Amazon.com leverages the AWS Cloud for Database Backups

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Abstract

This paper describes how Amazon.com evaluated and adopted Amazon Simple Storage Service (Amazon S3) as a backup solution for the company's Oracle databases. These databases are owned and operated by individual teams within the company, and are essential for Amazon.com's day-to-day business operations.

Oracle has introduced a seamless backup solution that makes it easy to use Amazon S3 as a backup medium for Oracle databases, while at the same time removing many of the problems we've encountered using tape for our backups. It was natural for Amazon.com to evaluate the costs and benefits of using Amazon S3 for Oracle Database backups, and to migrate to Amazon S3 where it made sense. Throughout the process, we[1] engaged with Amazon Web Services (AWS) like any customer would. In turn, AWS treated us as it would treat any enterprise customer.

This paper describes our migration path as an AWS reference customer to an Amazon S3 backup solution. Our experience is detailed in the following sections:

- Where We Were
- Where We Wanted to Go and Why
- Our Success Criteria
- Total Cost of Ownership
- How We Launched
- Lessons We Learned
- What Benefits Emerged

[1] Throughout this document, the term 'we' refers to Amazon corporate IT team that oversees backup and storage needs.

Where We Were

From its founding, Amazon.com relied on Oracle database software for much of its data management needs. Our use of Oracle software has grown with the company and over time, we created a number of in-house management tools to supplement Oracle tools. We have a highly decentralized and geographically distributed business structure and we need to ensure that the management tools are globally available to all database administrators (DBAs) who need to use them.

In a 24x7 environment like Amazon.com, DBAs require the highest levels of availability for any backup and recovery solution. Our in-house database backup scripts work seamlessly with Oracle Recovery Manager (RMAN) so that the databases can be backed up at any time. Using these scripts, DBAs can setup a recurring backup schedule for their databases. Other tools allow the DBAs to check the status of their backups, and to be automatically notified if a backup fails.

The following diagram shows the infrastructure we've used for Oracle backups:

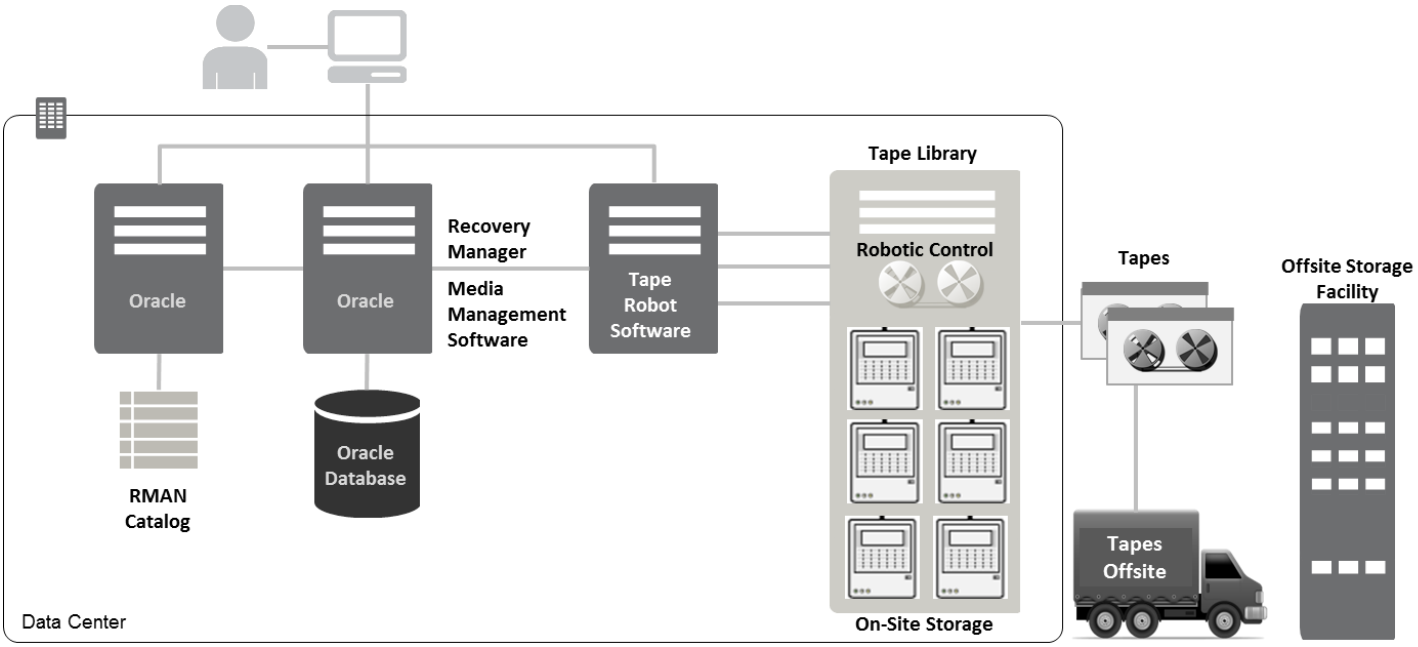

Figure 1: Oracle Database Backup Infrastructure before Migration

At Amazon.com, our primary backup media has been magnetic tape using a number of robotic tape library systems. This infrastructure is centrally managed and is available for use by the entire company, although its primary usage is for Oracle database backups. The tape hardware is front-ended by commercially available tape backup software, which provides an interface to catalog all of the tapes, moves a particular tape to an available tape drive, performs read/write operations, and so on. The Oracle RMAN software uses media management software to communicate with the tape backup software, providing a level of abstraction to the RMAN interface.

The combination of RMAN and in-house tools effectively insulates the DBAs from the physical backup media: when backing up database files, RMAN works seamlessly with the tape hardware to perform the backup, check the integrity of the backup, and report the success or failure to the DBA. RMAN also maintains a backup catalog and a set of database tables that tracks the metadata for all backups. After a successful database backup, the RMAN catalog updates to reflect the change.

We configure Oracle databases for maximum fault tolerance and recoverability and incorporate Oracle Data Guard as a standard part of any database setup. Using physical standby databases and Oracle Data Guard Fast-Start Failover, a DBA can usually "flip" to a standby database within a very short time after a hardware or software failure. In virtually all cases, this operation is fully automated. While this minimizes downtime, a catastrophic failure would mean restoring database backups and then using the database's log files (redo logs) to roll forward to a point in time prior to the failure. If a disaster strikes, the DBA responsible needs to restore the database files from tape as quickly as possible. The RMAN interface handles the low-level interaction with the tape backup software, which in turn reads the tape backup catalog, chooses the tapes to restore, loads the tapes into available drives, and begins restoring the files. Several factors determine the speed with which this can be accomplished:

- The total number of bytes to be restored.
- The number of tapes that must be switched during this operation.
- Contention for available tape drives.

We invested significant resources over the years to build and operate our backup infrastructure. In general, it has served us well, but rapid growth has caused significant challenges in scaling the tape infrastructure. We are always receptive to improvements that could save the company money and make the DBAs' job easier.

Where We Wanted to Go and Why

As Amazon.com grows larger, the size of the Oracle databases and the raw number of databases we must maintain continues to expand. This has caused some growing pains related to database backups.

One major issue is paying for and managing the client licenses for our commercial tape backup software. We need a software license for each Oracle database server. We need to track usage and purchase additional licenses if we exceed the total number of licenses. We do our best to obtain realistic volume discounts in our contractual negotiations with the vendor; however, we cannot predict with 100% accuracy the number of database hosts that need licenses. Our business highly seasonal and we are continuously innovating to add new products and features. When a new Oracle database comes online, we often need to juggle software licenses among different hosts to ensure backup for the new database. Alternatively, we sometimes purchase a small number of additional licenses from our vendor, but we end up paying much higher prices for incremental licensing using this approach.

With the release of version 10g, Oracle introduced a new media management layer that allows RMAN to backup Oracle databases to Amazon S3. This media management layer does not alter the RMAN interface at all – it simply redirects database backup and restore activity to Amazon S3. From a DBA's point of view, the changes appeared to be minimal: Configure the Oracle Secure Backup Cloud Module on the database server, make a few simple changes to the RMAN commands used for backup, and backups could go to Amazon S3 instead.

We presumed that Oracle backups to Amazon S3 would be suitable for Amazon.com; however, we performed a verification process prior to production deployment. Verification included:

- **Complexity and time required for capacity planning and managing tape.** We incurred significant capital expenditures over the years for tape hardware, data center space for this hardware, and licensing fees for tape software. In addition, it's been difficult for us to hire engineers with the requisite experience for operating such hardware. We knew that Amazon S3 could reduce these costs to near zero.

- **Effort required to ensure durable data storage.** When we purchase new tape hardware, we have to install it, configure the tape backup software to work with it, and so on. Our data center environments are very dynamic, so from time to time we need to move the hardware elsewhere and reinstall it, get it recertified by the vendor, and continue where we left off. All of this can be very time-consuming, so the prospect of moving to Amazon S3, which would obviate these requirements, was very enticing.

- **Cost of backup software required to support multiple tape devices.** Tape robots provide basic read/write capability, but in order to fully utilize them, sophisticated tape backup software is required. For us, the cost of this software adds significantly to our overall spending. With Amazon S3, we could eliminate this software completely, and realize significant cost savings.

- **Amount of time and effort required to successfully maintain and locate backup data.** When everything is working correctly, and there is minimal contention for tape resources, the tape robots and backup software can easily find the required data. However, if there is a hardware failure, human intervention is necessary to make repairs, while at the same time manually locating and mounting the correct tapes. Amazon S3 would remove this pain point.

Our Success Criteria

We decided to investigate further, taking a careful look at the security, availability, and performance aspects of Amazon S3 backups. We also performed a cost-benefit analysis to ensure that a migration to Amazon S3 would be financially worthwhile. Our success criteria included:

- **Data Security.** Before deciding on a company-wide rollout, we needed to evaluate our security posture. Amazon S3 resides outside of our company firewall and we had to mitigate the risk of outsiders being able to view any of our data. We needed to assure ourselves that we could protect our data in flight (en route from the Amazon.com corporate network to Amazon S3), and at rest (residing in an Amazon S3 bucket). The obvious solution for protecting data is encryption; however, we also had to address the issue of credential rotation. Our security policies mandate that we change our encryption keys on a regular basis, so we needed a workable solution.

- **Cost Competitiveness.** Amazon.com has a long track record of managing a tape-based backup infrastructure and we could determine a dollars-per-gigabyte figure for the costs of our backups. Before deciding on the widespread adoption of Oracle backups to Amazon S3, we needed to show that the overall cost would be comparable with our existing tape solution. We also needed to take into account other costs that are not as easily quantified – operations overhead, hardware investments, long-term storage costs, and so on.

- **Availability and Durability.** Amazon S3 is designed to provide 99.999999999% durability and 99.99% availability of objects over a given year. We needed to compare these figures with those observed from our tape infrastructure, and then determine whether Amazon S3 delivered significant improvements.

- **Low Operational Friction.** We had to ensure that Amazon S3 backups would be attractive to our DBAs by demonstrating that Amazon S3 for backups would be no more difficult than using tape and that it would work seamlessly with RMAN. The time and effort required for backup and recovery operations had to be the same as tape or less.

Total Cost of Ownership

Before we could compare the cost of tape backups to Amazon S3 backups, we had to construct a cost model. We considered several key inputs:

- Capital expenditures:
  - Hardware costs, including robotic tape libraries, media servers, and tape drives
  - Software licensing, for tape robots and media management
- Annual throughput activity (GB)
- Annual retained activity (GB)
- Facility costs
  - Powering, cooling and real estate
- Personnel costs
- Depreciation
- We used these inputs to calculate annual operating expenses. Dividing these expenses by throughput, we obtained a cost per gigabyte for tape backups.

For an Amazon S3 solution, we didn't need to model capital expenditures, support personnel, facilities, or software licensing: All we needed to know was the Amazon S3 pricing. Given our annual retained activity figure, we looked at Amazon S3 costs:

- Storage costs (per GB)
- Outbound data transfer costs (inbound data transfer is free of charge)

We divided the amount of retained data by the total per-gigabyte cost of Amazon S3, and arrived at a cost per gigabyte for Amazon S3. We compared this with the per-gigabyte cost for tape, and determined that we could save at least $1m per year by using Amazon S3.

How We Launched

As a company, we have been interested in leveraging Amazon S3 for backups since its release. We realized that the ever-decreasing cost of Amazon S3, combined with its pay-as-you-go model, would become increasingly attractive. With the release of Oracle Secure Backup Cloud Module for Amazon S3, integrating RMAN with Amazon S3, we felt that the time was right for to use this solution for our own database backups.

The following diagram shows our new, greatly simplified infrastructure for Oracle backups:

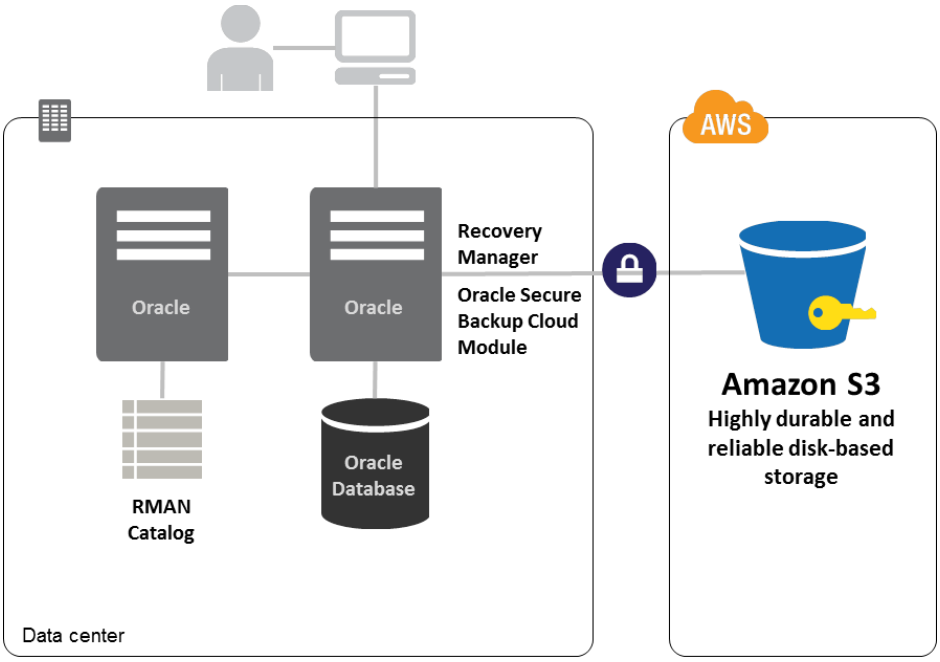

Figure 2: Oracle Database Backup Infrastructure after Migration

Oracle published a whitepaper[2] on how to configure RMAN to backup databases to Amazon S3. The solution requires purchasing the Oracle Advanced Security option, a separately licensed software option that includes Oracle Secure Backup (OSB) Cloud Module. This latter module provides the requisite level of interface abstraction for RMAN. With the OSB Cloud Module installed, the RMAN commands that are used for backups remain unchanged, except for the "destination" parameter, which must point to Amazon S3 rather than tape.

Using the Oracle whitepaper as a starting point, we began testing the OSB Cloud Module, running benchmarks on how long it took to perform Amazon S3-based backups for databases of various sizes, and how long it took to restore the backups from Amazon S3. In general, we found that backups and restores were faster overall than using tape. These operations were even faster, and took up less bandwidth, when we enabled RMAN data compression. We also experimented with different degrees of parallelism – performing the backups or restores using multiple channels – to determine appropriate settings.

Next, we wrote a detailed DBA guide description on how to configure the OSB Cloud Module in an Amazon.com environment. In this customized internal document, we described how to manage AWS credentials and Amazon S3 buckets, modify existing backup scripts to take advantage of Amazon S3, rotate encryption credentials, and verify that backups were completing successfully. With this guide prepared, we began contacting individual DBAs around the company, asking them to migrate to Amazon S3 backups as time allowed.

Feedback from DBAs has been overwhelmingly positive, so far. Dalibor Marceta, Database Engineering Manager for Amazon Merchant Technologies, says, "Due to the rapid growth of Amazon.com, our team's databases are rapidly increasing in size. This was causing our backup and restore operations to take a lot longer than before. As soon as we learned that Amazon S3 was available for Oracle backups, we began using it. DBAs don't have to contend for available tape drives anymore, and in case of disaster recovery, they don't have to wait for hours while a backup is restored from tape. Amazon S3 backups are very fast, and since we don't need to worry about resource contention, we can schedule our backups so that they don't have any impact during peak times."

[2] http://docs.oracle.com/cd/E14072_01/backup.112/e10643/web_services001.htm

We will keep encouraging the migration to Amazon S3, allowing DBAs to do so at their own pace. By the time we need to renegotiate our contract with the vendor of the tape backup software, we expect that overall spending for Amazon.com on backup software licenses to be drastically reduced. To illustrate this point, consider the following:

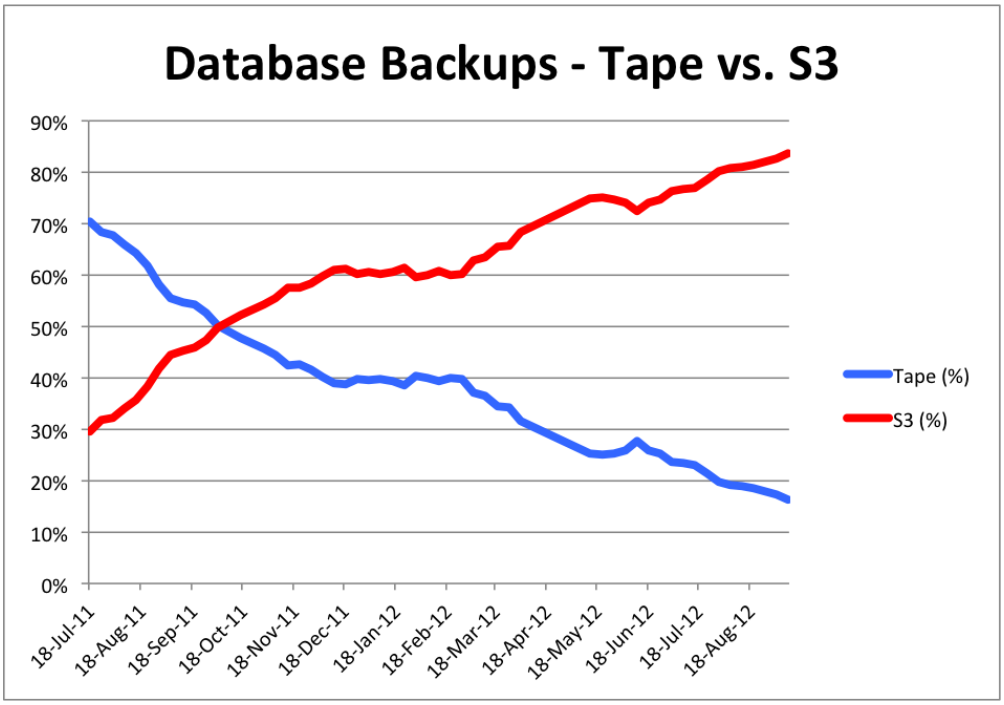

Figure 3: Database Backups Transition Over Time

During the summer of 2011, we began tracking how Amazon.com DBAs were backing up their Oracle databases – how many were being backed up to tape, and how many were using Amazon S3. The migration had already begun, with nearly 30% of our databases already using Amazon S3. Three months later, we hit equilibrium with a 50/50 mix. After that, Amazon S3 usage began to eclipse tape. At the time, 85% of our databases are being backed up to Amazon S3, and we are on track to reach 100% by the end of 2012.

The data in the chart above comes from our RMAN backup catalogs. RMAN keeps track of metadata regarding Oracle database backups, and writes this metadata to database tables. From there, it is possible to query which databases are backed up to tape, and which are backed up to Amazon S3. We can also determine the number of bytes per backup destination, distribution of backups by data center, and much more. Most importantly, we can determine which databases in our company have not moved to Amazon S3, determine the reasons why, and work with the DBAs to make it happen (provided that these databases are candidates for migration).

We plan to migrate all Oracle database backups to Amazon S3 by the end of 2012, except for databases in regions where Amazon S3 is not available. With the current rate of migration on the part of our DBA community, we should not have any trouble meeting that goal.

Considerations for Migrating to Amazon S3 Backups

We've been satisfied with our overall progress in migrating to Amazon S3 backups for our databases. However, there are several key takeaways that should be passed along to anyone else pursuing such a strategy:

- **Accurate cost models are hard to construct, yet essential.** With Amazon S3, it is relatively easy to determine the overall cost of database backups: multiply the sizes of your database backups by the price that AWS charges per gigabyte of storage; multiply that figure by the frequency of your backups (daily, weekly, etc.); and finally, calculate the AWS bandwidth charges for outbound data. However, tape-based solutions do not lend themselves well to this kind of cost modeling. You first need to determine your overall spending for the tape hardware, the tape backup software, and the tapes themselves. Next, you must determine depreciation, resale value, and the cost of additional hardware (i.e., for an expanding business). You also need to factor in the cost of replacing tapes, and the cost of offsite storage. Finally, don't forget about operational costs associated with retaining people to physically manage the tape hardware, repair mechanical problems when they occur, resolve contention issues with multiple users trying to access the tape devices, and so on.

- **Take data protection seriously.** Any time you transmit data over a public network, you need to consider the implications carefully. If you do not take steps to protect your data, then it's possible that your data could be intercepted en route to Amazon S3, or that your data files might be publicly accessible once they've been written to Amazon S3. To mitigate the risk to in-flight data, always use industrial strength encryption. We strongly recommend using the encryption features built into Oracle Secure Backup for this purpose. For at-rest data, we recommend that you set the access controls on your Amazon S3 buckets and data objects to restrict file access, and that only you can write to them. In addition, consider using Amazon S3 Server Side Encryption. Whatever encryption regimen you use, be sure to factor in the amount of additional time it takes during backups to encrypt the data – this is likely minimal, but is also measurable.

- **Manage your encryption credentials.** Be sure to change the encryption credentials for all backups on a regular basis. The frequency with which you do this will depend upon your company's security policies. At Amazon.com, we had to construct our own key rotation solution, verify it with our IT security team, and then integrate it with our backup scripts. This added significant work to our company-wide rollout of Amazon S3 backups, but the peace of mind this offers is worth the effort.

- **Manage your network bandwidth.** When using RMAN, specify multiple backup channels to increase parallelism. This will have the effect of utilizing more network bandwidth, and speeding up your backups – but only to a point: If your network becomes fully saturated, there is no reason to increase the number of RMAN channels beyond what you're already using. At Amazon.com, we experiment with the number of RMAN channels to strike a balance between speed and network saturation. We've also had to experiment with RMAN data compression, which requires higher CPU utilization but uses less bandwidth.

- **Determine your data retention policies.** You probably don't need to retain every Oracle database backup; to recover an Oracle database you need a good backup, plus all of the redo logs that have been generated since then. For example, if you were to do a full database backup every night, you would not need to retain any prior backups; those extraneous files would not be necessary for database recovery. Nevertheless, your company might have policies regarding data retention, and may mandate that you follow these policies.

Security Best Practices

When we began backing up Oracle databases to S3, we evaluated the security implications every step of the way. Because we believe that everyone should be security-conscious, we'd like to share a list of best practices:

- **Ensure that you have the latest version of the Oracle Secure Backup Cloud Module.** Download it from *http://www.oracle.com/technetwork/topics/cloud/downloads/index-102039.html*.
- **Password-protect your Oracle wallet.** During the installation process for OSB Cloud Module, you are asked to supply your AWS credentials. These credentials are stored in an Oracle wallet file on disk; however, that file is not password-protected by default. We recommend that you add a password to your Oracle wallet immediately, using Oracle Wallet Manager.
- **Rotate your AWS credentials periodically.** Use the AWS Management Console to generate a new Secret Access Key, and update your Oracle wallet with this key.
- **Make sure to use RMAN backup encryption.** You should configure Oracle Recovery Manager so that it automatically encrypts your backups. For more information on this topic, consult the RMAN documentation.
- **Rotate your RMAN passphrases.** Change your RMAN passphrases on a regular basis. We recommend doing so on a more frequent basis than that for your AWS credentials.
- **Lock down your Amazon S3 bucket**. Set a bucket policy such that only IP addresses you approve are allowed to access the bucket. You can use the AWS Management Console to add a bucket policy.
- **Consider using Amazon S3 server-side encryption.** RMAN encryption will protect your data before it ever leaves your firewall – your backups will be encrypted upon arrival in your S3 bucket. Nevertheless, you might decide to encrypt it there, too; the choice is yours.

What Benefits Emerged

Although our migration to Amazon S3 is not yet complete, we have already seen several benefits:

- **Cost savings.** We no longer need to negotiate separate contracts with a tape hardware vendor, tape software vendor, and so on. There's no need to purchase licenses, calculate depreciation on hardware, or pay annual maintenance fees. With Amazon S3, we are saving over $1 million per year in tape hardware and software expenses.

- **Reduced operational overhead**. With tape backup, Amazon.com business groups have to write annual backup plans, quantifying the amount of storage that they plan to use for the year and the frequency with which they will use the tape resources. These plans are then used to charge each organization for their tape usage. With Amazon S3, teams are billed for their usage as they go along. There are no practical upper limits to how much data can be stored in Amazon S3, so there are no worries about running out of resources. For database backups, the need for formal planning has been eliminated; yielding a 100% reduction in labor hours spent creating reports and conducting meetings.

- **Dramatic reduction in time to backup and restore**. We've observed that it takes less than half the time to back up a database to Amazon S3 than it does to backup to tape. To get maximum performance, we take advantage of built-in RMAN data compression and allocate multiple RMAN channels to fully utilize network throughput. Similarly, Amazon S3 lets us perform high-speed database restores. As an example, one of our DBAs was able to restore 3.8 terabytes in 2 ½ hours over gigabit Ethernet. This amounts to 25 gigabytes per minute, or 422 megabytes per second. In addition, since we use RMAN data compression, the effective restore rate was 3.37

gigabytes per second. Amazon S3 has removed the delays incurred by locating, mounting and reading tapes – data restores begin immediately, leading to faster database recovery.

- **Helps us focus on our domain more**. With our tape infrastructure, we had to seek out engineers experienced with very large tape backup installations – a specialized, vendor-specific skill set that is very difficult to find. We also needed to hire data center technicians and dedicate them to problem-solving and troubleshooting hardware issues – replacing drives, shuffling tapes around, and so on. Amazon S3 frees these employees from day-to-day operations and lets us assign work that is more meaningful. The total cost for these employees are the same, but now they are working on more strategic engineering tasks, which will yield long-term business benefits.

- **Increased durability.** We have experienced many hardware failures with our tape infrastructure – tapes that break or fail, and robotic components that fail. Sometimes this happens when a DBA is trying to restore a database, which dramatically increases the time to recover (TTR). For example, if a tape breaks, our infrastructure engineers need to determine which backups are on the tape, notify the DBAs responsible, and determine how to solve the problem. These events are to be expected – tape robots are designed more for long, linear read/write operations than the very frequent, ad-hoc, relatively short read/write cycles required for multiple simultaneous database backups. With Amazon S3, all of these issues simply go away: Amazon S3 is designed to provide 99.999999999% durability for stored objects over a given year, a figure unmatched by even the most resilient tape-based solution.

References

1. Step by Step Video Tutorial on How to Backup Oracle Databases to Amazon S3 using Oracle OSB Module and RMAN - https://aws.amazon.com/backup-storage/gsg-oracle-rman/
2. Whitepaper: Cloud Offsite Database Backups - http://www.oracle.com/technetwork/database/features/availability/twp-oracledbcloudbackup-130129.pdf
3. Getting Started with OSB Cloud Module - http://docs.oracle.com/cd/E11882_01/backup.112/e10643/web_services002.htm#CHDEFGBD
4. Download Oracle Secure Backup Cloud Module - http://www.oracle.com/technetwork/topics/cloud/downloads/index-102039.html
5. Oracle Secure Backup - http://www.oracle.com/us/products/database/secure-backup/overview/index.html