



QUALITY MANUALS | FIRST EDITION

IAF IN LINE QUALITY AND COMPUTER VISION MANUAL

Reliable automated inspection
through validated evidence

STABLE RELEASE

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Press cracks and weld and paint inspection
Optical calibration and decision tolerances
Model validation and controlled line release

International Automotive Federation

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Publication identity and use

IAF In Line Quality and Computer Vision Manual

This manual provides the requirements, operating procedures and evidence framework for the defined supplier assurance, automated inspection or automotive service activities. Apply it through a controlled site implementation plan and equipment-specific work instructions.

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Reading and applying requirements

“Shall” identifies a requirement when adopted by a site, programme or agreement. “Should” identifies a recommendation. An example is illustrative; it is not a machine setting, test acceptance limit or completed operating record. Annex worksheets may be reproduced for controlled internal use.

Controlled implementation

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Contents

Every entry links to its section. Page numbers include the cover.

1 Purpose and inspection scope	5
2 Definitions and decision boundaries	6
3 Accountability and authorization	7
4 Application requirements and feasibility	8
5 Defect taxonomy and reference parts	9
6 Camera optics and image formation	10
7 Illumination geometry and environmental control	11
8 Geometric calibration and independent verification	12
9 Measurement uncertainty and decision tolerances	13
10 Press crack and forming defect inspection	14
11 Weld and joint inspection	15
12 Paint surface and appearance inspection	16
13 Image collection and label quality	17
14 Dataset separation and representative coverage	18
15 Model development and configuration control	19
16 Validation plan and statistical evidence	20
17 Performance measures and error interpretation	21
18 Threshold and review band approval	22

Contents - continued

Every entry links to its section. Page numbers include the cover.

19 Line integration and reject confirmation	23
20 Installed station qualification and release	24
21 Start of shift and reference challenge checks	25
22 Drift monitoring and ongoing verification	26
23 Inspection failure and suspect product containment	27
24 Human review and controlled overrides	28
25 Changes retraining and revalidation	29
26 Cybersecurity privacy and evidence protection	30
27 Audit metrics and management review	31
28 Implementation and continuing control	32
Annex A Station specification and tolerance matrix	33
Annex B Calibration and intermediate verification record	34
Annex C Defect catalogue and reference control	35
Annex D Dataset and model release record	36
Annex E Worked validation and tolerance examples	37
Annex F Shift challenge and line audit checklist	38
Annex G Failure containment and recovery worksheet	39
Annex H Implementation and IAF document interfaces	40

Using the annexes

Enter actual values, evidence references, names and dates in the worksheets. A blank, unsigned or illustrative record is not proof of completion. Retain the record with its governing instruction and revision.

1 Purpose and inspection scope

1.1 This manual controls the design, calibration, validation, operation and audit of camera-based automotive inspection. It covers press surface cracks, visible weld anomalies, paint defects, dimensional image measurements and their connection to production release. The adopting site shall define every product family, inspection station, characteristic and operating condition within scope.

1.2 The objective is a trustworthy decision for the correct physical part, supported by suitable images, validated methods and confirmed segregation of nonconforming output. A high model score or a successful laboratory demonstration is insufficient. The complete installed application includes illumination, optics, fixtures, triggering, software, interfaces and the reject or hold mechanism.

1.3 The system shall distinguish conforming, nonconforming and indeterminate results. Missing images, unknown variants, uncertain identity, incomplete coverage and invalid calibration shall produce the defined hold or safe fallback response. They shall not be silently converted into a pass to maintain throughput.

1.4 Product acceptance limits come from the approved engineering and appearance requirements. This manual defines how to establish and verify inspection tolerances; it does not create one crack size, weld limit, paint score, pixel count or confidence threshold suitable for every part. Each activated station requires its own approved acceptance and validation matrix.

1.5 Use this manual with IAF production, supplier quality, OT cybersecurity and document-control requirements. An inspection camera shall not be credited as a personnel safety device unless the complete safety function has been separately designed and validated for that purpose. Product inspection performance and machinery safety are separate engineering responsibilities.

2 Definitions and decision boundaries

2.1 A defect is a departure from a specified requirement. An anomaly is an unexpected pattern that may or may not be a defect. Classification assigns a category; detection locates an object or indication; segmentation identifies image regions; metrology estimates a physical quantity. Validation shall match the actual decision being made.

2.2 Calibration establishes a relationship between the measurement system and a suitable reference under stated conditions. Verification checks whether specified performance is met. Validation demonstrates fitness for the intended use. Camera calibration, measurement-system suitability and model validation are related but distinct activities; completing one does not complete the others.

2.3 Ground truth is the independently established reference decision used in evaluation. It shall include the method, assessor and uncertainty or disagreement. A model prediction copied into a label is not independent truth. Some internal defects require a different physical test to establish their presence.

2.4 A false accept occurs when nonconforming product is passed. A false reject occurs when conforming product is rejected. An indeterminate result is held for a validated alternative decision. Define denominators and the unit of analysis: part, joint, image or defect instance. One part may contain many images and several defects.

2.5 The operating envelope is the validated range of parts, materials, finishes, poses, speeds, lighting, environment and configurations. Data outside that envelope require the prescribed hold or alternative inspection. A model output expressed between zero and one is not automatically a calibrated probability of product conformity.

3 Accountability and authorization

3.1 Product Engineering owns the required characteristics, defect definitions and product acceptance limits. Quality owns inspection strategy, release criteria, nonconforming product and independent acceptance of validation evidence. Manufacturing Engineering owns the installed station, fixtures, line timing and mechanical segregation. The Production owner provides resources for the approved reaction plan.

3.2 The metrology lead owns reference artefacts, calibration methods, measurement uncertainty and verification intervals. The vision engineer owns optics, illumination, software recipes and model implementation. The data owner controls image provenance, labelling, access and approved use. A model developer shall not be the sole independent approver of its validation.

3.3 OT Security owns access, network boundaries, controlled remote support and recovery arrangements. Maintenance acts within released instructions and records any adjustment that could affect inspection. Operators execute start-up checks, respond to alarms and protect product identity; they shall not change thresholds to clear a backlog.

3.4 Authorized human reviewers require defect-specific competence and access to sufficient evidence. They may not override an indeterminate decision outside their delegated technical scope. A difficult structural indication may need a specialist test, not a supervisor's visual opinion. Record the rationale and evidence for each permitted override.

3.5 The site shall publish a responsibility and escalation matrix for calibration failure, missed defects, reject-system faults, data loss and suspected manipulation. All personnel may raise a concern. Conflicts, complaints, privacy and protected disclosures follow the applicable IAF policies without suppressing immediate product containment.

4 Application requirements and feasibility

4.1 Before purchasing equipment or training a model, define the inspected features, defect classes, minimum relevant defect boundaries, surface zones, functional consequences and production mix. Specify whether the output is advisory, an inspection gate or one component of a combined decision. State what the system cannot observe.

4.2 The application specification shall include field of view, working distance, depth variation, part speed, pose range, cycle time, environment, cleaning method and expected changes. Establish image coverage for edges, curved surfaces, joints and occluded regions. A convenient camera location shall not determine which required features are ignored.

4.3 Assess feasibility using representative good, defective and borderline parts across actual finishes, suppliers, colours and tools. Include contamination, reflections, motion and normal variation. Demonstrate sufficient information in the image before relying on more model complexity. No algorithm can reliably recover a defect that the optical arrangement does not reveal.

4.4 Define required false-accept and false-reject performance by defect class and consequence, acceptable indeterminate rate, latency and segregation reliability. Agree the statistical evidence and confidence required before the study. Production economics may inform false-reject objectives but shall not override mandatory conformity requirements.

4.5 Record the approved specification, unresolved limitations and alternative inspection route. If a required defect is not observable, retain a suitable complementary method or change the process. Annex A provides the station requirement and tolerance matrix; its values must be established for the actual application.

5 Defect taxonomy and reference parts

5.1 Engineering and Quality shall maintain a defect catalogue with names, mechanisms, affected zones, severity, required limits and reference evidence. Separate a harmless surface feature from a functionally relevant indication. Define how combined defects, borderline conditions and multiple indications on one part affect the final decision.

5.2 Reference parts shall represent both sides of the acceptance boundary and normal production variation. Identify part revision, material, finish, defect location, physical condition and the independent method used to characterize it. Preserve photographs and measurements that allow deterioration or accidental substitution to be detected.

5.3 Known-good and known-defective artefacts shall be clearly controlled, stored appropriately and prevented from entering saleable production. Artificially introduced indications may test an optical response but shall not automatically substitute for natural production defects. Demonstrate whether their appearance and physical significance are representative.

5.4 Where experts disagree, record the disagreement, obtain technical adjudication and retain an uncertain category until resolved. Do not force disputed examples into convenient labels to improve a metric. Validation reports shall identify how uncertain cases were treated and whether excluding them limits the supported scope.

5.5 Review reference sets after design, material, supplier, finish or defect-mechanism changes. Periodically inspect their condition and reconfirm their assigned status. A scratched or faded master can shift production decisions even when the software remains unchanged. Annex C captures the defect catalogue and reference-control record.

6 Camera optics and image formation

6.1 Select sensor, lens and acquisition mode for the required object detail, contrast, field of view, depth range and line speed. Record pixel dimensions, magnification, focus, aperture, working distance, exposure, gain and relevant filters. Nominal sensor resolution alone does not establish defect detectability or measurement accuracy.

6.2 Estimate object sampling as field width divided by the corresponding image pixels, then verify across the actual field and depth. The smallest relevant indication shall occupy enough informative pixels for the validated task. Blur, contrast, sensor noise, demosaicing and lens distortion can dominate performance even when a sampling calculation appears adequate.

6.3 Control perspective and depth effects with suitable fixturing, optics or calibrated three-dimensional methods. A single scale factor shall not be applied across a tilted or varying-depth surface without validation. Define the coordinate frame and datum relationship for each dimensional result.

6.4 Motion blur shall be assessed at the maximum permitted speed and relevant exposure. Synchronize lighting, camera trigger and part position. Rolling readout, vibration and asynchronous acquisition can distort moving geometry. Test worst-case timing and motion in the installed system rather than relying only on stationary reference images.

6.5 Protect lenses, windows and mounts from contamination, damage and unauthorized adjustment. Mark controlled settings where useful and maintain configuration records. A replacement lens with the same catalogue description may still require recalibration and validation of the actual installed optical path.

7 Illumination geometry and environmental control

7.1 Illumination shall reveal the relevant defect while controlling nuisance variation. Select direction, diffusion, polarization, wavelength and intensity through application trials. Reflective metal, textured welds and glossy paint may require different arrangements; a lighting recipe suitable for one surface family shall not be assumed suitable for another.

7.2 Define and control ambient-light exclusion, reflections, shadows, part orientation and background. Record the permitted range of image brightness, saturation, contrast or another validated quality indicator. These limits shall protect the task; a visually attractive image is not necessarily the most reliable inspection image.

7.3 Assess light-source ageing, heat, vibration, lens contamination, protective-window damage and cleaning residue. Cleaning instructions shall identify the material, method, safe access and post-cleaning check. A maintenance action that moves the camera or changes optical transmission shall trigger the appropriate verification before release.

7.4 For multiple exposures, views or three-dimensional scans, verify registration and complete coverage. Prevent a missing view from being replaced by a previous part's image. If exposure or gain adjusts automatically, define its permitted range and validate the resulting decision performance across that range.

7.5 Monitor environmental conditions relevant to performance and provide alarms with an actionable response. Where measurements depend on thermal expansion or surface condition, include the effect in the uncertainty and acceptance decision. The operating envelope shall state when environmental variation requires hold, recalibration or independent inspection.

8 Geometric calibration and independent verification

Owner: authorized metrology or vision specialist. Trigger: initial installation, defined interval, equipment change, disturbance or failed verification. Use a method suitable for the actual two-dimensional or three-dimensional measurement.

Step / owner	Required action and evidence
1 Establish conditions	Identify station, camera, lens, mount, fixture, software and coordinate frame. Stabilize the required environment and verify clean optics, focus, exposure and permitted part position.
2 Verify the reference	Confirm artefact identity, calibrated dimensions or justified reference values, uncertainty, condition and suitability for field and depth. Record the reference evidence and validity.
3 Acquire the calibration	Use the controlled method and required positions or views. Preserve images, parameters and fitting results. Cover the intended measurement region rather than only the image centre.
4 Inspect residuals	Assess local and overall residual errors, coverage and implausible results. Investigate failed points. Do not discard unfavourable points without a documented technical cause and repeat evidence.
5 Verify independently	Measure separate known features or positions not used to fit the calibration. Include field edges, depth variation and representative production conditions. Compare with pre-agreed error limits.
6 Release or hold	Record configuration, results, uncertainty, decision, approver and next check. If unsuccessful, block affected measurement release and assess product since the last valid state.

A low fitting residual alone does not demonstrate independent measurement accuracy or defect detection. Annex B captures calibration and verification; model and complete-station validation remain separate requirements.

9 Measurement uncertainty and decision tolerances

9.1 For each measured characteristic, define the measurand, unit, specification limits, uncertainty and acceptance rule. Consider reference uncertainty, sampling, optics, calibration residuals, part pose, thermal effects, edge extraction and repeatability. Evaluate contributions under production conditions; a calibration certificate alone is an incomplete uncertainty assessment.

9.2 Use a documented decision rule where measurement uncertainty affects conformity. One conservative rule accepts a result only when the full stated uncertainty interval lies within the specification. Results near a boundary may require a hold and more capable evaluation. The approved rule shall state its risk basis and treatment of equality at the limits.

9.3 Keep geometric tolerances separate from classifier thresholds. A crack-width limit expressed in millimetres is a product requirement; a model score threshold is a decision parameter. There is no universal conversion between them. Validate detection performance for known defect sizes, orientations and contrasts around the relevant boundary.

9.4 For qualitative appearance decisions, control viewing conditions, zone definitions and adjudicated references. Evaluate repeatability between reviewers and the automated system. When multiple defects combine into one part decision, validate that logic and preserve the contributing measurements or classifications.

9.5 No threshold, mask, region of interest or uncertainty allowance may be changed locally to turn failing parts into passes. Changes require technical justification, independent approval and revalidation proportionate to impact. Annex A records approved limits; Annex E illustrates a guarded measurement decision without prescribing a production tolerance.

10 Press crack and forming defect inspection

10.1 The press inspection specification shall distinguish open cracks, edge splits, thinning indications, wrinkles, scratches, dents and harmless material texture. Engineering shall define the relevant zones and consequences. A two-dimensional surface image does not directly establish remaining thickness or subsurface integrity unless the proposed inference has been independently validated.

10.2 Validate image coverage of trimmed edges, draw radii, holes, flanges and curved regions where relevant defects occur. Challenge different crack orientations, opening widths, lengths and locations, including indications near highlights or shadows. Include normal oil, surface texture, material grades and permitted tool-related variation.

10.3 Associate each inspected piece with coil or blank lot, press, die, cavity where applicable, stroke or batch context and inspection recipe. Where individual identity is impracticable, the control plan shall define an adequate batch boundary and containment method. Lost synchronization between strokes and images shall trigger a hold.

10.4 Confirm indications with suitable independent evidence during validation and investigation. Retain difficult good parts and natural defective parts for future challenge sets. A simulated dark line is not automatically equivalent to a narrow physical crack, especially where reflection changes with viewing direction.

10.5 The reaction plan shall address tool wear, lubrication changes, material variation and repeated localized defects. Stop or restrict affected production, establish the suspect boundary and involve process engineering. Releasing a part after sanding, cleaning or reimaging requires a controlled disposition; repeated acquisition shall not be used to search for an accidental pass.

11 Weld and joint inspection

11.1 The weld inspection plan shall identify joint type, material, geometry, visible features and required internal or mechanical properties. Camera inspection may evaluate presence, position, continuity, surface profile, spatter or other observable indications. A visually regular bead or indentation does not by itself demonstrate penetration, fusion, nugget size or joint strength.

11.2 Engineering shall specify complementary verification where internal integrity or mechanical performance cannot be established optically. Link destructive or other suitable test samples to the actual process settings and joint population. The camera system shall not claim coverage of an internal defect merely because it was trained on external images with weak correlations.

11.3 For each joint family, validate surface variation caused by coating, oxidation, heat tint, consumables, electrode condition, access angle and permitted geometry. Include missed joints, displaced joints, interrupted seams and plausible borderline conditions. Verify coverage around occlusions and robot fixtures at the actual inspection stage.

11.4 Associate the result with part, joint identifier, weld station, process programme and production event. Where a part contains many welds, maintain a complete required-joint list. A missing image or unexecuted joint shall not disappear from the denominator because no detection was returned.

11.5 The disposition route shall define when an optical anomaly requires specialist review, process testing, rework or rejection. Any additional weld or repair shall use an approved engineering instruction and receive appropriate reinspection. The original failed image and decision shall remain linked to the final release record.

12 Paint surface and appearance inspection

12.1 The paint catalogue shall define relevant defect types such as inclusions, runs, craters, pinholes, scratches, colour mismatch and texture variation. State inspection zones, finish families, severity boundaries and the required observation conditions. A customer-visible outer panel may have different acceptance requirements from a concealed surface.

12.2 Control reflections and illumination geometry for curved glossy panels. Validate each colour, metallic or special-effect finish and permitted texture range. A model trained mainly on one dark finish shall not be released for a bright metallic family without adequate evidence. Environmental light and protective films shall be included in the operating envelope.

12.3 Where colour, gloss or texture is a physical acceptance quantity, use a suitable calibrated method with defined geometry and conditions. An ordinary camera's colour values are not automatically a traceable colour measurement. Establish how automated findings are correlated with the approved appearance assessment and how disagreements are adjudicated.

12.4 Preserve panel and body identity, paint batch where required, booth or process route, cure status and inspection configuration. Distinguish removable contamination from a paint defect through an approved handling and reassessment method. Cleaning shall not damage the surface or erase evidence needed to investigate recurring process failures.

12.5 Rework decisions shall address permitted polishing, local repair, repainting and repeated processing limits. Verify final appearance and any relevant functional properties after the approved repair. A reduced defect score alone is insufficient if film integrity, geometry or another required property has been compromised.

13 Image collection and label quality

13.1 The data collection plan shall sample the actual production distribution and deliberately obtain meaningful rare and borderline defect examples. Record station, part family, revision, material, finish, tool, shift, date, configuration and independent inspection outcome. Capture failures and indeterminate cases as well as obvious successes.

13.2 Labels shall follow the controlled defect catalogue and identify the decision unit. For detection or segmentation, define annotation boundaries and treatment of partial, overlapping or uncertain indications. Train labelers and assess agreement using blinded repeated samples. Resolve disagreements through a competent adjudicator independent of the model output where practicable.

13.3 Do not label all rejected production as a specific defect without confirming the cause. A rejection may arise from a missing image or another station. Keep process status, expert judgement and physical test outcome as distinct fields so that later model training does not learn an incorrect relationship.

13.4 Preserve original images and record every transformation used for training or inference. Compression, resizing, cropping and normalization can remove defect information or shift dimensions. Evaluate the deployed preprocessing pipeline with the same care as the model. Images modified for illustration shall not enter validation as original evidence.

13.5 Protect proprietary designs and any incidental personal data. Collect only what is required, restrict access and document permitted reuse. Data collected for one customer or purpose shall not be transferred into another model or shared externally without the necessary rights and authorization.

14 Dataset separation and representative coverage

14.1 Define training, tuning and independent final-test datasets before model selection. Group correlated observations by physical part, batch, tool campaign, vehicle or other relevant source. Images of the same part, near-duplicate frames and augmented versions shall not be divided between training and final testing in a way that inflates performance.

14.2 Use temporal or source-separated evaluation where future production, new batches or supplier variation are part of the intended claim. Preserve a final test set that is not repeatedly used to choose thresholds or architectures. If test results drive design changes, that set has become development evidence and a fresh independent evaluation is needed.

14.3 Report coverage across defect class, severity, boundary size, material, colour, cavity, station, shift and environmental conditions. Identify unsupported combinations explicitly. A large total dataset can still contain almost no evidence for the most consequential defect or a newly introduced variant.

14.4 Synthetic images and augmented samples may support development and stress testing. They shall not be counted as independent real production parts or used alone to claim detection capability for a physical defect mechanism. Document how their realism was assessed and what claim they support.

14.5 Freeze dataset identities, labels, split logic and access history for each released model. Annex D captures the dataset and model record. Preserve enough provenance to reproduce the evaluation and investigate later leakage, relabelling or contamination of the test population.

15 Model development and configuration control

15.1 The model owner shall record architecture or algorithm identity, software dependencies, training configuration, data versions, preprocessing, randomization controls and output interpretation. Development shall compare suitable baselines and evaluate whether simpler deterministic inspection is adequate for the task. Complexity is not itself a quality advantage.

15.2 Choose model-selection criteria before comparing candidates. Evaluate error consequences and class-specific performance rather than selecting on overall accuracy alone. Document tuning history and why the final model was chosen. Avoid selecting a threshold from the independent test set and then reporting that set as an unbiased validation.

15.3 For anomaly detection, define the normal training population and test sensitivity to known defects and legitimate novelty. An anomaly score shall not be represented as a direct measurement of severity or probability without supporting evidence. A novel conforming finish and a dangerous defect can both appear unusual.

15.4 Release the model together with preprocessing, label map, thresholds, regions, calibration dependencies, runtime and hardware compatibility. Protect the package against unauthorized alteration and verify its identity on the installed station. A model file alone does not describe the operational decision configuration.

15.5 Keep a verified rollback package and clear restrictions on its use. Rolling back to an earlier model is acceptable only if that version remains valid for the current product and equipment. Automatic learning or threshold adaptation in production requires a separately controlled and validated change process; unreviewed adaptation shall not alter release decisions.

16 Validation plan and statistical evidence

16.1 Quality shall approve a validation plan before final testing. Define the intended use, operating envelope, defect classes, decision unit, reference method, sample design, acceptance criteria and confidence requirements. Include optical measurement, classification, timing, identity and physical segregation as separate but connected evidence requirements.

16.2 Select independent representative conforming and nonconforming parts, including difficult boundary cases and plausible disturbance conditions. Report the number of independent physical units, not only the number of images. Correlated frames from one defective part do not provide the same evidence as defects on many independent parts.

16.3 Evaluate performance for each critical defect class and relevant operating subgroup. Provide uncertainty intervals or another justified statistical treatment. For rare defects, a study with zero misses still has finite uncertainty; it does not establish a zero escape probability. Annex E illustrates a one-sided bound under stated assumptions.

16.4 Test the complete decision logic, including missing or corrupt images, unknown parts, calibration failure, model failure, timeout, identity mismatch and failed rejection. Verify that the response holds the correct material and records the event. A high offline model metric cannot compensate for a reject gate that releases the wrong part.

16.5 Record all exclusions, failed runs, retests and configuration changes. Independent review shall determine whether the evidence supports the claimed scope or requires restriction. Approval may be limited to a validated subset, but the station shall reliably prevent use for unsupported variants or conditions.

17 Performance measures and error interpretation

Define defect as the positive class for this matrix. Evaluate only cases with an adequate independent reference, and report indeterminate and invalid cases separately. Preserve both the model result and the final production disposition.

Reference condition	System flags defect	System passes
Nonconforming	True positive TP	False negative FN
Conforming	False positive FP	True negative TN

Measure	Definition and interpretation
Detection sensitivity	$TP / (TP + FN)$. Fraction of known nonconforming units flagged.
False-accept rate	$FN / (TP + FN)$. Miss rate among known nonconforming units.
False-reject rate	$FP / (FP + TN)$. Rejection rate among known conforming units.
Precision	$TP / (TP + FP)$. Fraction of flagged units that are nonconforming; depends on prevalence.
Indeterminate rate	Held uncertain or invalid units / all attempted units, with causes shown separately.
Outgoing escape estimate	Requires representative production and final-disposition evidence; a balanced test set alone is insufficient.

For multiple defects per part, report defect-level detection and part-level disposition without mixing denominators. Localization or segmentation overlap scores may help development but do not replace the product acceptance decision. Identify treatment of partially detected defects and repeated views.

Overall accuracy can appear high when defects are rare. Present per-class counts, confidence intervals, subgroup results and actual exposure. An indeterminate case held safely is not a false accept, but excluding such cases without reporting their frequency would overstate operational capability.

18 Threshold and review band approval

Owner: Quality with Product Engineering, metrology and the model owner. Thresholds shall be derived from development evidence and approved requirements before independent final validation.

Step / owner	Required action and evidence
1 Define consequences	Identify defect classes, relevant sizes or severity, acceptance requirements and the cost or consequence of each error. State mandatory limits and the permitted alternative inspection route.
2 Compare operating points	Use development data to examine false accepts, false rejects and uncertain cases at candidate thresholds. Evaluate each critical class and subgroup rather than one aggregate curve.
3 Define the decision logic	Specify pass, reject and review bands, required image-quality conditions, combined-defect rules and missing-data behaviour. A score shall not override an invalid calibration or wrong part identity.
4 Validate independently	Freeze the logic and evaluate it on the independent final test set and installed line. Include boundary parts, maximum speed and abnormal interface conditions.
5 Approve the scope	Record thresholds, engineering limits, uncertainty rule, validated variants, restrictions, reviewer authority and activation configuration. Obtain independent technical approval.
6 Protect and monitor	Restrict changes, log active values and monitor performance. Any proposed threshold change follows change review and renewed validation before affecting production release.

If sensitivity is inadequate at every practical operating point, improve image formation, data, model or complementary inspection. Do not solve an unresolved safety-critical miss rate by relabelling defects as acceptable.

19 Line integration and reject confirmation

19.1 The integration design shall maintain a unique relationship among physical part, acquisition trigger, image set, recipe, result and disposition. Validate conveyor tracking, encoder behaviour, buffers, reordering and line restart. Where identity cannot be guaranteed, hold the defensible affected population instead of assigning a result to an assumed part.

19.2 Define the deadline by which a valid decision must be available before the part reaches its controlled disposition point. Include acquisition, processing, communication, queuing and actuation. Test worst-case latency and jitter under realistic load. Mean processing time alone cannot establish reliable operation at maximum line speed.

19.3 Reject devices shall have appropriate capacity, guarding and confirmation of actual segregation. Monitor full bins, blocked chutes, actuator faults, removal of held parts and manual retrieval. A reject command sent by software is not proof that the nonconforming part was physically removed.

19.4 On loss of camera, controller, network, power, time synchronization or required record storage, execute the validated response. The permitted response may stop the line or route all affected parts to a controlled hold. A fail-open path shall not be introduced as an undocumented production convenience.

19.5 Challenge sequence changes, multiple adjacent defects, missing parts, mixed variants and interrupted cycles. Reconcile all attempted inspections with final physical statuses. After restart, verify the first affected units and clear or preserve queued results through the approved procedure so that stale data cannot release new product.

20 Installed station qualification and release

Owner: Manufacturing Engineering and Quality, supported by metrology and OT. Qualification applies to the complete application at its actual site and line configuration.

Step / owner	Required action and evidence
1 Verify installation	Check camera, optics, lighting, fixtures, guards, wiring, environment, software identities and documentation against the approved design. Resolve unauthorized substitutions.
2 Verify measurement	Complete calibration, independent checks, uncertainty assessment and reference-part control. Confirm that the production coordinate frame and product limits are correctly implemented.
3 Demonstrate inspection	Run the approved independent validation population and required operating conditions. Preserve class-specific results, raw evidence and all limitations.
4 Challenge interfaces	Test identity, timing, missing data, unknown variants, reject confirmation, full bins, faults and recovery. Confirm safe work arrangements during testing.
5 Train and prepare	Demonstrate operator and reviewer competence, start-up checks, containment, escalation, maintenance and recovery. Confirm access restrictions and backup availability.
6 Authorize production	Record exact scope, released package, acceptance evidence, restrictions, actual effective date and accountable approvers. Activate only the validated variants and conditions.

Any incomplete critical function prevents release of the affected scope. Supplier demonstrations and factory tests may contribute evidence, but the installed line shall still be shown to operate correctly under its actual conditions.

21 Start of shift and reference challenge checks

Owner: trained station operator. Perform checks at the approved frequency and after relevant cleaning, intervention, changeover or interruption. The plan shall define controlled test parts and safe insertion methods.

Step / owner	Required action and evidence
1 Confirm the configuration	Check station identity, product recipe, model package, calibration status and unresolved alarms. Verify that the intended variant is within the released scope.
2 Inspect the optical path	Check permitted cleanliness, window condition, lighting, focus indicators and fixture condition without entering a danger zone. Escalate any movement or damage.
3 Run known references	Present identified good, defective and borderline challenge parts as required. Confirm the expected result for every required view and defect class; prevent reference parts from shipment.
4 Challenge disposition	Verify correct identity, decision timing, reject or hold confirmation and the applicable fault response. Use the approved safe test method rather than placing people in moving equipment.
5 Review and activate	Record actual results and the released configuration. A failed challenge blocks the affected release function until a competent person has investigated and authorized recovery.
6 Handover the status	Record unresolved issues, held populations, temporary controls and next checks. Ensure the incoming shift understands restrictions and cannot assume a green screen means full validity.

A daily challenge is an intermediate verification, not a complete recalibration or replacement for periodic validation. Annex F records the check and the physical recovery of all reference artefacts.

22 Drift monitoring and ongoing verification

22.1 Monitor changes in image quality, score distributions, feature measurements, indeterminate rates, false rejects and independently verified escapes. Stratify by product family, colour, tool, station and shift. A change in defect prevalence is different from a change in model performance; investigate both before choosing a response.

22.2 Use periodic independent checks of passed as well as rejected product to detect hidden false accepts. Define the sampling plan and suitable reference method by consequence and exposure. Reviewing only rejected images cannot establish the miss rate. Retain the sampled population and results even when no defect is found.

22.3 Establish alert and action limits from validated performance and operating history. Define the owner, required investigation and affected-product rule for each trigger. A distribution-shift alarm is a signal to investigate; it does not alone prove product failure or identify its cause.

22.4 After lens cleaning, light replacement, fixture repair or recalibration, verify the relevant characteristics and reference responses. Extend the assessment if the change affects image formation or model behaviour. Repeated manual adjustment to keep a metric within range shall be treated as evidence of an unstable inspection process.

22.5 Review monitoring intervals using actual drift, maintenance and incident evidence. Do not lengthen intervals solely to reduce downtime. The station record shall preserve the last defensible valid state and enough history to determine the affected population when a check fails.

23 Inspection failure and suspect product containment

Owner: Quality with Production, vision engineering and metrology. Trigger: missed defect, failed reference check, invalid calibration, identity error, reject failure or material data-integrity concern.

Step / owner	Required action and evidence
1 Protect the output	Stop or restrict the affected release function and establish controlled hold. Maintain machinery safety and prevent uncontrolled manual diversion of parts.
2 Preserve evidence	Record station configuration, images, results, alarms, maintenance, timestamps and physical product status. Secure relevant logs without erasing or repeatedly resetting the fault.
3 Define the boundary	Identify the last defensible valid check and all affected products through the current point. Include in-process buffers, downstream stock, rework and shipped material.
4 Assess and inspect	Determine failure mode and detection capability. Use a validated independent method to evaluate suspect product. Do not reinspect with the same failed configuration and call it independent evidence.
5 Correct and verify	Repair or change the system through approved control. Repeat the relevant calibration, model, interface and segregation tests. Address occurrence and escape causes.
6 Release with authority	Record disposition, customer notification where needed, restart evidence, restrictions and approver. Monitor the initial recovery period and verify that held quantities reconcile.

Where the start of invalid operation cannot be established, expand containment to a defensible earlier boundary. Annex G records the incident and recovery decision; production pressure shall not narrow the boundary without evidence.

24 Human review and controlled overrides

24.1 The human review procedure shall identify which results may be adjudicated, the required evidence and the reviewer's competence. Provide calibrated measurements or the original image set, product specification, defect references and relevant physical access. A compressed screenshot may be inadequate for a fine or structural indication.

24.2 Reviewers shall distinguish an invalid inspection from an acceptable product. An absent image or unobservable feature may require another inspection method. They shall not issue a pass merely because they cannot see a defect in the available evidence. Record an indeterminate outcome when the evidence remains insufficient.

24.3 For high-consequence or borderline decisions, require an independent second review or specialist test as defined in the control plan. Review shall be blinded to unnecessary production targets or commercial pressure where practicable. Measure reviewer agreement and investigate inconsistent interpretations of the same defect boundary.

24.4 Every override shall preserve the original result, evidence, reason, reviewer identity, authority and final disposition. Limit bulk overrides and prohibit shared credentials. A repeated override pattern shall trigger investigation of the model, requirements, image quality or reviewer practice rather than become an informal new threshold.

24.5 Keep review queues within validated storage, identification and staffing capacity. Product shall remain physically controlled while awaiting a decision. If the queue exceeds capacity, reduce or stop affected production or activate an approved alternative inspection; do not automatically pass aged queue entries.

25 Changes retraining and revalidation

25.1 Changes to camera, lens, illumination, fixture, line speed, part geometry, finish, supplier material, software, model, threshold or preprocessing require documented impact review before use. Define whether recalibration, targeted verification or full validation is necessary. A minor-looking optical change may affect an important defect class.

25.2 Retraining shall use controlled data and labels with independent test separation. Preserve the previous release and compare performance on critical classes, boundary cases and relevant subgroups. Improvement in average performance shall not conceal deterioration in a safety-relevant class or unsupported new product family.

25.3 Deploy changes through a controlled release package and a planned production window. Confirm active versions on all affected stations and prevent mixed incompatible configurations. Shadow operation may collect evidence without making release decisions; clearly identify which system remains authoritative during the trial.

25.4 Rollback shall restore a known valid complete configuration, including thresholds, preprocessing and calibration dependencies. Verify compatibility with current hardware and products. A previous software version shall not be reinstated automatically if the physical process has changed beyond its validated envelope.

25.5 Record the change reason, affected population, validation evidence, independent approval, activation point and monitoring plan. Communicate revised instructions and retrain affected roles. Online adaptation shall not alter product disposition without a defined, validated and auditable approval mechanism.

26 Cybersecurity privacy and evidence protection

26.1 Apply the IAF Connected Factory and OT Cybersecurity Manual to inspection networks, controllers, edge computers and remote services. Restrict administrative access, separate roles and use individual accounts. Protect model packages, thresholds, calibration files and result databases from unauthorized modification.

26.2 Authenticate software and model updates through the approved release process. Record package identity and integrity checks, origin, approvals and installed versions. Remote support shall be time-bounded and supervised according to the OT procedure. A supplier support account shall not retain unrestricted access by default.

26.3 Protect image and result transfer against substitution, replay and mismatched identities. Validate recovery after communication interruption and prevent stale results from authorizing new parts. Preserve audit logs and synchronize time with an approved source appropriate to the application; timestamps alone shall not replace unique part identity.

26.4 Collect only necessary production and personal information. Define access, retention, customer rights, authorized sharing and secure disposal under the IAF Data Protection and Privacy Policy and Documents and Records Guide. Preserve evidence under investigation or legal hold. A training dataset shall not be retained indefinitely without a justified purpose.

26.5 Backups shall cover model packages, calibration, recipes, labels, traceability relationships and required records. Test restoration and verify that the recovered configuration is valid for the current line. A cyber incident affecting inspection integrity shall trigger product-impact assessment as well as system recovery.

27 Audit metrics and management review

27.1 The audit programme shall inspect the complete chain from product requirement to physical disposition. Sample active variants, calibration evidence, independent tests, daily challenges, failed inspections, overrides, maintenance and change records. Verify that the configuration on the machine matches the one approved in the release record.

27.2 Report false accepts and false rejects with known reference populations, indeterminate causes, independent pass-audit results, calibration failures, reject faults, queue delays and unauthorized changes. Separate development-test results from production monitoring. Show counts and exposure so that a percentage cannot hide a small or biased sample.

27.3 Investigate repeated restarts, missing images, disabled checks, unexplained threshold changes and unusually perfect performance. Such patterns may reflect logging gaps or invalid evidence rather than improvement. Auditors shall be able to reconstruct selected part decisions from original data and physical segregation records.

27.4 Management review shall assess remaining blind spots, new defect mechanisms, competence, resources for independent evaluation and the cost of ineffective inspection. Prioritize process improvement and better detection where needed. A lower reject rate is not a success if missed defects or unsupported overrides have increased.

27.5 Corrective action shall address the cause and verify effectiveness under representative conditions. Use the IAF supplier quality and complaint procedures for external providers or customer impacts. An unresolved critical inspection failure shall remain visible and prevent unrestricted release of the affected scope.

28 Implementation and continuing control

28.1 The adopting site shall map existing inspection stations to this manual and identify gaps in requirements, reference evidence, calibration, datasets, model validation, integration and product containment. Assign technical owners and an actual operational adoption date. Publication status does not imply that any installed station has been validated.

28.2 Prioritize stations used for consequential release decisions. Establish the approved operating envelope and alternative inspection before activation. Where existing equipment lacks sufficient evidence, restrict its decision role until competence is demonstrated. Do not reconstruct missing validation records as though the tests had been performed.

28.3 Pilot the complete lifecycle on representative press, weld or paint applications within the intended scope. Demonstrate a normal release, a borderline review, an invalid image, a missed-defect investigation and a reject-system failure. Exercises shall protect personnel and keep test artefacts out of customer output.

28.4 Train operators, reviewers, maintenance, data personnel and approvers for their actual responsibilities. Competence shall be demonstrated through practical tasks and interpretation of evidence. Technical authorization shall list limitations and review triggers rather than treating a generic AI course as permission to change production decisions.

28.5 Review this manual and local procedures after major incidents, new technology and scheduled management review. Process revisions through the IAF Documents and Records Guide and communicate changes before activation. Annex H provides implementation checks and connections to the wider IAF quality system.

Annex A Station specification and tolerance matrix

Form ICV F01. Station _____. Site and line _____. Product families and revisions _____. Decision role _____. Engineering owner _____. Quality approver _____.

Characteristic	Approved requirement and method
Defect class and consequence	_____
Product zone and boundary	_____
Physical limit and unit	_____
Reference decision method	_____
Optical coverage and operating envelope	_____
Measurement uncertainty and decision rule	_____
Score thresholds and review band	_____
Required class-specific performance	_____
Latency and segregation requirements	_____
Missing-data and fallback response	_____

Repeat for each characteristic and product family. Record specification revision, evidence supporting each limit, equality rules and required confidence. Geometric limits and classifier thresholds shall occupy separate fields; one shall not be substituted for the other.

Unsupported defects or conditions _____. Complementary inspection _____. Required revalidation triggers _____. Actual approval and activation date _____. An unfilled critical limit prevents activation of the affected release decision.

Annex B Calibration and intermediate verification record

Form ICV F02. Record ID _____. Reason _____. Station and configuration _____. Specialist _____.
Method revision _____. Date _____.

Calibration element	Actual evidence
Camera lens fixture and coordinate frame	_____
Reference identity values and uncertainty	_____
Environment focus and illumination	_____
Calibration images and field coverage	_____
Fitting residuals and rejected points	_____
Independent features and positions	_____
Measured errors and acceptance limits	_____
Uncertainty and permitted measurement scope	_____

Result: valid / restricted / invalid. Limitations _____. Approved package identifier _____.
Reviewer and date _____. Next calibration or verification due and rationale _____.

Intermediate check: reference part ____; expected result ____; actual result ____; station state ____; operator ____; timestamp _____. A successful check does not extend the calibration scope or replace independent model validation.

If invalid: last defensible valid state ____; affected products ____; hold reference ____; impact review ____; correction ____; independent verification ____; authorized return to use ____.

Annex C Defect catalogue and reference control

Form ICV F03. Catalogue revision _____. Product family _____. Engineering owner _____.
Reference custodian _____. Use a separate record for each defect and boundary condition.

Field	Required entry
Defect identity	Name, mechanism, zone, consequence and applicable product requirement: _____
Decision boundary	Permitted and nonpermitted condition, unit or appearance reference and combined-defect rule: _____
Reference evidence	Part identity, revision, material, finish, natural or simulated origin and independent characterization: _____
Optical conditions	Views, lighting, pose and acquisition configuration that reveal the indication: _____
Ground-truth review	Assessor, method, measurement or test evidence, uncertainty and adjudication: _____
Control and storage	Location, condition check, protection, inspection interval and removal from saleable flow: _____

Reference set shall include conforming variation, nonconforming examples and meaningful boundary cases. List defect sizes or severities actually represented and the unsupported range. Do not infer coverage from labels alone.

Condition check date _____. Change or deterioration _____. Status reconfirmed by _____.
Replacement reference and linkage _____. Any invalid reference requires assessment of decisions or checks that relied on it.

Annex D Dataset and model release record

Form ICV F04. Dataset ID _____. Model ID _____. Application scope _____. Data owner _____.
Developer _____. Independent reviewer _____.

Record element	Evidence and decision
Provenance	Sites, dates, product families, configurations, physical-unit counts and collection rights: _____
Labels	Catalogue revision, labeler competence, agreement, adjudication and unresolved cases: _____
Split design	Training, tuning and final-test populations; grouping and duplicate controls: _____
Coverage	Defect classes, boundaries, finishes, shifts and unsupported combinations: _____
Development	Algorithm, dependencies, preprocessing, parameters, candidate comparisons and selection rule: _____
Validation	Frozen package, independent test ID, results by class, intervals and limitations: _____
Release	Thresholds, regions, calibration dependencies, hardware and runtime, package integrity and scope: _____

Synthetic or augmented data and their permitted evidential role _____. Test-set access and any reuse _____. Required new independent evaluation _____.

Approval reference and date _____. Installed stations _____. Activation population _____.
Rollback package and compatibility _____. Monitoring owner _____. Retention and access schedule _____.

Annex E Worked validation and tolerance examples

Illustrative calculations only. The examples do not prescribe production limits or demonstrate any real station performance.

Classification counts

In a test of 1,000 independent parts, 100 are nonconforming and 900 conforming. The system flags 98 defective and 18 good parts; it passes 2 defective and 882 good parts. TP = 98, FN = 2, FP = 18 and TN = 882.

Measure	Calculation	Result
Sensitivity	98 / 100	98.0%
False-accept rate	2 / 100	2.0%
False-reject rate	18 / 900	2.0%
Precision	98 / 116	84.48%

These counts need uncertainty intervals and subgroup review. Precision would change with defect prevalence. This deliberately selected test population does not establish the outgoing production escape rate.

Zero observed misses

With zero misses in n independent representative defective parts, a one-sided 95% upper binomial bound for miss probability is $1 - 0.05^{(1/n)}$. At $n = 300$ the bound is approximately 0.994%. Repeated images of one part do not meet the independence assumption; zero observed misses does not prove zero risk.

Guarded dimensional decision

Suppose a feature must lie between 9.90 and 10.10 mm. Under a rule requiring the full interval $y \pm U$ to lie inside these limits, $U = 0.03$ mm gives an acceptance region from 9.93 to 10.07 mm inclusive. A result of 10.08 mm is held for further evaluation under this rule; it is not automatically a proven nonconforming part.

Annex F Shift challenge and line audit checklist

Form ICV F05. Station _____. Shift and date _____. Product recipe _____. Model and calibration IDs _____. Operator _____. Record actual observations and evidence identifiers.

Check	Expected or required result	Actual and status
Configuration and scope	Released versions and supported variant	_____
Optical path and environment	Within approved operating envelope	_____
Known conforming references	Expected pass without missing views	_____
Known defective references	Expected detection and disposition	_____
Borderline or uncertain references	Expected review or hold response	_____
Identity and timing	Correct part association within deadline	_____
Reject and fault response	Confirmed segregation or controlled stop	_____
Reference-part recovery	All test artefacts accounted for	_____

Any failure: affected scope _____. Last valid check _____. Held population _____. Escalation contact and time _____. Do not activate affected release until authorized recovery is documented.

Auditor extension: independently sample a passed part, a rejection, an override, a missing-image event and a recent change. Trace original evidence to final physical status and the active approval. Record omissions or inaccessible data as limitations.

Shift release or restriction _____. Approver where required _____. Handover issues _____. Next check _____. This form records verification; it is not a substitute for periodic complete validation.

Annex G Failure containment and recovery worksheet

Form ICV F06. Incident ID _____. Detection time _____. Station and scope _____. Reporter _____. Quality owner _____. Immediate product and equipment controls _____.

Investigation stage	Required record
Evidence preservation	Images, logs, package, thresholds, calibration, maintenance and physical stock state: _____
Failure mechanism	Optical, metrology, model, identity, timing, reject, human review or data integrity: _____
Affected boundary	Last defensible valid state, first and last suspect units, downstream locations and shipments: _____
Independent evaluation	Method capability, population, screened and unresolved quantities, results and disposition: _____
Correction and testing	Cause, authorized changes, calibration, validation, interface checks and evidence of effectiveness: _____
Recovery decision	Scope, restrictions, activation point, approver, customer communication and follow-up: _____

Quantity reconciliation: total suspect ____; located ____; awaiting evaluation ____; accepted ____; rejected ____; transferred under control _____. Define mutually exclusive states and reconcile transfers.

Original inspection results remain preserved. A replacement result shall link to the original unit and state why the original decision was superseded. Retention hold _____. Independent closure reviewer _____. Review date _____.

Annex H Implementation and IAF document interfaces

Form ICV F07. Site _____. Stations and product scope _____. Adoption owner _____. Actual effective date _____. Gap review _____.

IAF document	Connected control
Quality Manual and Constitution	Institutional authority, accountable technical approval and management review.
Lean Manufacturing and SOP Manual	Process requirements, line reaction, controlled rework and restart.
Supplier Quality Assurance and Auditor Manual	Characteristic approval, measurement evidence, submissions and supplier change.
Gigafactory and Advanced Assembly Manual	Battery production context, genealogy and specialist test controls.
Connected Factory and OT Cybersecurity Manual	Identity, access, package integrity, network control and recovery.
Documents and Records Guide	Publication control, raw evidence, retention, corrections and disposal.
IAF policy documents	Privacy, conflict management, protected disclosures, complaints and mark use.

Activation evidence: application and tolerance matrix ____; defect catalogue ____; calibration and uncertainty ____; independent model validation ____; line and reject validation ____; operator and reviewer competence ____; fault exercise ____.

Role authorization: person ____; station or technology scope ____; permitted actions ____; witnessed evidence ____; assessor ____; limitations ____; review trigger ____.

Management review and remaining actions _____. This manual does not grant accreditation, certify a model or authorize a claim that all defects are detected. Such claims require their own competent evaluation and a supported scope.