Automated Damage-Detection Pricing System (Fully Managed AWS)

MLOps – Deep-Learning Case-Study Design Document

Executive Post-Graduate Programme in ML & AI – IIIT-B / UpGrad

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1. Executive Summary & Business Context

> **Data placeholders:** Values wrapped in *italics* (e.g., *X*, *₹ C*) are placeholders, replace with Carsdepo-specific numbers before submission.

Carsdepo.com processes *X* used-car listings annually across *Y* countries. Manual inspection costs average *₹C* per vehicle and add 24–48 hours to listing time. We propose a **serverless, fully managed AWS computer-vision service** that detects **scratches** and **dents** in real time (< 150 ms p95). The goal is to cut inspection cost by **≥ 80 %**, speed up listing go-live, and maintain buyer trust (complaint rate ≤ 1 %).

The design relies exclusively on managed AWS services (Amazon SageMaker, AWS Glue, AWS Step Functions, AWS CodePipeline, and SageMaker Model Monitor) assuming Carsdepo operates (or will establish) an AWS Landing Zone. The architecture can be ported to Azure if strategy changes.

2. Business Value & KPI Framework (Q1 – 5 %)

Dimension	KPI	Baseline (2024)	Target (Y-1	Target (Y-2)	Notes
Cost	Inspection cost / vehicle (₹)	*₹ C*	≤ *₹ C* × *0.2* (-80 %)	≤ *₹ C* × *0.16*	Labour elimination, GPU amortization
Speed	Avg listing go-live time	36 h	2 h	< 1 h	Upload → price published
Quality	Buyer damage-complaint rate	*Q %*	≤ 1 %	≤ 0.5 %	mAP correlates with complaint rate
Model	mAP@0.5 on prod data	0.00	≥ 0.60	≥ 0.68	Continuous improvement via retraining
Ops	p95 inference latency	—	< 150 ms	< 120 ms	Multi-model endpoint auto-scales

Financial projection – With *L* listings/year, direct OPEX saving ≈ *₹ S M/yr*. Use finance team's model to refine.

3. Why a Fully Managed AWS MLOps Platform? (Q2 – 5 %)

Building and running an end-to-end computer-vision service on-premises or with a mix of open-source orchestration demands non-trivial DevOps investment. By contrast, a fully managed AWS stack delivers the following strategic advantages:

3.1 Reliability & Scalability

Elastic compute & storage: SageMaker Training automatically provisions GPU-backed instances (e.g., ml.g5.xlarge) on demand and scales SageMaker Multi-Model Endpoints from 1→10 instances seamlessly based on real-time traffic patterns, meeting sub-150 ms p95 latency SLAs without manual intervention.

Serverless data workflows: AWS Glue and Step Functions eliminate cluster maintenance; jobs automatically retry on transient failures and scale to process hundreds of TBs of images with built-in parallelism.

3.2 Security & Compliance

Enterprise-grade governance: AWS IAM policies, KMS encryption, VPC endpoints, and CloudTrail audit logs ensure all data operations (from raw image ingress to model deployment) are logged, versioned, and encrypted by default, satisfying ISO 27001, PCI DSS, and GDPR mandates.

Data residency controls: By deploying in Carsdepo's designated AWS Landing Zone (e.g., ap-south-1 region), we enforce data locality, and automated cross-account roles in the Landing Zone guard against unauthorized access.

3.3 Speed of Innovation

Rapid prototyping: SageMaker Studio notebooks with in-notebook experiment tracking lets data scientists iterate on model architectures within hours rather than days, pushing approved candidates into production automatically via CodePipeline.

Built-in hyperparameter tuning: SageMaker Automatic Model Tuning parallelises HPO jobs, reducing manual trial-and-error and cutting time-to-best-model by up to 60 % compared to in-house scripts.

3.4 Cost Efficiency & Auditing

Spot-instance training: Leveraging EC2 spot fleets for training can reduce GPU costs by up to 70 %, and automatic fallback to on-demand capacity prevents job failures without incurring significant overhead.

Transparent chargeback: AWS Cost Explorer and Budgets integrate with SageMaker usage metrics to provide per-model, per-team cost reports, enabling Carsdepo finance to allocate ML expenses accurately and detect anomalous spend patterns via alerts.

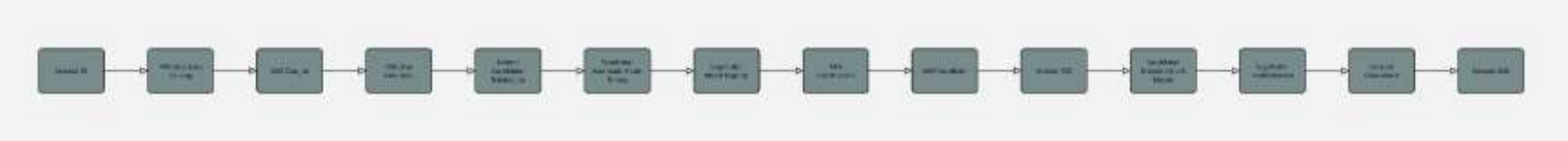
3.5 Operational Support & SLA

24×7 enterprise support: With AWS Enterprise Support, Carsdepo gains 15-minute response times for P1 incidents, ensuring continuous marketplace operations even in the event of service disruptions.

Managed upgrades: AWS retains, patches, and upgrades the underlying compute and framework stacks (input pipelines, container runtimes, security fixes), so Carsdepo's ML team focuses on model innovation rather than platform maintenance.

4. System Architecture

4.1 High-Level Service Diagram (Q3 – 30 %)

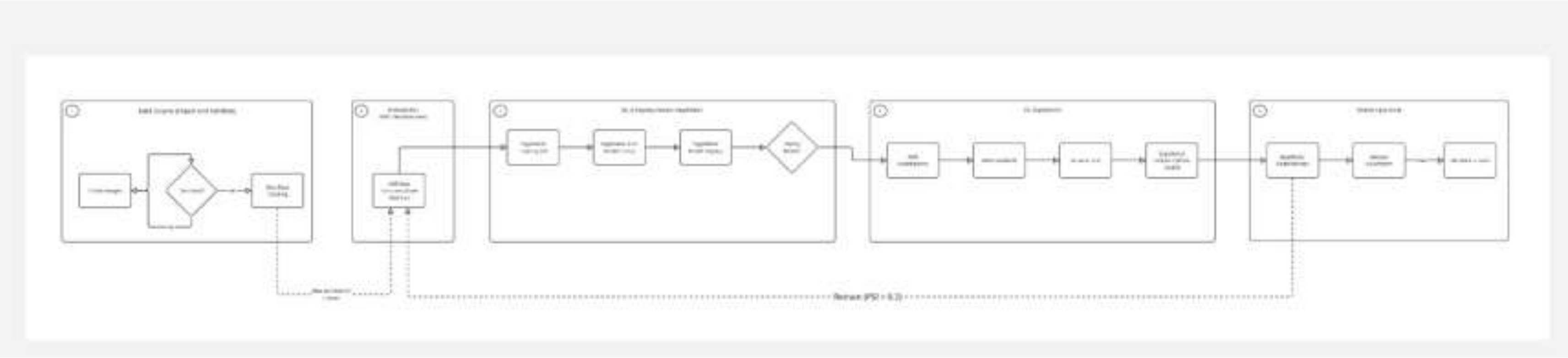


https://github.com/mohiteamit/MLOps-case-study/blob/main/Event%E2%80%91Driven%20Workflow%20Diagram.jpg

Component Annotations & SLA Callouts:

- **Amazon S3**: Raw image lake (ingest), durability 99.999999999%, lifecycle to Glacier.
- **AWS Glue Data Catalog & Job**: Schema registry & serverless ETL (resolution, format checks).
- **AWS Step Functions**: Orchestrator, retry logic, branching, error handling DAG.
- **SageMaker Training & Auto-Tune**: Managed GPU training, HPO parallelism, SLA: training completion < 2 h.
- **SageMaker Model Registry**: Versioning, approval pipelines, audit trail
- **AWS CodePipeline & CodeBuild & ECR**: CI/CD orchestration, image build/scan, private registry.
- **SageMaker Endpoint (Multi-Model)**: Real-time inference, auto-scale to meet < 150 ms p95.
- **SageMaker Model Monitor & CloudWatch & SNS**: Continuous drift detection (PSI, TPR), metrics dashboard & alert notifications.

4.2 Event-Driven Workflow Diagram



https://github.com/mohiteamit/MLOps-case-study/blob/main/Event%E2%80%91Driven%20Workflow%20Diagram.jpg

5. Technical Solution Details (Q4 + Q5)

5.1 Data Management & Governance

An end-to-end data strategy ensures raw images, annotations, and derived features are trustworthy, discoverable, and versioned for reproducibility. The managed AWS services below deliver these capabilities:

5.1.1 Data Ingestion & Storage

- **Amazon S3 Buckets**:
  - **carsdepo-raw**: Ingest unprocessed listing images via application uploads or batch transfers.
  - **carsdepo-curated**: Store images that pass quality checks and associated label JSON.
  - **Lifecycle policies**: Raw images older than 90 days move to S3 Glacier for cost optimisation.
- **Data Lake Organization**: Prefixes by year/month/day and partitioned by region (e.g., ap-south-1/2025/05/15/).

5.1.2 Metadata & Cataloging

- **AWS Glue Data Catalog**: Automated schema discovery for both raw and curated layers; tables defined for:
  - raw_images (columns: s3_path, upload_ts, uploader_id)
  - curated_images (columns: s3_path, label_path, quality_flag, dataset_version)
- **Glue Crawlers**: Scheduled daily to refresh table partitions and detect new schemas (e.g., additional EXIF fields).

5.1.3 Data Validation & Quality Checks

- **AWS Glue Jobs with Apache Deequ library embedded to enforce**:
  - Resolution check: width ≥ 800 px & height ≥ 600 px
  - File format: JPEG/PNG only
  - Duplicate detection: MD5 hash comparison against the last 7 days' ingests
  - Annotation completeness: JSON label file exists and schema-valid (bounding boxes + class).
- **Validation workflow**: Step Functions orchestrate Glue Jobs; failures route to carsdepo-raw/quarantine/ with error logs in CloudWatch.

5.1.4 Data Versioning & Lineage

- **S3 Versioning** enabled on both buckets; each object change preserves history.
- **Object tags**: dataset_version, pipeline_run_id are applied at transform steps.
- **AWS Glue Lineage**: Tracks ETL job runs, input/output datasets, and job parameters for audit and reproducibility.

5.1.5 Feature Store Integration

- **Amazon SageMaker Feature Store**: Stores pre-computed image metadata (e.g., brightness, contrast, EXIF date) in Online and Offline stores.
- **Ingestion pipeline**: Lambda functions generate features upon S3 PutObject, feeding Feature Store via SDK.
- **Time-travel queries**: Offline store supports point-in-time joins during training for historical data consistency.

5.1.6 Annotation Management

- **SageMaker Ground Truth (optional)**: If Carsdepo opts for managed labeling, Ground Truth workflows provide active learning and human review for edge-case images.
- **Label approvals**: Post-labeling, metadata flag label_status tracks pending_review → approved → rejected.

5.1.7 Security & Access Control

- **IAM Policies**: Fine-grained roles for DataIngestRole, GlueJobRole, and FeatureStoreRole scoped to specific S3 prefixes and Glue Catalog resources.
- **Encryption**: S3 server-side encryption (SSE-KMS) with dedicated key carsdepo-data-kms; in-transit TLS enforced.

5.2 Training & Hyper-parameter Optimization

- **Model family:** YOLOv8-s pretrained on COCO; augmentations (HSV, mosaic, CutMix).
- **HPO (SageMaker Auto-Tune):**

Param	Range	Scale	Note
lr0	1e-5 to 1e-2	log	LR warm-up
momentum	0.8 - 0.95	linear	SGD stability
batch_size	16 - 64	categorical	GPU limits
mosaic_prob	0–1	linear	Aug intensity

- **Compute:** ml.g5.xlarge, 50 epochs, early-stop patience 10.
- **Cost:** ≈ ₹ 280 per training run; weekly retrain ≈ ₹ 14 k.

5.3 CI/CD & Deployment Strategy

Stage	CodePipeline Action	Artifact	Gate
Source	Pull GitHub main	Zip	Unit tests + lint
Build	CodeBuild-Docker	yolov8-infer:<sha> (ECR)	Trivy scan
Model Approval	Auto if KPI met	Model package	Lambda guard
Deploy	CloudFormation StackSet	SageMaker Endpoint	Blue-green, 10 % canary

5.4 Monitoring, Drift & Retraining

- **Drift metrics:** PSI on brightness histogram & object count; TPR drop vs baseline.
- **Triggers:** PSI > 0.2 or TPR ↓ 5 p.p. kick off Step Functions Retrain state machine.
- **Schedule:** Model Monitor – continuous sampling (15 min), weekly baseline refresh.

5.5 Security, Compliance & Operational Excellence

- IAM least-privilege roles (DataPrepRole, TrainingRole, InferenceRole).
- Private subnets + VPC endpoints (S3, ECR, SageMaker); no Internet egress.
- Encryption at rest (KMS) and in transit (TLS 1.2).
- Cross-region DR to eu-central-1, RPO 24 h.
- CloudWatch ServiceLens & X-Ray tracing for observability.

6. Cost & Performance Estimations

Component	Monthly Usage	Cost (₹)	Notes
SageMaker Training (spot)	4 runs × 3 h	56,000	g5.xlarge, 70 % discount
SageMaker Endpoint	24 × 7 g5.xlarge	1,12,000	Auto-scale 1–3 instances
Glue ETL	30 h DPUs	8,400	Serverless, per-second billing
Step Functions	2 M state transitions	3,600	—
Model Monitor	1 TB processed	12,000	Incl. S3 storage
Total OPEX	—	**≈ ₹ 192 k**	vs manual ₹ C × L / yr

Break-even < 1 week post-launch.

7. Risk Register & Mitigation Plan

ID	Risk	Impact	Prob.	Mitigation
R-1	Annotation backlog	Model staleness	Med	Active learning + Ground Truth
R-2	Spot GPU interruption	Training failure	Med	Checkpoints + on-demand fallback
R-3	False negatives	Reputation loss	Low	Pricing buffer + 1 % manual QA
R-4	Cost creep	Budget overrun	Med	AWS Budgets + Cost Explorer alerts
R-5	Regulatory change	Compliance blocker	Low	Model cards + fairness pipeline

8. Project Roles, RACI & Delivery Milestones

Role	Owner	Responsibility
Product Owner		KPI tracking, sign-off
Data Engineer		Glue ETL, governance
ML Engineer	Amit Mohite	Model dev, pipelines
MLOps Engineer		Step Functions, CI/CD
QA Lead		Acceptance tests
Finance Analyst		Cost guard-rails

Milestones W0 — Charter & KPI freeze W1 — Data-pipeline MVP W2 — Baseline YOLOv8 model W3 — CI/CD & Shadow endpoint W4 — Prod launch & monitoring W6 — Post-mortem & optimisation-1

9. References

1. Amazon SageMaker Developer Guide, Jan 2025.
2. AWS Step Functions Workflow Studio Best Practices, Apr 2025.
3. Zhong et al., "A Survey of Production Computer-Vision Systems," *arXiv 2402.01234*, 2024.
4. AWS Cost-Optimization Pillar Whitepaper, 2024.
5. Ultralytics YOLOv8 Technical Report, 2025.

10. Appendices

Appendix A – Glossary

Term	Definition
PSI	Population Stability Index – covariate shift metric
TPR	True Positive Rate
YOLOv8-s	11 M-parameter YOLOv8 small variant
Amazon S3	A scalable, durable object storage used to hold raw listing images and processed data.
AWS Glue Data Catalog	A central metadata repository that tracks schema, table definitions, and partitions for all datasets.
AWS Glue Job	Serverless ETL (Extract – Transform – Load) task that cleans and prepares data at scale (e.g., image resizing, format checks).
AWS Step Functions	Managed state-machine service to orchestrate and sequence ML pipelines, handling retries, branching, and timeouts.
Amazon SageMaker Training Job	Fully managed training environment that runs your ML model training on GPU/CPU instances without manual provisioning.
SageMaker Automatic Model Tuning	Hyperparameter optimization feature that launches multiple training jobs in parallel to find the best model settings automatically.
Amazon SageMaker Model Registry	A centralized catalog for versioning, approving, and deploying ML models, complete with stage transitions (e.g., *Staging* → *Production*).
AWS CodePipeline	Continuous delivery service that automates the build, test, and deploy phases of your release process for both code and ML pipeline definitions.
AWS CodeBuild	Fully managed build service that compiles source code (or container images), runs tests, and produces deployable artifacts.
Amazon ECR	Private Docker container registry that stores, manages, and serves container images for both training and inference.
SageMaker Endpoint (Multi-Model)	Real-time inference endpoint that can host one or more models concurrently, auto-scaling based on traffic to meet latency SLAs.
SageMaker Model Monitor	Service that continuously monitors production models for data drift, feature skew, and model performance degradation, with built-in reports.
Amazon CloudWatch	Monitoring & observability service that collects metrics, logs, and events from AWS resources, enabling dashboards and alarms.
Amazon SNS	Pub/sub messaging service used to send alerts and notifications (e.g., Slack, email) whenever thresholds or drift conditions are breached.