacity 15k rpm or SSD drives result in shorter times for corrective actions. This is important when foreground I/O is prioritized over corrective I/O, which increases times for corrective actions. Performance drives help offset that performance delta.
Aggregate Fullness	Monitor aggregate “fullness” as performance degrades as disks get full (the drive heads need to travel farther to complete I/Os). Drive failures further degrade foreground I/O performance when drives are nearing full data capacity.
Utilization Monitoring	Monitor CPU utilization, disk utilization, and loop/stack bandwidth. If your utilization is greater than 50%, you are at increased risk to see greater foreground I/O degradation in degraded mode situations. This can also increase the time it takes for corrective actions to complete.
I/O Prioritization	Prioritize foreground I/O over corrective I/O by adjusting the RAID option `raid.reconstruct.perf_impact` to Low.
Scrubs	Use the default settings for RAID scrubs and media scrubs. Systems are assumed to be highly utilized, so increasing the duration of scrubs will likely provide a reduced benefit to data integrity while consuming additional system resources.
Maintenance Center	Maintenance Center is recommended to enable intelligent triage of suspect drives in the field. This also facilitates the RMA process for failed drives to make sure the system returns to a normal operating state in a timely manner.

6.2 TIER 2: BUSINESS CRITICAL

These types of environments are likely subject to compliance requirements, and although maintaining client access to the storage system is important, the loss of data would be severely detrimental to the customer. No customer likes to lose data, but these customers are under legal obligations and are subject to significant penalties when found to be noncompliant. This could also be a configuration that protects a company's intellectual property. Medical records, software source code, and e-mail are examples of environments that fit into this tier of data availability. This tier is tuned toward prioritizing corrective I/O while balancing foreground I/O. By prioritizing corrective I/O over foreground I/O in degraded situations, you increase the impact to foreground I/O performance.

Table 3) Recommendations and best practices for business-critical data availability.

Business-Critical Recommendations	
Flash Cache	Use Flash Cache to improve system performance and minimize the impact on foreground I/O while in degraded mode situations.
SyncMirror	Use local SyncMirror to make sure of shelf-level resiliency and to improve performance in degraded mode situations. Note that Data ONTAP 8.1 Cluster-Mode systems do not currently support SyncMirror.
Spares	Use a maximum hot spares approach to make sure sufficient disks are available for corrective actions. Set the RAID option `raid.min_spares_count` to the recommended number of spares to make sure the administrator will be notified when spare counts are below recommendations.
Drive Type	Use performance drives (SAS, FC, or SSD) instead of capacity drives (SATA). Smaller-capacity 15k rpm or SSD drives result in shorter times for corrective actions. This is important when foreground I/O is prioritized over corrective I/O, which increases times for corrective actions. Performance drives help offset that performance delta.
Aggregate Fullness	Monitor aggregate "fullness" as performance degrades as disks get full (the drive heads need to travel farther to complete I/Os). Drive failures will further degrade foreground I/O performance when drives near full data capacity.
Utilization Monitoring	Monitor CPU utilization, disk utilization, and loop/stack bandwidth. If your utilization is greater than 50%, you are at increased risk to see greater foreground I/O degradation in degraded mode situations. This can also increase the time it takes for corrective actions to complete.
I/O Prioritization	Use the default setting of Medium for the RAID option `raid.reconstruct.perf_impact` to balance foreground I/O and corrective I/O.
Scrubs	Consider increasing the frequency of RAID scrubs to increase integrity of data at rest.
Maintenance Center	Maintenance Center is recommended to enable intelligent triage of suspect drives in the field. This also facilitates the RMA process for failed drives so that systems return to a normal operating state in a timely manner.

6.3 TIER 3: REPOSITORY

Repository environments are used to store collaborative data or user data that is noncritical to business operations. Scientific and engineering compute data, workgroup collaboration, and user home directories are examples of environments that fit into this tier of data availability. This tier is the middle ground that balances foreground operations with corrective actions (should they be needed). Defaults are normally appropriate for these configurations.

Table 4) Recommendations and best practices for repository data availability.

Repository Recommendations	
Flash Cache	Use Flash Cache to improve system performance and minimize the impact on foreground I/O while in degraded mode situations.
SyncMirror	Use local SyncMirror to make sure of shelf-level resiliency and to improve performance in degraded mode situations. Note that Data ONTAP 8.1 Cluster-Mode systems do not currently support SyncMirror.
Spares	Use a balanced hot spares approach to allow more disks to be used to add to the system capacity. Set the RAID option `raid.min_spares_count` to the recommended number of spares so that the administrator will be notified when spare counts are below recommendations.
Drive Type	Consider using SATA drives (backed by Flash Cache) for these types of configurations.
Aggregate Fullness	Monitor aggregate “fullness” as performance degrades as disks get full (the drive heads need to travel farther to complete I/Os). Drive failures will further degrade foreground I/O performance when drives near full data capacity.
Utilization Monitoring	Monitor CPU utilization, disk utilization, and loop/stack bandwidth. If your utilization is greater than 50%, you are at increased risk for greater foreground I/O degradation in degraded mode situations. This can also increase the time it takes for corrective actions to complete.
I/O Prioritization	Use the default setting of Medium for the RAID option `raid.reconstruct.perf_impact` to balance foreground I/O and corrective I/O.
Scrubs	Consider increasing the frequency of RAID scrubs to increase the integrity of data at rest.
Maintenance Center	Maintenance Center is recommended to enable intelligent triage of suspect drives in the field. This also facilitates the RMA process for failed drives so that systems return to a normal operating state in a timely manner.

6.4 TIER 4: ARCHIVAL

This type of environment is subject to a large initial ingest of data (write), which then is seldom accessed. System utilization on average is not expected to be very significant. Because the data is seldom accessed, it is important to fully leverage subsystem features that exercise that data for continued integrity. Given that the priority is maintaining data integrity, these configurations are tuned toward prioritizing corrective I/O and minimizing completion time for corrective actions. Backup and recovery, archiving, near-line, and reference data are examples of environments that fit into this tier of data availability.

Table 5) Recommendations and best practices for archival data availability.

Archival Recommendations	
Spares	Use a maximum hot spares approach so that sufficient disks are available for corrective actions. Set the RAID option `raid.min_spares_count` to the recommended number of spares so that the administrator is notified when spare counts are below recommendations.
Drive Type	Consider using SATA drives (backed by Flash Cache) for these types of configurations.
Aggregate Fullness	Monitor aggregate “fullness” as performance degrades as disks get full (the drive heads need to travel farther to complete I/Os). Drive failures will further degrade foreground I/O performance when drives near full data capacity.
Utilization Monitoring	Monitor CPU utilization, disk utilization, and loop/stack bandwidth. If your utilization is greater than 50%, you are at increased risk for greater foreground I/O degradation in degraded mode situations. This can also increase the time it takes for corrective actions to complete.
I/O Prioritization	Use the default setting of Medium for the RAID option `raid.reconstruct.perf_impact` to balance foreground I/O and corrective I/O.
Scrubs	Consider increasing the RAID scrub duration (`raid.scrub.duration`) to help make sure of the integrity of data at rest. Consider increasing the media scrub rate (`raid.media_scrub.rate`) to increase drive-level block integrity.
Maintenance Center	Maintenance Center is recommended to enable intelligent triage of suspect drives in the field. This also facilitates the RMA process for failed drives so that systems return to a normal operating state in a timely manner.

6.5 TIER 5: MULTIPURPOSE

One of the many strengths of NetApp storage is the ability to host multiple tiers of data availability within the context of a single system (HA pair). This tier simply calls out this capability, which might result in conflicting configuration recommendations. In a Data ONTAP 7G multipurpose environment, aggregates and volumes are likely to compete for the same system resources. For truly global options NetApp recommends that you tune those toward the most sensitive data-availability tier being hosted in the storage configuration. With the introduction of Data ONTAP 8.0 Cluster-Mode, the ability to segregate how the logical configuration of a system utilizes system resources is much improved.

For example, the RAID option `raid.reconstruct.perf_impact` could be set to either Low or High if your storage configuration is hosting both mission-critical and archival data. Because mission-critical data is more sensitive to system configuration than archival data, the recommendation is to set the option to Low as per the application data-availability tier (tier 1) recommendations.

Table 6) Recommendations and best practices for multipurpose data availability.

Multipurpose Recommendations	
Prioritize Recommendations	Prioritize configuration recommendations for the most sensitive tier of data availability when conflicting recommendations are present.
FlexShare®	Consider using FlexShare to prioritize system resources between data volumes.
Physical Segregation	Segregate the physical shelf and the drive layout for multiple data-availability tiers. For example, if you have both SAS and SATA (DS4243) attached to the same system, you could use the SAS drives to host mission-critical data while using the SATA drives to host archival data. Although you can mix DS4243 SAS shelves with DS4243 SATA shelves in the same stack, NetApp recommends separating the shelves into stacks so that physical failures affecting one tier of data availability will not directly affect both tiers of storage being hosted (in this example).

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