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Risk-Driven Database Security

A practical approach to securing the Oracle Database

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Why you should read this paper

This paper is intended to help you evaluate options for reducing security risk and improving regulatory compliance for your Oracle Databases. If you are responsible for designing, implementing, maintaining, or operating security controls for an Oracle Database this paper is intended for you.

It does not replace the more than 8,000 pages of security-related documentation spread across dozens of different product manuals. Instead, it covers WHY to use security-focused database features, options, and related products. Where there are multiple controls you could use to accomplish the same goal, I try to help you choose the right path. The appendix: Tools—Features, Options, Products, and Packs contains a key to those controls, along with links to the documentation if you'd like more information about them.

Disclaimer

This document is for informational purposes only and is intended solely to assist you in planning for the implementation and upgrade of the product features described. It is not a commitment to deliver any material, code, or functionality, and should not be relied upon in making purchasing decisions. The development, release, timing, and pricing of any features or functionality described in this document remains at the sole discretion of Oracle. Due to the nature of the product architecture, it may not be possible to safely include all features described in this document without risking significant destabilization of the code.

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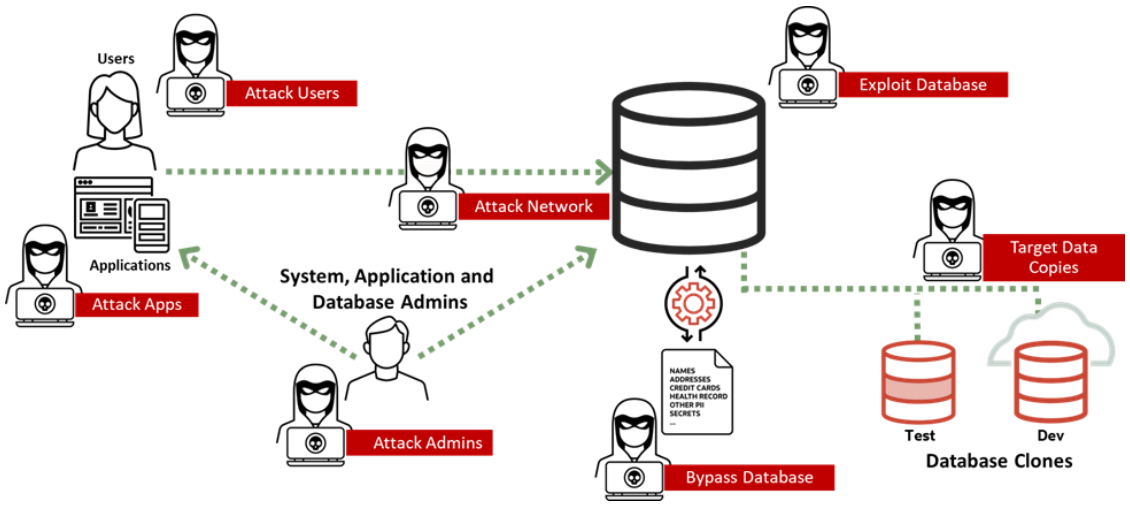
Introduction

Oracle Databases contain the majority of the world's relational data, including sensitive data that is a prime target for data thieves and ransomware gangs. That sensitive data should be protected from theft or misuse. Two primary imperatives drive the need for organizations to protect data:

- Regulatory requirements – there are over 160 national laws governing data privacy (including EU GDPR, India DPDPA, Canada PIPEDA, Japan PIPA, and Australian Privacy Principles), a huge number of laws and regulations from state and provincial governments (California CCPA, Quebec Privacy Act), and industry regulations (PCI, US FFIEC, US HIPAA, EU PSD2, BASEL). Listing all of the different laws and regulations would make this paper very long and would mean it would be out of date almost immediately because the regulatory environment is constantly evolving. The cost of non-compliance with regulations can be severe – US HIPAA fines have been as high as $16M, and GDPR fines have been as high €1.2B.
- Risk reduction and data theft concerns – Data has value, and data thieves spend a lot of time stealing it. Billions of personal data records are stolen each year. The economic impact of this theft is easily in the trillions of dollars. "If cybercrime was a state, it would be the third-largest economy in the world" *Edi Rama, Prime Minister of Albania, speaking at the 53rd annual meeting of the World Economic Forum, January 2023*

What I'd like you to take away from this paper is the framework for your database security plan. What are the different features, options, and products, and how do they combine to provide an appropriate level of protection for your sensitive data?

I'll focus on risk reduction, with the goal of preventing data theft (or misuse). Despite the focus on risk reduction, these security controls also play a vital role in regulatory compliance. After all, most data security-focused regulations are attempts to manage risk.



Attack points for a database

How are databases compromised?

To better understand how to protect a database, you should first consider how databases are typically breached.

- The most common point of compromise for a database is a valid database account. That can be a DBA account, an application service account, or even an end-user account. Most data stolen from a database departs through a valid account that is compromised or being used in a way that violates policy.
- Another attack technique is to bypass the database altogether. Attackers access the underlying storage for the database, steal a database backup, or acquire a database export. This lets them sidestep the database's access and monitoring controls. Bypass attacks are how most ransomware works—by simply scraping the database files from storage and exfiltrating the data back to the ransomware gang's servers.
- Attackers will probe the database and the underlying operating system for known exploits in hopes of finding un-patched vulnerabilities. Unless you are using one of the Autonomous Database cloud services, then you're managing the application of security patches to your database to prevent database exploits.
- Attackers who penetrate your network perimeter may simply lurk on your network and sniff for "interesting" data – these types of network attacks are attractive because the chances of being caught are so low.
- All of these attacks can be executed against the production database, but copies of production, frequently made for test and development purposes, are also good targets. In fact, those non-production copies of the database are BETTER targets because they are less likely to be closely monitored and often lack the security controls used in production. If it is the same data, does it matter which copy of the database it came from?

Keep in mind that a solution that only protects against one of these attacks just redirects the attacker to another weak point - you need to cover all the avenues of attack to truly secure your data.

What is Risk?

Risk is a product of threat, impact, vulnerability, and value.

- Threat: how likely is it that someone will attempt to steal, destroy, or misuse your data?
- Impact: how much damage would a breach cause to the organization? This could be in terms of fines, lost opportunity costs, or damage to customer confidence.
- Vulnerability: how exposed is the data? What are the chances that an attempt to compromise the data will succeed?
- Value: what is the value of the data? Both to the attacker and to your organization?

You have little ability to change threat or impact, but your efforts can reduce the vulnerability and, in the case of non-production database copies, reduce the value of the data to the attackers.

You can only do three things with risk – mitigate it, insure it, or accept it. We will focus on mitigating risk – reducing risk to an acceptable level.

Establish a security baseline

There are certain controls that ought to be implemented in each of your databases – these create a minimum security baseline that should reflect your organization's policies and risk tolerance. A good way to think about your database security baseline is that this is what you expect to see to reduce vulnerability in ALL databases, regardless of who might want to steal the contents (threat), what data they contain (value), or what their usage is (impact). There should be few exceptions (if any) granted to the baseline, and when there IS an exception that exception should be periodically reviewed to ensure it is still valid. Here are the procedures and controls we think should be part of all database security baselines.

Assess your database

Before you make any changes, it is a good idea to assess your database to understand its current state of security. Review the database configuration, basic security policies, user entitlements, and password policies. Scan your database for sensitive data to determine what additional protections are appropriate for it. You should repeat this assessment periodically to detect configuration drift away from your approved baseline.

Validate Database Configuration

A security assessment of your database examines initialization parameters, listener settings, missing security patches, and more. Oracle Databases are extremely flexible and configurable to meet almost any business need with thousands of parameters. Use a security assessment to identify configuration choices that introduce unnecessary risk and, where possible, reconfigure the system to remove that risk. Your baseline security posture should reflect configurations that support your minimum security standard. If you do not already have an organizational standard for secure database configuration, consider adopting either the Center for Internet Security (CIS) benchmark configuration, or the United States Defense Information Systems Agency (DISA) Secure Technical Implementation Guide (STIG) for Oracle Database.

Oracle provides several tools to help you assess your database security, including the Database Security Assessment Tool (DBSAT), Oracle Data Safe, and Oracle Audit Vault and Database Firewall (AVDF). All three tools map findings to the CIS Benchmark and STIG.

Which should you choose?

If your database runs as an Oracle Cloud service (that includes Oracle Database at AWS, GCP, and Azure) then Data Safe is included at no cost and is the obvious choice. Data Safe can also be used with other Oracle Databases, including on-premises, for a subscription fee. If your organization prefers not to use a cloud service, then AVDF is a good choice. If you just have one or two databases to inspect, and do not require drift detection, then DBSAT is quick and easy to use and is included with ALL Oracle Databases – simply download it from My Oracle Support.

Review User Authentication

Oracle Database supports authentication via username and password, PKI certificate, Kerberos, RADIUS, Oracle Cloud Infrastructure (OCI) Identity and Access Management (IAM) tokens, OCI-IAM password, and Microsoft Entra ID OAuth2 tokens.

By far the most common authentication mechanism is the simple username and password. If your database accounts are still authenticated by password, ensure that you are enforcing good password discipline. In most cases, your database password policies should reflect your standard organizational policies, which include requirements for password length, lifetime, and complexity. Your Oracle Database is a business-critical system containing sensitive information—why would you accept weaker password policies than you allow for less critical systems like laptops?

For database service accounts, where expiring passwords may be impractical because of the downstream impact on availability, consider mitigating the risk of passwords not expiring with additional controls that closely limit the conditions under which those accounts are allowed to connect. Locking accounts after a certain number of failed logins is also a good practice and reduces the chance of a brute-force password attack succeeding.

Consider moving to stronger authentication for interactive database accounts. The most common strong authentication used with the database is Kerberos, typically using a Microsoft Active Directory Domain Controller as the Kerberos key distribution center. Moving authentication outside of the database into Active Directory has several advantages, including centralized control of authentication, single sign-on with the Windows desktop, and the ability to disable database logins for ALL databases with a single action.

Another strong authentication mechanism is the tokens issued by Microsoft Entra ID or Oracle Cloud's Identity and Access Management (OCI-IAM). Both Entra ID and OCI-IAM offer multiple paths to multifactor authentication.

Microsoft is encouraging their Active Directory customers to modernize their identity management infrastructures with a transition to Entra ID. It's likely that over the next few years we will see tokens replace Kerberos as the most common mechanism for strong authentication.

Yet another strong authentication mechanism is RADIUS. RADIUS is a venerable, well known authentication mechanism that has been supported for over a decade with the Oracle Database. One driver of recent adoption is the embrace of RADIUS by cloud-based authentication services like Oracle Identity Cloud Service and Okta.

And finally, PKI certificates also provide strong authentication for the Oracle Database. We see certificate-based authentication frequently used for application or API connections to the database. PKI certificates also are the underlying authentication mechanism used for most smart card authentication, including US Department of Defense Common Access Cards (CAC) and US Government Personal Identify Verification (PIV) cards.

Which should you choose?

I'd like to say "anything but passwords" but despite their shortcomings, passwords are still the only practical choice in some cases. So, instead, I'll say that if you CAN move away from passwords to a stronger authentication mechanism it's a great way to reduce risk. The key thing to remember is that Oracle Database is flexible. There are very few authentication services that it cannot work with. Your choice of strong authentication mechanisms for databases is almost always going to be driven by your organization's choices for other authentication needs. If your organization uses Entra ID, then it usually makes sense to use Entra ID for your databases. If your organization has settled on Oracle Access Manager, Oracle Cloud IAM, or Okta, then you'll probably want to connect those services to your databases using RADIUS.

User Entitlements

Since compromised accounts are the most common source of database breaches, review assigned privileges and remove any that are not necessary to reduce the threat those accounts pose if compromised. Data Safe, AVDF, and DBSAT help with entitlement reviews by reporting on the privileges an account has been granted. Both AVDF and Data Safe add drift detection to their reporting, making it easy to identify changes to user and their privileges. Additionally, Oracle provides *privilege analysis* to assist in assessing the privileges an account actually *uses*. Knowing which privileges an application account requires is valuable because it helps you identify candidate privileges to be revoked as you drive towards accounts with only the privileges required to complete their assigned tasks.

A good practice with privilege analysis is to identify candidate privileges and roles for removal, and then audit the use of those privileges and roles for a period of time to ensure you don't accidentally revoke a privilege that is required infrequently. Caution in revoking privileges is especially appropriate for non-human accounts like those used by applications or batch processes.

Encrypt Data in Motion

Data is at risk as it traverses the network between the database and the database client or application. Skilled attackers will frequently monitor network traffic, sniffing for sensitive data. This type of passive attack is extremely difficult to detect because the attackers don't actually try to penetrate the database or database server. Fortunately, Oracle Database offers a few options for encrypting data in motion.

Oracle Native Network Encryption

Oracle Native Network Encryption (NNE) is the easiest way to encrypt data in motion. It requires a single line added to the database's network configuration file (sqlnet.ora), and in most cases no changes to database clients. Oracle Database can either request or require encryption. If the database requests encryption, clients that support encryption will automatically default to encryption and clients that do not support encryption will fall back to an unencrypted connection. If the database requires encryption, clients that do not support encryption will fail to connect. The encrypted connection will use the strongest mutually-supported encryption algorithm, most commonly AES256.

Transport Layer Security

Transport Layer Security (TLS) also encrypts data in motion. Unlike NNE, TLS requires a certificate for the database server and allows a certificate for the database client. If only the server uses a certificate, then the connection is referred to as "server authenticated" and the client still requires user authentication to connect. If the database client is also issued a certificate, then the connection is mutually authenticated, and the client certificate may also be used to authenticate the user. Oracle Database 23ai supports the latest version of the standard – TLS 1.3.

Which should you choose?

NNE or TLS? The choice depends on your use case. Performance is roughly the same and will seldom drive the choice. The encryption quality used for both is equivalent in terms of strength, but TLS adds server authentication to encryption, and can be used to also authenticate the client. TLS is an industry-standard protocol, well known by most security teams – but TLS almost always requires changes to the client configuration and uses certificates that eventually expire and need to be maintained. NNE is easier to set up and seldom requires any changes to the client. In cases where operational efficiency is most important, we will usually see NNE used. In cases where the highest level of security is required – even if it means some compromises for operational efficiency – TLS is the most common choice. If you are concerned about post-quantum computing resistance, especially to steal-store-and-decrypt-later attacks, we recommend TLS.

Manage Database Users and Roles

Database users and roles can be managed locally, within the database. They can also be centrally managed in an LDAP directory. If you have few users that connect to your databases, and few databases for them to connect to, then local user management is probably the right choice for you. If you have LOTS of database users, or are managing lots of different databases, then centrally managing your users is probably a better choice. There are several options for centrally managing database users. All options let you manage database accounts for multiple databases in a single place using common credentials across all connected databases. The options include:

Cloud-based identity services

Oracle Database supports cloud-based identity services like Microsoft Entra ID and Oracle Identity and Access Management (IAM). The minimum database version with support for Centrally Managed Users is Oracle Database 19c. Both cloud services support multi-factor authentication and provide token-based integration with application services.

Centrally Managed Users

Centrally Managed Users is a database feature that connects Oracle Databases to Microsoft Active Directory. Database schemas are mapped to Active Directory users or groups, and database roles are mapped to Active Directory groups. Authentication is typically by Kerberos or PKI certificate. Password-based authentication is supported but not recommended. The minimum database version with support for Centrally Managed Users is Oracle Database 18c.

Enterprise User Security

Enterprise User Security is similar to centrally managed users but connects Oracle Databases to an Oracle Directory instead of Active Directory. The minimum database version with support for Enterprise User Security is Oracle Database 9i. Enterprise User Security continues to be supported for all current database versions but is deprecated in Oracle Database 23ai.

Audit database activity

After a security incident, you will need to determine what happened, who did it, where the attack originated from, when it occurred, how it happened, and what data was impacted. Having a record of database logins, changes to users, alterations of database objects, and access to sensitive data lets you support investigations and provides evidence of the scope of an incident. Database auditing gives you that record in an audit trail.

Audit policies determine which activities are captured and stored in the audit trail. Auditing always impacts performance and storage to some degree, so your audit policies should consider the value of the audit data being collected. "Audit everything" is not usually practical because of the significant additional load it places on the system. Here are a few activities that are normally low frequency, and of high security value. Auditing policies should capture these activities as part of the auditing baseline:

- Changes to user accounts (create, alter, drop)
- Grants of privileges and roles
- Create, alter, and drop of database objects including tables, views, database links, and stored procedures
- Database logins – especially login failures
- All database administrator actions
- Database exports and backups

Oracle Database comes pre-configured with audit policies to capture most of this baseline activity with the two pre-configured `ORA_SECURECONFIG` or `ORA_LOGIN_LOGOUT` policies. Both are enabled by default in 19c and higher databases, so you'll just need to make sure no one disabled them. Enable the non-default `ORA_ALL_TOPLEVEL_ACTIONS` policy for your database administrators. You'll need to create a custom audit policy to audit Data Pump exports. Beyond the baseline, audit policies should also capture attempts to access data outside of policy. For example, if your organization's policy does not allow access to data from outside the application, then auditing should capture attempts to circumvent the policy.

Starting in Oracle Database 12c, unified auditing was offered alongside the legacy audit facility. In Oracle Database 23ai, the legacy audit facility is desupported, and unified auditing is now the only audit facility.

Discover Sensitive Data

For most databases, the decision to go beyond the security baseline will be determined by the data stored within the database. Are there regulatory requirements for additional security measures? Does the data present a business risk that justifies an investment in additional security controls? For some databases, the answer will be obvious – if this is your HCM, CRM or financial database, then you know it contains sensitive personal data and can act accordingly. If it is a database that hosts run-time sensor data for your production shop floor, then perhaps it does not need additional protection (unless that data exposes sensitive intellectual property).

For other databases, you may not know the appropriate level of protection – and that's where sensitive data discovery comes into the picture. Sensitive data discovery scans your database for sensitive data "types" – I use the quotes because this is not data types the way we normally talk about them in a database sense – char, number, blob, etc. This is "types" as in email addresses, taxpayer identifiers, and account numbers. Sensitive Data Discovery tells you what types of data are in your database and how much of it there is. Use this information to make a data-driven decision about the risk a database contains, and the protections required to mitigate that risk.

Oracle offers four tools that can help with sensitive data discovery. Database Security Assessment Tool (DBSAT), Data Safe, Audit Vault and Database Firewall (AVDF), and Enterprise Manager Data Discovery, part of the Data Masking and Subsetting Pack.

Which should you choose?

If you have access to it, Data Safe should be your first choice. Data Safe offers sensitive data discovery, scanning database metadata (column names and comments) and actual data within tables for over 150 different types of sensitive data. Data Safe's sensitive data format library is extensible, allowing both create and create-like to easily model organizational or regionally unique data patterns.

If your organization is uncomfortable using a cloud service or wants a higher degree of control than possible with one, AVDF is a good choice.

If you already use Oracle Enterprise Manager and have the required license for the Data Discovery feature, then it is another good choice for sensitive data discovery.

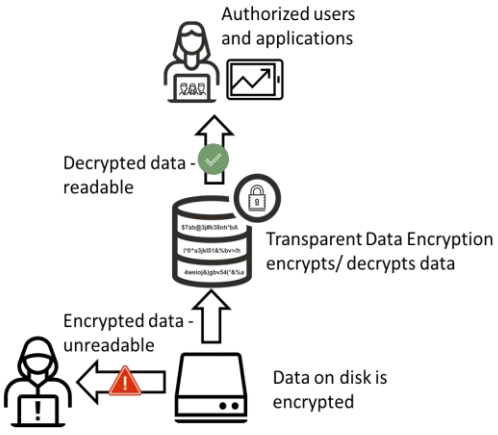
If you are working with non-English databases, consider DBSAT - DBSAT is the only sensitive data discovery tool from Oracle that supports scanning using other languages, and as of the time I'm writing this DBSAT ships with discovery pattern files in English, Spanish, German, Portuguese, Italian, French, Dutch, and Greek. Unlike Data Safe or Enterprise Manager, DBSAT does not actually scan table data, only metadata including column names and column comments.

Beyond the baseline – Maximum security architecture

If you determine that the risk inherent in the database requires protection beyond the baseline, you will begin to approach Oracle's maximum security architecture (MSA). The MSA applies a defense-in-depth approach to database security, extending the security baseline to further reduce risk in systems that contain sensitive data or are subject to regulatory constraints. Different components of the MSA are used to mitigate various attack vectors. Very few databases will use all features of the MSA, but most databases containing sensitive data will use one or more components of the MSA to reduce risk, improve security, and strengthen regulatory compliance.

Encrypt Data At-Rest

At-rest data encryption mitigates the risk of database bypass. If an attacker gains access to the underlying database storage, database backups, or database exports, then encryption prevents the attacker from simply reading the data directly without using a database API. That type of bypass attack would circumvent access controls and would not trigger audit records – a worst-case situation that it is critical to avoid. At-rest encryption is the most common control above the baseline – implemented by more Oracle customers than any of the other non-baseline security features. In many organizations, at-rest encryption is part of the baseline.



Encrypting Data at Rest with Transparent Data Encryption

Encryption is also a common requirement for data privacy and protection regulations. Failure to encrypt data is typically considered a failure to exercise due care in protecting data. Oracle's primary encryption solution is Transparent Data Encryption (TDE), a feature of a database option called Oracle Advanced Security (ASO).

Most TDE implementations are trouble-free – TDE is a mature feature with two decades of successful deployments by many thousands of customers. Here are a few things to consider.

Do your own performance benchmarks on real data workloads – not on artificial queries. It is important to use actual workloads to accurately judge the impact on production. Encryption always adds some performance overhead because you are asking the system, and especially the CPU, to do more work. Combining TDE with Advanced Compression is a great way to reduce that overhead since Advanced Compression lowers the number of data blocks that need to be decrypted. Tablespace encryption tends to perform better with most workloads than column-level encryption, and with tablespace encryption, you lessen the chance that you'll forget to encrypt a sensitive column or that someone will insert sensitive data into a column that shouldn't contain it. Use the strongest encryption supported by your database version – as of the time this is written, that is Advanced Encryption Standard (AES) with a 256-bit key. Lower levels of encryption and shorter key lengths should no longer be used due to concerns about post-quantum computing impacts on their effectiveness, and if you have databases using lower levels of encryption you should consider rekeying them to AES256. In Oracle Database 23ai, AES256 is the default. In earlier versions of the database, you can manually configure each tablespace for AES256 or set an initialization parameter that modifies the database's default algorithm.

Remember to consider the impact of encryption on your backup system – most modern backup storage compress and de-duplicate backups. When a database is first encrypted, all of the encrypted data blocks look new to the storage system, so there is no de-duplication and you will see an initial sharp rise in storage requirements. As time goes on and unencrypted backups age out of the system, you will see de-duplication return to normal levels. Encrypted data tends not to compress well, and as a result, there will be some permanent loss of compression. Here again, Advanced Compression can help mitigate the impact because with Advanced Compression the data is compressed before being encrypted. This subject of encryption's impact on backup storage is one of the most commonly overlooked areas in deployment plans for Transparent Data Encryption.

Manage and Protect Encryption Keys

Data at rest encryption requires a persistent key, and the security of the encryption is no better than the security of the encryption key. Transparent Data Encryption includes automated key management, and Oracle Key Vault provides secure key storage, centralized administration, and secure distribution of keys to support advanced data architectures like Real Application Clusters and Oracle Data Guard.

Ensure your keys are backed up (separately from the database backups). Use Oracle Key Vault instead of the default Oracle Wallet for key storage. For enhanced security, consider chaining the Key Vault with a Hardware Security Module (HSM) as a root of trust.

Enforce Separation of Duties

In databases containing sensitive data, separating administrative duties is a common security goal. The administrator who can create an account and manage authentication credentials cannot grant access to data. The data administrator does not have the ability to the ability to create users or change their credentials. Oracle Database Vault is a database option that helps with this requirement. When Database Vault is enabled, it implements separation of duties (SOD) for user account management by default. Other separations are enabled by Database Vault policies. The appropriate level of SOD for an organization depends on a lot of factors – not just the sensitivity of the system or the data within it. If an organization only has one DBA, then a complex SOD setup is probably less important. On the other hand, if an organization has dozens or hundreds of DBAs, then further separating responsibilities is a good way to limit the damage if an administrator account is compromised. Other areas we have seen separated (in just about every combination imaginable) include backup and recovery management, performance management, data integration, security administration, data administration, and patching. Adopt a model that makes sense in the context of your organization, but wherever possible drive towards using accounts with the least privileges required for

a job function. If your DBAs are specialized, then they should not have the privileges contained in the generic DBA role. They should have privileges tailored to their job function.

Control Administrator Access to Sensitive Data

Database administrator accounts are one of a hacker's favorite targets, and most database breaches involve the use of compromised credentials. For that reason, compromised database administrator accounts can be dangerous to the organization. Fortunately, database administrators rarely need access to sensitive data – or to any application data at all. Block database administrator access to sensitive data with Database Vault and you significantly reduce the amount of damage a compromised administrator account can inflict.

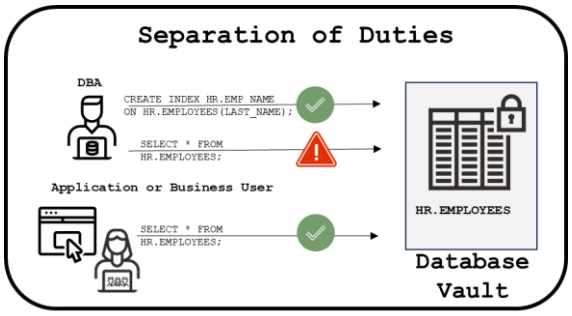


Figure 1: Control privileged user access to data

Enforce Trusted Path Access to Sensitive Data

For a data thief, compromising the service account used by the application to access sensitive data is almost as good as compromising the DBA account. The application service account typically has full access to data, and in many cases, the application service account credentials are difficult to update without negative operational impact. This can lead to widespread dissemination of the credentials (especially within the developer/DevOps team) and that opens the potential for misuse and an increased risk of compromise for the account. Lockdown those application service accounts with Database Vault, limiting their use to just the application servers, running the application server programs, started as the application server's operating system user. Use multiple factors to restrict the use of the application service account to that trusted path and deny an attacker or curious team member the opportunity to misuse the account.

Centrally Manage Audit Data

You may recall from our discussion of auditing in the baseline security section that audit data can be used for supporting investigations, both forensic and operational. Analyzing that audit data for any individual database can be done manually with simple SQL queries, but if you have multiple databases it may be more effective to collect audit data from those databases into a central repository where it can be more easily analyzed and reported on. Plus, an attacker with privileged user credentials may be able to alter/delete locally stored audit data – especially for older databases that have not switched to unified audit yet.

Both Oracle Data Safe and Oracle Audit Vault and Database Firewall collect audit data and place that audit data in a secure data warehouse where it can be reviewed, analyzed, reported on, and (when appropriate) generate alerts.

Which should you choose?

If your Oracle Databases are running as Oracle Cloud services (including Oracle Database at Azure, GCP, or AWS) then Data Safe is included with those services at no extra cost and is the obvious solution. Data Safe is available for use with other Oracle Databases, including on-premises, for a subscription fee.

If you are not using an Oracle Database cloud service, or if you want to collect both Oracle Database and non-Oracle database audit data, then Audit Vault and Database Firewall is probably your best choice. AVDF can collect audit data from almost anything that produces an audit trail.

Detect and Block Activity Anomalies

Anomaly detection and prevention are among the most important capabilities for protecting data. Databases typically perform the same tasks repeatedly, and anything new should be viewed with suspicion until it's proven to be benign. An account that suddenly behaves differently – new programs, unusual OS usernames, new IP addresses – might be an indication that the account is being used by someone other than the person the account actually belongs to. An application that suddenly begins executing never-before-seen SQL commands could be an application that is passing through SQL injection.

There is no substitute for database auditing, but auditing is usually not well-suited for anomaly detection. This is because you can very rarely audit ALL activity (the performance impact of auditing all activity would be high, and the storage required to maintain all of those audit records would also be significant). Detecting anomalies requires that all activity be inspected. We work around the impact of auditing by supplementing audit data with another control, the database firewall. Oracle offers two different types of database firewalls. Both provide essentially the same capabilities and approach the task of detecting anomalies in similar ways.

The first is the "Database Firewall" part of Oracle Audit Vault and Database Firewall. Database Firewall runs on a separate server from the database, monitoring SQL commands being sent to the database at the network layer. Database Firewall can be configured as a proxy (where database traffic flows through the firewall before reaching the database), or it can sniff SQL commands from the network as they travel across the network from client to database server. Either configuration allows for anomaly detection, only the proxy configuration permits anomaly blocking.

The second is the "SQL Firewall," a new component in Oracle Database 23ai. SQL Firewall runs inside the database kernel, inspecting SQL commands as the database receives them. It is always in line with traffic coming to the database and can be configured to log anomalies or block them.

Both the SQL Firewall and Database Firewall approach the problem of anomaly detection in the same way – they learn typical activity (which IP addresses, OS usernames, programs, and SQL commands are sent to the database) and create an allow list based on that typical behavior. After the allow list is created, it's a simple matter to say that anything that isn't in that allow list is an anomaly and should be investigated. This same approach makes it easy to detect and block SQL injection attacks.

Although they are functionally similar, the difference between the two controls is significant. Database Firewall is heterogeneous, protecting Oracle Database (all editions and versions), Oracle MySQL, Microsoft SQL Server, IBM Db2, and SAP Sybase. SQL Firewall only works with Oracle Database 23ai Enterprise Edition.

Database Firewall operates at the network layer and has no access to the underlying database session context. That means it cannot know the impact of recursive SQL, new synonyms, or dynamically generated SQL. Network-based monitoring doesn't give audit-quality data, but it is very good at providing enough data to spot deviations from normal patterns. SQL Firewall operates within the database, so it has full access to underlying session context and database metadata. SQL Firewall has visibility into synonyms, recursive SQL, and dynamic SQL. Also, since SQL Firewall is part of the database, an attacker cannot "go around" the SQL Firewall by using a different network path. The violation data captured by SQL Firewall is of audit quality and SQL Firewall policy violations can even be written to the audit trail.

From a licensing standpoint, both Database Firewall and SQL Firewall are included with AVDF. SQL Firewall is also included with Oracle Database Vault.

Which should you choose?

If you are using Oracle Database 23ai, the best option is usually going to be the new SQL Firewall. If you are using an older database version, or a database other than Oracle Database, then Database Firewall is the right way to go.

Minimize Sensitive Data – Remove Risk from Non-Production Databases

The controls discussed so far limit and monitor data access – but there are times when that limitation defeats the purpose of the system. A good example of this is non-production test or development systems. By their very nature, these systems tend to have more relaxed access controls and more variation in how they are operated. If your non-production database is created with artificial data, then this is not a problem because there is no risk inherent in the artificial data. But if you create your non-production system by the common practice of just cloning production then you duplicate the risk in the production system, increasing the chances of a security incident.

Minimize sensitive data in non-production database copies with Data Masking

For these non-production copies of production systems, a good technique is to mask the sensitive data – replace it with artificial values that remove the sensitivity of the data while still providing an environment suitable for testing and development. Masking differs from the other controls we have discussed in that it doesn't mitigate risk; it actually removes the risk. Oracle offers two solutions for data masking, Oracle Data Safe, and Oracle Enterprise Manager Data Masking and Subsetting. Both solutions let you discover sensitive data, identify referential integrity constraints, and mask the data to remove security risk.

Which should you choose?

If your organization allows the use of cloud services, Data Safe is almost always the right choice, both because it's going to provide quicker time to value and because of the other security capabilities we've already discussed that Data Safe provides. If you prefer to keep security controls on-premises, then Data Masking and Subsetting is the way to go.

Take a risk-based approach

Remember that we started with the idea of a security baseline applied to ALL your databases. Next, we talked about sensitive data discovery and added controls beyond the baseline to minimize the system's risk level. Here are a few sample systems with associated risk levels and controls.

System	Risk Level	Controls above baseline	Remarks
Human Resources	High	Encryption, key management, separation of duties, trusted path	Privacy concerns/regulations
Financial Reporting	High	Encryption, key management, separation of duties	Sarbanes-Oxley or similar
Order Fulfillment/ Shipping/ CRM	Very High	Encryption, key management, separation of duties, trusted path, anomaly detection	Privacy concerns/regulations
Web Store	Very High	Encryption, key management, separation of duties trusted path, anomaly prevention	Internet facing application, privacy concerns/ regulations
Test and Development	High	Data Masking	Remove sensitive data from these systems

Start Here

We have covered a lot, and each of the areas I have briefly introduced could be the subject of its own book! The amount of work to be done can be daunting – I've seen more than one organization lapse into analysis-paralysis, spending inordinate amounts of time trying to put together the perfect implementation plan, and never actually accomplishing anything that reduces their risk. In one very memorable case, about six months into that analysis phase I saw a very good customer – some of the nicest people you could ever hope to work with – breached with very public disclosure, resulting in over $175M in breach costs and significant organization upset. Here is what I suggest in hopes of helping you avoid that trap.

Do Something!

There is no perfect security in a usable system. It is a balancing act between the drive to secure data and the need to support operations and use the data. The best you can usually do is chip away at risk until you reduce it to a level that your organization can live with. Any of the security controls I outlined above should help with risk reduction, getting you closer to that "acceptable risk" level.

A smart place to start is the first thing I covered in this paper – begin improving security with an assessment of your system and configuration. Identify your current state and decide what state you would like to get to. Decide which controls make the most sense to adopt. I outlined a baseline level of security in the first part of this paper – does that baseline make sense to you? If so, then adopt it and begin to apply it to systems during maintenance periods. If you have systems that you KNOW are sensitive, focus on them first. Remember, the risk you remove today may be the risk an attacker would have exploited tomorrow.

Parting Thoughts

As you begin to reduce risk and improve security, you are virtually certain to face organizational inertia – do not be discouraged. The stakes are too high to continue to accept the status quo. Enlist the help of your organization's security group – they may have resources to help plan and organize this effort – allowing you to focus on the technical implementation.

Remember where we started? Your databases contain some of your most valuable information—it is a safe bet that someone would be happy to take that information from you and find ways to profit from it. The controls I've outlined in this paper reduce the chances of their success, with each control contributing its part to a more secure system. Best of luck with your project!

Further reading

If you'd like to learn more about securing databases or give your teams more information to help them prioritize efforts and select the best controls for your environment, here are a few resources:

- Oracle Database Security – an executive overview
- Oracle Database Security – a technical primer
- Database security product documentation

Appendix: Tools – Features, Options, Products, and Packs

Any discussion of this nature can easily devolve into a listing of products and features – I've tried to minimize that in the main portion of this paper. Below is a list of the different features, options, products, and packs mentioned in the paper, along with links to documentation. The features are listed in the order in which they were mentioned above. One thing to consider about those documentation links – they are current as of the time I write this, but white papers tend to linger for a long time, while database versions and documentation are fluid and frequently updated. Check docs.oracle.com to find the latest version of the documentation – the links provided here will at least let you know which manual (and usually chapter or appendix) to look for.

Database Security Assessment Tool (DBSAT)

DBSAT is a standalone utility included with your database support. DBSAT helps with security assessment, user assessment, and sensitive data discovery. There is no additional fee for the use of DBSAT. DBSAT works with all supported versions of the Oracle Database, on all supported operating systems, and can be run for databases on-premises or in the cloud – including non-Oracle clouds. The utility may be downloaded from My Oracle Support – check MOS note 2138254.1 for more information on downloading the tool. DBSAT documentation is available here.

Oracle Data Safe

Data Safe is an Oracle Cloud service, included with Oracle Database as a Service offerings and available for use with on-premises databases and Oracle Databases running on Oracle Cloud Compute. Data Safe includes several database security capabilities, including security assessment, user assessment, sensitive data discovery, sensitive data masking, unified audit policy control, audit data retrieval, reporting, and alert generation. Data Safe is Oracle's newest database security service and is rapidly evolving (two-week development sprints) new features and capabilities. Click "What's New" in the documentation for updates on recent changes. Documentation for Data Safe is included here.

Enterprise Manager Database Lifecycle Management

Database Lifecycle Management is a management pack for Oracle Enterprise Manager Cloud Control. Database Lifecycle Management provides numerous functions for managing the lifecycle of your database, including configuration management, and can play a valuable part in security assessments. Information about configuration management using Enterprise Manager Database Lifecycle Management is available here.

Privilege Analysis

Privilege analysis is a database feature included with all databases and database services except for standard edition. It helps with user assessment, particularly with determining which privileges a user account has, but is not using. Privilege Analysis was introduced in Oracle Database 12c Release 1. Privilege Analysis documentation is available here.

Native Network Encryption

Native Network Encryption (NNE) is a database feature included with all databases and database services with the exception of Autonomous Database (Autonomous Database uses TLS instead of NNE). NNE encrypts data as it travels between the database and database client or application. NNE documentation is available here.

Transport Layer Security

Transport Layer Security (TLS) is a database feature included with all databases and database services. It is configured by default for Autonomous Databases. TLS encrypts data as it travels between database and database client or application. TLS documentation is available here.

Centrally Managed Users

Centrally Managed Users (CMU) is a database feature included with Oracle Database Enterprise Edition. CMU was introduced with Oracle Database 18c. CMU allows Oracle Databases to connect directly to Microsoft Active Directory. With CMU, users are created in Active Directory and mapped to database schemas. Optionally, database roles can be associated with Active Directory groups, and database role membership controlled by Active Directory group membership. CMU documentation is available here.

Enterprise User Security

Enterprise User Security (EUS) is a database feature included with Oracle Database Enterprise Edition. EUS was introduced with Oracle Database 8.1 (Oracle 8i). EUS allows Oracle Databases to connect to an Oracle directory service. With EUS, users are created in Internet Directory and database schemas are mapped to users or to collections of users within an LDAP organizational unit. Database roles can be associated with Internet Directory groups, and database role membership controlled by LDAP group membership. EUS documentation is available here.

Traditional Auditing

Traditional auditing was first introduced in Oracle Database 7 and was the primary auditing mechanism for Oracle Database until the release of Oracle Database 12c. Traditional auditing is being replaced by unified audit. Traditional auditing is desupported starting with Oracle Database 23ai. Traditional audit documentation is available here.

Fine-Grained Auditing

Fine-grained auditing was introduced in Oracle Database 9.0 (9i Release 1). As the name suggests, Fine-grained auditing allows audit policies to be focused more narrowly than traditional auditing, allowing audit policies based on columns. Fine-grained auditing also introduced the concept of conditional auditing, where audit records would only be generated if a certain condition evaluated to true. Documentation for fine-grained auditing is available here.

Unified Auditing

Unified auditing was introduced in Oracle Database 12.1 (12c Release 1). Unified auditing consolidates audit records into a single location, combining audit data from Database Vault, Label Security, Data Pump, SQL*Loader, Recovery Manager (RMAN), fine-grained auditing, and audit records generated from unified audit policies. Unlike traditional auditing, unified audit policies may be conditional, may choose to audit only top-level statements, and are extensible to include context information not in the default audit trail. Documentation for unified auditing is available here.

Enterprise Manager Data Discovery

Data Discovery is available in Enterprise Manager. Data discovery scans databases to locate sensitive data and helps drive Data Masking and Subsetting (DMS), Audit Vault and Database Firewall (AVDF) sensitive data audit reporting, and Transparent Sensitive Data Protection (TSDP) policies. Enterprise Manager Data Discovery stores the list of applications, tables, and relationships between table columns that are either declared in the data dictionary, imported from application metadata, or user specified. Data Discovery maintains sensitive data types and their associated columns, and is used by test data operations, such as data subsetting and data masking, to securely produce test data. Like Data Safe, Data Discovery scans data contained within tables to find sensitive data.

Data Discovery is included at no additional cost with Oracle Advanced Security, Oracle Database Vault, Oracle Label Security, Oracle Data Masking and Subsetting, and Oracle Audit Vault and Database Firewall. Use Data Discovery to understand a database schema or schemas, including how columns relate to one another and which columns contain sensitive data. Documentation for Data Discovery is available here.

Oracle Advanced Security

Oracle Advanced Security (ASO) is a database option that includes Transparent Data Encryption, RMAN backup encryption, Data Pump export encryption, encrypted Database File System (DBFS), encrypted SecureFile LOBs, and Data Redaction. Advanced Security is one of the oldest database options, tracing its roots to the Advanced Networking Option introduced in Oracle 7. Documentation for Advanced Security's Transparent Data Encryption is available here. Documentation for Advanced Security's Data Redaction is available here.

Oracle Key Vault

Oracle Key Vault is a key management system supporting the Oracle infrastructure, optimized for use with Transparent Data Encryption. Key Vault provides continuous access to encryption keys with a multi-master fault-tolerant cluster architecture. In addition to protecting encryption keys, Key Vault also provides complete SSH key governance (an important capability for protecting all of your Linux servers, not just the database servers), secrets management, DBMS_CRYPTO key management, and much more. Documentation for Key Vault is available here.

SQL Firewall

SQL Firewall is a new component of Oracle Database 23ai. It is designed to detect and block SQL injection and other anomalies. SQL Firewall is included with both Oracle Database Vault and Oracle Audit Vault and Database Firewall. Documentation for SQL Firewall is available here.

Oracle Database Vault

Oracle Database Vault is a database option that provides advanced access control capabilities. Database Vault is commonly used to enforce separation of duties, block administrator access to sensitive data, and enforce trusted path access to data. Database Vault includes SQL Firewall. Documentation for Database Vault is available here.

Oracle Audit Vault and Database Firewall

Oracle Audit Vault and Database Firewall (AVDF) is a database activity monitor with heterogeneous capabilities – covering Oracle Database, Oracle MySQL, Microsoft SQL Server, PostgreSQL, MongoDB, IBM DB2, and SAP Sybase. For Oracle Databases, AVDF also provides security assessment, tracks user entitlements, performs drift detection, discovers sensitive data, and includes SQL Firewall. Documentation for Audit Vault and Database Firewall is available here.

Oracle Data Masking and Subsetting

Oracle Data Masking and Subsetting (DMS) is a management pack for Oracle Enterprise Manager. DMS removes risk from databases by replacing sensitive data with artificial values. DMS can also be used to create subsets of a database – smaller copies with only a portion of the original data. Documentation for Data Masking and Subsetting is available here.

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