National College of Ireland

Healthcare-Grade Cross-Cloud Policy Delivery: Signed OPA Bundles as OCI Artifacts on AWS, Azure & GCP

MSc Research Project
MSc in Cloud Computing

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MSc Project Submission Sheet

School of Computing

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Configuration Manual

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1. Introduction

Provide a complete, operator-focused configuration manual for building, signing, publishing, discovering, verifying, and enforcing OPA policy bundles delivered as OCI artifacts across AWS, Azure, and GCP, with verify-before-use gating and audit-ready evidence outputs.

2. Requirements

2.1. Hardware

- Local workstation (Windows/Linux/macOS)
    - CPU: 2+ cores (4+ recommended for faster bundle builds and repeated verify/test runs)
    - RAM: 4 GB minimum (8 GB recommended)
    - Disk: 1–2 GB free for tools + artifacts + evidence (more if you retain long evidence history)
- Cloud shell / CI runner
    - Any standard Linux shell environment with outbound internet (HTTPS/443) and enough disk to download binaries and store a few bundles/evidence files (typically < 500 MB is sufficient for MVP-scale runs)
- Network Outbound HTTPS (TCP 443) access to:
    - OCI registries (ECR/ACR/GAR/GHCR as used)
    - Cloud identity endpoints used by your auth flow (AWS/Azure/GCP)
    - Optional Sigstore services only if you use keyless signing (otherwise not required for offline/keyed verification)

2.2. Software

Core toolchain is as follows:

- Open Policy Agent (OPA)
- ORAS CLI
- Cosign (Sigstore)

Imports

```python
import os, shutil, subprocess
from pathlib import Path

os.environ["PATH"] += r";C:\Tools"
os.environ.setdefault("COSIGN_PASSWORD", "1")

COSIGN = r"C:\Tools\cosign.exe" if Path(r"C:\Tools\cosign.exe").exists() else shutil.which("cosign")
if not COSIGN or not Path(COSIGN).exists():
    raise SystemExit("Cosign not found at C:\\Tools\\cosign.exe (or on PATH).")

def run(cmd, *, check=True, capture=True, env=None, cwd=None):
    p = subprocess.run(
        cmd, text=True, capture_output=capture, check=False,
        env=(env or os.environ.copy()), cwd=cwd
    )
    if check and p.returncode != 0:
        raise RuntimeError(
            f"Command failed ({p.returncode}): {' '.join(cmd)}\n"
            f"--- stdout ---\n{p.stdout}\n--- stderr ---\n{p.stderr}"
        )
    return p

keys_dir = Path("keys"); keys_dir.mkdir(exist_ok=True)
priv = keys_dir / "cosign.key"
pub  = keys_dir / "cosign.pub"
derived_pub = keys_dir / "from_priv.pub"

print("Using cosign at:", COSIGN)
print("Keys dir:", keys_dir.resolve())
```

```
Using cosign at: C:\Tools\cosign.exe
Keys dir: C:\Users\pc\Desktop\Prasanna Code\keys
```

- Cloud CLIs (for registry creation/auth where applicable)
    - AWS CLI (ECR)
    - Azure CLI (ACR)
    - Google Cloud SDK (gcloud) (Artifact Registry)
- Utilities (recommended)
    - jq for extracting digests/fields from JSON outputs
    - sha256sum (or equivalent) for file hashing
    - tar (or a deterministic packer implementation if not using opa build)

Keys

```
if not priv.exists() or not pub.exists():
    print("Keys missing -> generating key pair in current directory...")
    for stray in [Path("cosign.key"), Path("cosign.pub")]:
        if stray.exists():
            stray.unlink()

    run([COSIGN, "generate-key-pair"], check=True, capture=True)

    src_priv = Path("cosign.key")
    src_pub  = Path("cosign.pub")
    if not src_priv.exists() or not src_pub.exists():
        raise SystemExit("cosign did not produce cosign.key/cosign.pub in the current directory.")
    src_priv.replace(priv)
    src_pub.replace(pub)
    print("Keys created and moved to ./keys")

p = run([COSIGN, "public-key", "--key", str(priv)], check=True, capture=True)
derived_pub.write_text(p.stdout, encoding="utf-8")

print("Wrote:", derived_pub)
print("Same as keys/cosign.pub? ->", pub.read_text(encoding="utf-8") == derived_pub.read_text(encoding="utf-8"))
```

```
Wrote: keys\from_priv.pub
Same as keys/cosign.pub? -> True
```

- If using a Python CLI wrapper
    - Python 3.10+ recommended (3.8+ acceptable if dependencies permit)
    - Ability to run subprocess tools and write evidence JSON to disk
- Accounts, credentials, and permissions
    - A registry namespace/repository in each target cloud registry (ECR/ACR/GAR), plus credentials that permit:
    - Publishers: push artifact manifests/blobs and publish associated signature artifacts (referrers)
    - Consumers/verifiers: pull by digest and discover associated artifacts (referrers) as required
    - Public key distribution (cosign.pub) to all verifier environments
    - Private key protection (file-backed MVP keys stored securely; never committed)

3. Definitions and Conventions

Following are some of the important definitions:

- Bundle: OPA bundle archive (e.g., bundle.tar.gz) containing Rego + data.
- OCI artifact: Content stored in an OCI registry using an OCI manifest/config/layers (not necessarily a container image).
- Tag: Mutable reference (e.g., :v1, :latest). Not trusted as a security anchor.
- Digest pin: Immutable reference @sha256:<digest>; unit of trust.
- Subject: The artifact being signed (the OCI manifest identified by digest).

- Referrer: An OCI associated artifact that references a subject (e.g., signatures, attestations).
- Verify-before-use gate: Hard requirement: if verify fails or required signature is missing → do not execute OPA.

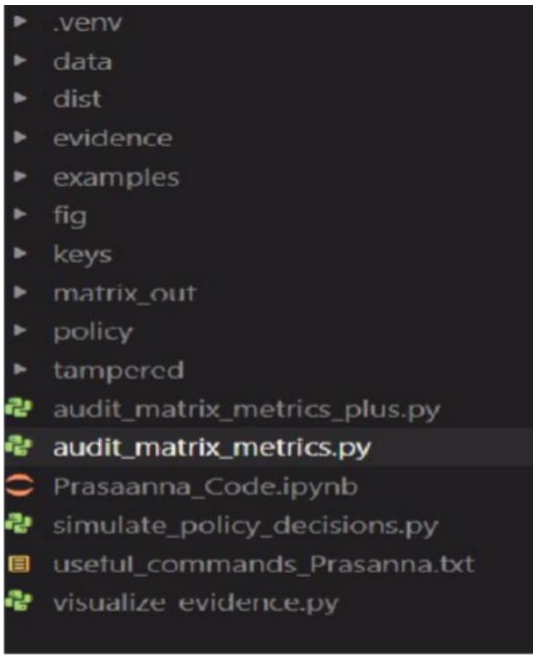
Following are some of the important notations:

- REGISTRY_HOST examples:
- ECR: <ACCOUNT_ID>.dkr.ecr.<REGION>.amazonaws.com
- ACR: <ACR_NAME>.azurecr.io
- GAR: <LOCATION>-docker.pkg.dev
- REPO example: medpolicy/policies
- REF_TAG example: prod-2025-12-31
- SUBJECT example: ${REGISTRY_HOST}/${REPO}@sha256:${DIGEST}

4. Repository Layout (Operational Standard)

Recommended layout:

- policy/ Rego + data inputs (source of truth)
- dist/ built bundle outputs (e.g., dist/bundle.tar.gz)
- keys/ public key only in repo; private key stored securely outside repo
- evidence/ JSON evidence per run
- tampered/ tamper-lab variants (optional for experiments)



Security rule: Never commit cosign.key (private key) to GitHub or shared storage.

5. Deterministic Build Configuration

You may use either:

- OPA bundle build
  - mkdir -p dist
  - opa build -b ./policy -o ./dist/bundle.tar.gz

Building

```
import os, subprocess
from pathlib import Path
```

```
os.environ["PATH"] += r";C:\Tools"
os.environ["COSIGN_PASSWORD"] = os.environ.get("COSIGN_PASSWORD", "1")

need("cosign"); need("opa")

src = Path("policy")
dist = Path("dist"); dist.mkdir(exist_ok=True)
bundle_path = (dist / "bundle.tar.gz").resolve()
sig_out = Path(str(bundle_path) + ".sig").resolve()
pub = (Path("keys")/"cosign.pub").resolve()
priv = (Path("keys")/"cosign.key").resolve()


for p in [bundle_path, sig_out]:
    if p.exists():
        p.unlink()


make_repro_tar(src, bundle_path)
```

```
WindowsPath('C:/Users/pc/Desktop/Prasanna Code/dist/bundle.tar.gz')
```

- Deterministic packer
  - If using a custom tar packer, enforce:
  - Sorted file order

    - Fixed UID/GID
    - Fixed mtime
    - Consistent permissions normalization (or preserved if required, but stable)
- Compute bundle digest (local evidence)
    - sha256sum ./dist/bundle.tar.gz | tee ./evidence/bundle.sha256.txt

6. OCI Artifact Packaging Standard

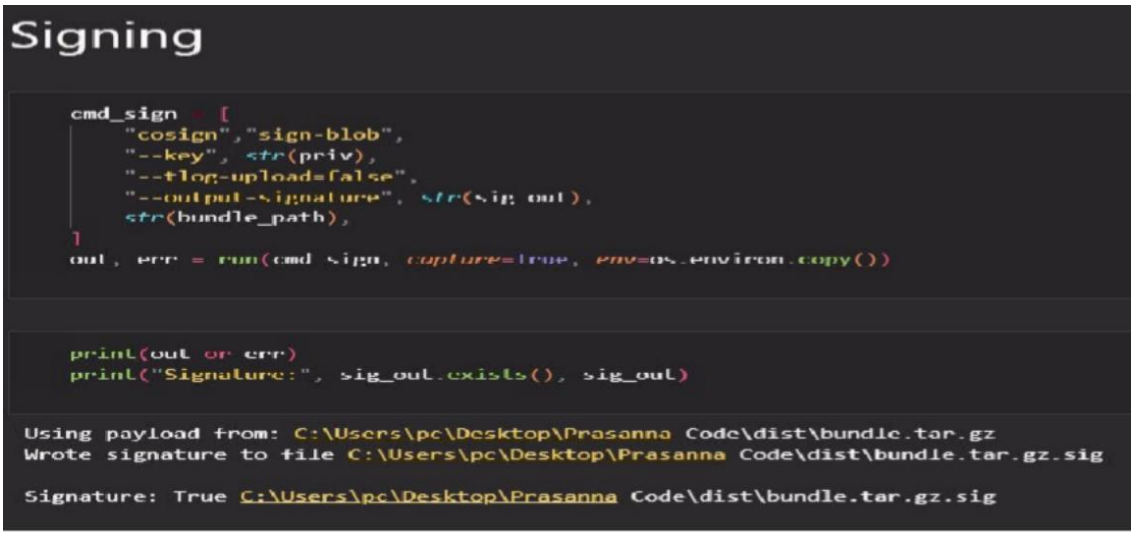
- Bundle layer: application/vnd.oci.image.layer.v1.tar+gzip
- Config blob: a small JSON config with a custom type
  eg. application/vnd.medpolicy.config.v1+json

```
cat > config.json <<'JSON'
{
  "artifact": "opa-bundle",
  "name": "medpolicy",
  "version": "1"
}
JSON
```

7. Signing Configuration (Cosign)

Generate keys (store private key securely outside repo; keep public key distributed to verifiers):

- cosign generate-key-pair



Sign the subject digest:

- cosign sign --key ./cosign.key ${SUBJECT}

Veryfiying

```
cmd_verify = [
    "cosign","verify-blob",
    "--key", str(pub),
    "--signature", str(sig_out),
    "--insecure-ignore-tlog",
    str(bundle_path),
]
run(cmd_verify, capture=False, env=os.environ.copy())
print("Verify OK and Done")
```

```
Verify OK and Done
```

Verification (required gate)

- cosign verify --key ./cosign.pub ${SUBJECT} | tee evidence/cosign-verify.json

Evaluating

```
need("opa")
import tarfile, tempfile
from pathlib import Path
def eval_with_input(bundle_path: Path, query: str, input_path: Path):
    with tempfile.TemporaryDirectory() as td:
        td = Path(td)
        with tarfile.open(bundle_path, "r:gz") as tar:
            tar.extractall(td)
        cmd = ["opa","eval","-i", str(input_path), "-d", str(td), query, "--format","pretty"]
        out, err = run(cmd, capture=True)
        return out.strip()

res_allow = eval_with_input(bundle_path, "data.med.allow", Path("examples/input_allow.json"))
res_deny  = eval_with_input(bundle_path, "data.med.allow", Path("examples/input_deny.json"))
```

- Gate rule (fail closed):
    - If cosign verify exits non-zero → stop pipeline immediately.
    - No OPA evaluation is permitted after a verification failure.

8. Referrers Discovery (Signatures)

Discover referrers for the subject digest:

- oras discover ${SUBJECT} -o json | tee evidence/referrers.json

Operational checks:

- Referrers output must include at least one signature artifact for regulated mode.
- If referrers are empty, treat them as non-compliant unless your policy explicitly allows offline signature distribution.

9. Registry Configuration by Cloud

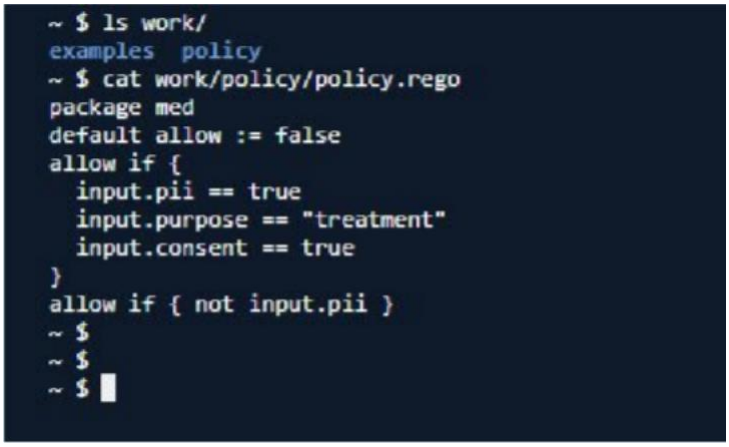
The artifact shape and commands remain cloud-neutral and the cloud differences are primarily authentication and IAM/RBAC.

AWS ECR (Elastic Container Registry)

- Create repository
    - aws ecr create-repository --repository-name ${REPO} --region <REGION>
- Login for ORAS
    - aws ecr get-login-password --region <REGION> \
    - | oras login ${REGISTRY_HOST} --username AWS --password-stdin

Minimum IAM guidance (high level)

- Publishers: permissions to create repo (optional), push blobs/manifests, and publish associated artifacts.
- Consumers/verifiers: permissions to pull blobs/manifests and query associated metadata/referrers (if supported in your environment).



Azure ACR (Azure Container Registry)

- Create registry
  - az group create -n <RG> -l <LOCATION>
  - az acr create -n <ACR_NAME> -g <RG> --sku Basic

Headless token login (recommended for Cloud Shell / CI)

- TOKEN=$(az acr login -n <ACR_NAME> --expose-token --output tsv --query accessToken)
- echo "$TOKEN" | oras login <ACR_NAME>.azurecr.io \
- --username 00000000-0000-0000-0000-000000000000 \
- --password-stdin

RBAC

- Publishers: role equivalent to push/upload to the registry.
- Consumers/verifiers: pull permissions plus metadata discovery as required.

Google Artifact Registry (GAR)

- Enable API and create Docker-format repository
    - gcloud services enable artifactregistry.googleapis.com
    - gcloud artifacts repositories create <REPO_NAME> \
    - --repository-format=docker \
    - --location=<LOCATION>

ORAS login using access token

- gcloud auth print-access-token| oras login <LOCATION>-docker.pkg.dev --username oauth2accesstoken --password-stdin

IAM

- Publishers: writer role to push artifacts.
- Consumers/verifiers: reader role to pull and (where needed) query attachments/metadata.

10. Runtime Consumption (OPA) Configuration

Verify-before-use enforcement sequence

- Resolve digest → construct SUBJECT
- cosign verify (gate)
- Pull bundle by digest (or use local bundle) only after verify
- opa eval

11. Evidence Configuration

Evidence files per run (minimum set) store under evidence/<run_id>/:

- bundle.sha256.txt
- descriptor.json (subject descriptor with digest)
- referrers.json
- cosign-verify.json
- opa-eval.json (OPA decision outputs)
- run.json (summary record)

```
run,status,evidence_completeness_score,has_timestamp,has_bundle_digest,has_signature_path,has_public_key_path,
1765808422,WARN,0.8571428571428571,True,True,True,True,True,False,,True,True,True
1765808424,FAIL,0.7142857142857143,True,True,False,True,False,,True,True,True,True,True
1766466705,WARN,0.8571428571428571,True,True,True,True,True,True,False,,True,True,True
1766466708,FAIL,0.7142857142857143,True,True,False,True,False,,True,True,True,True,True
1766472201,WARN,0.8571428571428571,True,True,True,True,True,True,False,,True,True,True
1766472204,FAIL,0.7142857142857143,True,True,False,True,False,,True,True,True,True,True
1766473787,WARN,0.8571428571428571,True,True,True,True,True,True,False,,True,True,True
1766473790,FAIL,0.7142857142857143,True,True,False,True,False,,True,True,True,True,True
1766473795,WARN,0.8571428571428571,True,True,True,True,True,True,False,,True,True,True
1766473798,FAIL,0.7142857142857143,True,True,False,True,False,,True,True,True,True,True
1766473802,WARN,0.8571428571428571,True,True,True,True,True,True,False,,True,True,True
1766473804,FAIL,0.7142857142857143,True,True,False,True,False,,True,True,True,True,True
1766474049,WARN,0.8571428571428571,True,True,True,True,True,True,False,,True,True,True
1766474052,FAIL,0.7142857142857143,True,True,False,True,False,,True,True,True,True,True
1766474119,WARN,0.8571428571428571,True,True,True,True,True,True,False,,True,True,True
1766474121,FAIL,0.7142857142857143,True,True,False,True,False,,True,True,True,True,True
```

Evidence schema (recommended) run.json should include at least:

- Timestamp (UTC)
- Tool versions (opa/oras/cosign + cloud CLI used)
- Bundle digest (local file digest)
- Registry subject digest (manifest digest)
- Signature verification outcome (pass/fail + signer info if available)
- Referrers discovered (count + identifiers)
- OPA evaluation query, inputs (hashes), outputs (decisions)
- Exit codes and stderr summaries on failure

audit_summary.json

matrix_out > audit_summary.json > ...


```json
{
  "runs_total": 16,
  "status_counts": {
    "WARN": 8,
    "FAIL": 8
  },
  "pass_rate": 0.0,
  "warn_rate": 0.5,
  "fail_rate": 0.5,
  "unique_bundle_digests": 8,
  "bundle_digest_counts": {
    "sha256:8c771596433efbe8c2881d9124d082a00ae7b91964e8bf26bae625d673dfe18b": 2,
    "sha256:fe1426e9a9af1fb6212635bedc008ee3ae1e4bbd28edb1c39c688783f7f9e107": 2,
    "sha256:fe44551208e35cbae419092240a417f95436a601451b6655c59d3ed2a903f61d": 2,
    "sha256:f86869a2d6be238a0ee87dd72f52b43aed0ac37b6cbf0c93f22123f82c745f7c": 2,
    "sha256:105ac2968ca2e1c1692ace621e91a6cc170504f2ad03f9284da800364973c566": 2,
    "sha256:8a81afc8df5f3b8a64ea1756b7f37fa44d6ff116e948308bf73ff6ec100fba74": 2,
    "sha256:065c50f32ee49c1a97316a17d366d58f639a24d71a39cc956e8917a79e7786c7": 2,
    "sha256:b889187eb7a0797a13a71e7a7bf4e1e552ad72f2a2bcacc496083f5d8d9959b0": 2
  },
  "avg_evidence_completeness": 0.7857142857142857,
  "tamper_expected_rate": 1.0,
  "opa_sanity_pass_rate": 1.0,
  "verify_ok_rate": 1.0,
  "private_key_path_logged_rate": 1.0
}
```


12. References

- Open Policy Agent Documentation Bundles (management bundles) and OCI registry usage
- Open Policy Agent Documentation OPA configuration example using services: type: oci for downloading bundles from OCI repositories
- ORAS Documentation oras discover command (referrers discovery; documented as preview/under development)
- Microsoft Learn (Azure Container Registry) Managing OCI/supply-chain artifacts with ORAS; explains referrers API usage and oras discover for reference graphs
- Open Containers Initiative OCI Image & Distribution Specs v1.1 release notes; describes the referrers API endpoint and the subject/artifactType model
- Open Containers Initiative OCI Distribution Specification project (registry API standardization)
- Sigstore Cosign Cosign overview and offline verification notes (bundle materials /annotation behavior)
- Sigstore Docs Cosign "Signing Other Types"; signatures stored as OCI artifacts in registries

- AWS Open Source Blog OCI 1.1 support in Amazon ECR; explains subject field and the referrers API in the registry context
- Red Hat Blog OCI 1.1 Referrers API overview and interoperability/security benefits