BEST PRACTICE MANUAL FOR THE FORENSIC EXAMINATION OF PAINT

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1. AIMS

This Best Practice Manual (BPM) aims to provide a framework for procedures, quality principles, training processes and approaches to the forensic examination of paint. This BPM can be used by Member laboratories of ENFSI and other forensic science laboratories to establish and maintain working practices in the field of forensic examination of paint that will deliver reliable results, maximize the quality of the information obtained and produce robust evidence. The use of consistent methodology and the production of more comparable results will facilitate interchange of data between laboratories.

The term BPM is used to reflect the accepted practices at the time of creation. The term BPM does not imply that the practices laid out in this manual are the only good practices used in the forensic field. In this series of ENFSI Practice Manuals the term BPM has been maintained for reasons of continuity and recognition.

This BPM provides the means to make a motivated choice between the methods that are currently accepted by the ENFSI Paint and Glass Working Group (EPG) community. If a practitioner wishes to use other methods this choice should be thoroughly motivated.

2. SCOPE

This BPM is aimed at experts in the field and assumes prior knowledge in the discipline. It is not meant as a standard operating procedure and addresses the requirements of the judicial systems in general terms only.

The scope of this manual includes the systems, procedures, personnel, equipment and accommodation requirements involved in the forensic process, from reception of samples at the forensic laboratory to presentation of evidence in court.

This manual applies to the comparative analysis of paint samples, to the analysis with the aim of providing investigative lead information relating to the origin of a paint sample, as well as to the analysis of physical and chemical characteristics of the sample. Finally it will address the forensic interpretation of the analytical results as part of the judicial process.

3. DEFINITIONS AND TERMS

For the purposes of this BPM, the relevant terms and definitions apply as given in ENFSI documents, in ILAC G19 [1], in ISO/IEC 9000 [2], ISO/IEC 17020 [3] and ISO/IEC 17025 [4] standards, and in ASTM E1610-18 [5].

Specific technical terms used in this guideline include:

Term	***Definition***
Additive (modifier)	any substance added in a small quantity to improve properties of the paint. Additives may include substances such as dryers, corrosion inhibitors, catalysts, ultraviolet absorbers, plasticizers, etc.
Background variation	the variation in characteristics for materials with similar appearance as the questioned paint but having no relation to the crime under investigation. Similar appearance as considered by a 'lay person' (e.g. a police officer) purely by observation without aids.
Binder	a non-volatile portion of a paint which serves to bind or cement the pigment particles together. This is also sometimes referred to as resin.
Coating	a generic term for paint, lacquer, enamel, or other liquid or liquefiable material which is converted to a solid, protective and/or decorative film after application.
Comparative examination	comparing a questioned sample to a reference sample using the same forensic features (e.g. dimensions, colour, texture, spectra) with the aim to determine their degree of correspondence.
Discriminate	to distinguish between two samples based on significant differences; to differentiate.
Discriminating power	the ability of an analytical procedure to distinguish between two different products from the same population.
Filler	mostly inorganic material which is used to enhance the properties of a layer of coating, to contribute hiding power and decrease the overall costs.
Interpretation	defining the degree of similarity between samples based on multiple methods and observations, constitutes the findings in the case.
Investigative examination	comparing a questioned sample to databases with the aim of providing investigative lead information relating to its origins, make or properties in view of further police investigations

Term	*Definition*
Known sample	a coating sample of established origin
Significant difference	a feature or property of a sample that does not fall within the observed/expected variation exhibited by the comparison sample, considering the limitations of the sample or technique, and therefore indicates the two samples do not share a common origin. The use of this term does not necessarily imply the formal application of statistics.
Paint	commonly known as a pigmented coating.
Pigment	an inorganic or organic, insoluble, dispersed particle. Besides colour, a pigment may provide many of the essential properties of paint, such as opacity, hardness, durability and corrosion resistance. The term pigment includes pigment extenders.
Proposition – alternative	mutually exclusive to another proposition with which it forms a pair.
Propositions – hierarchy of	propositions can be classified in hierarchical levels: 'activity level' (propositions about an activity) and 'source level' (propositions about the source of physical matter)
Questioned sample	a coating sample whose original source is unknown
Reference sample	known sample in a comparitive examination.
Reporting – evaluative	providing an assessment of the strength to be attached to the findings in the context of alleged circumstances.
Reporting – investigative	providing explanations for technical/factual findings when it is not possible to formulate a pair of competing propositions.
Reporting – technical	providing a descriptive account of findings
Validation	demonstrate that the method is appropriate for the application intended

4. RESOURCES

4.1 Personnel

4.1.1 Roles and responsibilities

Key roles suggested for laboratories performing paint examinations are:

Reporting Scientist : the forensic scientist responsible in a particular case for directing the examination of the items submitted, interpreting the findings, writing the report and providing evidence of fact and opinion for the court.

Reporting Analyst : an analyst responsible in non-complicated cases for performing the examination of the items submitted, interpreting the analysis results, writing the analyses report and, if necessary, providing factual evidence for the court.

Analyst/Assistant : an individual carrying out general casework examinations or analytical tests under the supervision of a Reporting Scientist and who is able to provide information to assist with the interpretation of the tests.

It is accepted that an individual may be responsible for more than one of the defined roles. Not all roles may be recognised by every organisation.

4.1.2 Competencies

The following experience and areas of competence would be expected as the minimum standard for the key roles defined above, in forensic paint examination:

Reporting Scientist : knowledge of the theories, analytical techniques and procedures (including health and safety requirements) applicable to paint examination; understanding of products and current practices on the paint market, competence in the evaluation and interpretation of findings in paint cases; knowledge and experience of the requirements and procedures of the criminal justice system for the presentation of evidence, both written and oral.

Reporting Analyst : knowledge of the theories, analytical techniques and procedures (including health and safety requirements) applicable to paint examination; competence in the evaluation and interpretation of analytical data in paint cases; knowledge and experience of the requirements and procedures of the criminal justice system for the presentation of evidence, both written and oral.

Analyst/Assistant : knowledge of the theories, analytical techniques and procedures applicable to paint examination; the practical skills to operate specialist equipment and to carry out forensic paint analysis safely and reliably in compliance with laboratory protocols; an understanding of the requirements of the criminal justice system.

General competencies are listed in the QCC-CAP-003 document [8]. Not all these roles may be recognised by every organisation.

4.1.3 Training and assessment

Laboratories should have written standards of competence for each role; a documented training programme; and processes for assessing that trainees have achieved the required level of competence.

4.1.4 Maintenance of Competence

An appropriate programme should be included in the laboratory's guidance to ensure that role holders maintain an adequate level of competence, in compliance to ISO 17025:2017. A comprehensive guideline is published by ENFSI [7]. If laboratories need to adopt a condensed program due to limited resources, their program should be justified and documented.

4.2 Equipment

See individual guidelines.

4.3 Reference materials

See individual guidelines.

4.4 Accommodation and environmental conditions

All laboratory work should be carried out in suitable accommodation meeting the standards of the ILAC Guidelines for Forensic Science Laboratories or other published guidelines from recognised authorities, e.g. ISO/IEC 17025 [4]. Laboratories for the examination of items for paint and the analysis of recovered paint should be designed for efficient and effective working. Particular consideration should be given to the need for avoidance of contamination. This requires the provision of adequate space for searching e.g. bulky items.

4.5 Materials and Reagents

See individual guidelines.

5. METHODS

The process of reception and adjustment of a customer/client request at the laboratory entails the evaluation of the examination request and a case pre-assessment as needed.

5.1 Examination request

The examination request should be unambiguous and complete. In case of doubt the scientist shall seek to redress any deficiencies through consultation with the customer/client. This should be documented in the case file.

5.2 Pre-assessment

Before starting work on the case the scientist should carry out an assessment of the information available and the items provided for examination in light of the agreed customer/client requirement. This allows the formulation of any propositions minimising any potential bias from the actual findings.

The scientist should consider to what extent the proposition put forward by the customer/client can be tested and should also consider relevant alternative proposition. Requesting additional context information should always be considered. The expert assesses the likely evidential value of the anticipated findings.

The scientist should also make an assessment of the risk of contamination, or any other issue that could affect the integrity of the items, before examination commences. If the integrity of the test item has been compromised, the expert should consult with the customer/client in order to assess the appropriateness of the examination.

The expert should identify and request any missing information regarding the suspected transfer, the risk of contamination and the potential significance of the findings. If this information is not obtained or not available, this should be mentioned in the final report.

5.3 Inspection, search and recovery

All items submitted are described and paint material is searched and recovered.

Method	**Initial Inspection, Search and Recovery**
Description	Description and unpacking of items submitted, search and recovery of paint fragments and initial inspection by low-power stereomicroscope
Input	Items submitted
Output	Description, photographs, drawings of localised paint fragments, paint fragments
Discriminating power	Not applicable
Consequences for subsequent analyses	As there is always a potential impact on other trace materials when items are handled for examination, the impact should be evaluated before the start of the examination.
Strengths	Fast, non-destructive, capable of discriminating significantly different items, search for and recovery of paint traces down to 0.1 mm
Limitations	Applicable to all items submitted
Equipment	Optical microscope system appropriate for the intended use. Details in the guideline.
Other remarks	None
Guideline	ASTM E1492 *Standard Practice for receiving, documenting, storing and retrieving evidence in a forensic science laboratory* [5] EPG-GUIDELINE-001 *Guideline for the initial inspection, search and recovery of forensic paint evidence* [6]

5.4 Analytical methods

The examiner can choose from the following potentially useful methods for paint analysis. All methods of analysis should have been subjected to appropriate in-house validation.

An analytical scheme shall include examinations to assess physical characteristics and instrumental analysis to compare the organic and inorganic composition of the paint layers, unless sample size or condition prohibits it, or the nature of the sample justifies a partial scheme.

The following tables summarize the characteristics of the commonly used analysis methods:

- High Power Microscopy, Fluorescence Microscopy
- Microspectrophotometry an Colour measurement
- FTIR Spectroscopy
- Raman Spectroscopy
- Scanning Electron Microscopy / Energy Dispersive X-Ray Spectroscopy (SEM/EDS)
- Micro X-Ray Fluorescence (µXRF)
- X-ray Diffraction (XRD)
- Pyrolysis Gas Chromatography – Mass Spectrometry (PyGC/MS)
- Chemical Tests and Low Temperature Ashing

Method	**High Power Microscopy, Fluorescence Microscopy**
Description	Optical microscopy is a non-destructive technique that allows one to observe a sample under different lighting conditions (bright field, dark field), with different filters, and at different magnifications. Fluorescence microscopy in particular illuminates the sample using a fluorescent light source and an excitation filter, and observes the fluorescent radiation emitted through an emission (stop) filter. Can be documented by appropriate photographs.
Input	Paint samples in different forms (multilayer paint chips, smears, spray paint droplets, etc.)
Output	Optical characteristics of a paint sample, comparison of sample characteristics such as: homogeneity, layer sequence and width, texture and morphology, colour, metamerism, pigments, other particles, contaminations,…
Discriminating power	Strongly discriminating but no quantitative data available.
Consequences for subsequent analyses	Depending on sample preparation (mounting medium, cleaning, …), possible loss of information (UV light can degrade DNA, modify the sample).
Strengths	Permits visual comparison, non-destructive, fast.
Limitations	Minimum size of observed detail: 5 µm, UV light can modify the sample.
Equipment	Optical microscope system appropriate for the intended use. In case of fluorescence microscopy, fluorescent light source and appropriate filter system.
Other remarks	None
Guideline	Standard textbooks on optical microscopy such as P.R. DeForest, *Foundations of Forensic Microscopy* [9] N. Petraco and T. Kubic, *Color Atlas and Manual of Microscopy for Criminalists, Chemists, and Conservators* [10]

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Method	**Microspectrophotometry and Colour Measurement**
Description	Colour is measured and compared using a microspectrophotometer (MSP). The light energy transmitted, absorbed or reflected by a sample is measured at each wavelength of the visible spectrum (about 380 to 780 nm) or ultra-violet (about 190 to 380 nm).
Input	Paint sample with a clean and undamaged area. For transmission UV-VIS colour measurements approximately 3 µm thin sections are required. Determination of UV-absorbers in clearcoats by transmission UV-VIS requires up to 20 µm thin sections. Reflectance measurement requires the measured area as large as possible, especially with effect paint samples.
Output	Spectra in the measured range. Colour space coordinates (CIE tristimulus values).
Discriminating power	> 95 % for gloss household paints [11]
Consequences for subsequent analyses	Non destructive
Strengths	Minute paint sections can be analyzed in transmission.
Limitations	Smeared paints pose challenges. Measuring effect paints in reflectance requires large area.
Equipment	Microspectrophotometer
Other remarks	Comparison can not only rely on CIE tristimulus values but also on the complete absorption, transmission or first derivative spectrum.
Guideline	ASTM E2808 *Standard Guide for Microspectrophotometry and Color measurement in forensic paint analysis*. [12]

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Method	**FTIR Spectroscopy**
Description	FTIR spectroscopy provides information on the chemical bonds in organic and inorganic compounds by detection of vibrational transitions. Results are presented in the form of a spectrum, i.e. radiative transmission or absorbance as a function of wavenumber. Can be applied to microscopic samples by the use of a special microscope. Samples can be prepared as microtome thin cuts, can be pressed in a diamond cell or measured in reflection ATR mode.
Input	Paint samples Minimum size for thin cut preparation 0.5 mm
Output	FTIR spectra of individual paint layers, permitting identification/comparison of coating materials by determination of chemical components such as binders, fillers, pigments or additives.
Discriminating power	> 90 % for white architectural paint [13], > 90 % for automotive paint [14]
Consequences for subsequent analyses	Depending on sample preparation, typically non-destructive
Strengths	Results from transmission measurements permit comparison to EPG paint databases. Comparison to commercial databases possible: transmission to transmission, ATR to ATR.
Limitations	Determination of group characteristics, most sensitive to paint binder. Pigments and inorganic constituents contribute to the spectrum.
Equipment	FTIR spectrometer Depending on acquisition method, IR microscope, diamond anvil cell, micro-ATR
Other remarks	Minimum size depends on the measuring technique. With microscopes the sample size is limited to the diffraction limit, with current systems at approx. 10 µm. On using an ATR objective the sample size minimum equals the diameter of the crystal. On comparing with database spectra, acquisition mode and sample preparation have to be taken into account, as they can result in differences in spectral features.
Guideline	EPG-GUIDELINE-002 *Guideline for the forensic examination of paint by Fourier-transform infrared spectroscopy* [15]

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Method	**Raman Spectroscopy**
Description	Raman spectroscopy provides information on the chemical bonds in organic and inorganic compounds by detection of vibrational transitions. Due to the difference in excitation mode and corresponding selection rules, the technique is complementary to FTIR, providing information about components barely detected in IR. Method of choice for pigment identification.
Input	Paint samples, no sample preparation or same preparation as for FTIR. Metal support can help dissipating heat from the laser excitation.
Output	Provides information on paint components that are hard to detect in FTIR, method of choice for pigment identification.
Discriminating power	> 90 % for solid automotive paint, > 95 % for metallic paint [16]
Consequences for subsequent analyses	Bleaching/Burning of the sample by heat if laser beam energy too high
Strengths	Pigments and fillers can be identified using reference databases, high spatial resolution 0.35 – 4.2 µm depending on laser wavelength and magnification Depth of excitation 7 – 26 µm
Limitations	Fluorescence can be excessive, obliterating signals. Bleaching of the sample by laser light. Burning of the sample by heat from laser beam. Calibration of wavenumber scale essential
Equipment	Raman spectrometer, Raman microscope, Lasers 785 nm or 830 nm, 633 nm, 514 nm or 532 nm (and others: 458 nm or 488 nm for dispersive spectrometers, 1064 nm for FT Raman)
Other remarks	Operator intervention skills high (parameter optimization)
Guideline	EPG-GUIDELINE-003 *Guideline for the forensic examination of paint by Raman spectroscopy* [17]

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Method	**Scanning Electron Microscopy / Energy Dispersive X-Ray Spectroscopy (SEM/EDS)**
Description	A scanning electron microscope (SEM) produces images of a sample by scanning the surface with a focused beam of electrons. Interactions with the atoms in the sample produce signals such as characteristic X-rays, back-scattered electrons (BSE) and secondary electrons (SE). Analysis depth is below 100 nm for electron imaging and typically a few µm for EDS. Used for comparison of paint samples.
Input	Paint samples (solid or cross-sections). Using a high vacuum SEM, carbon coating of the samples is required. For semi-quantitative results grinding and polishing of the paint sample is required.
Output	Characteristic X-rays: qualitative and semi quantitative elemental composition Secondary electrons: topography of the sample surface, no chemical information Back scattered electrons: chemical distribution according to the (average) atomic number (Z) without indicating the identity of the chemical elements.
Discriminating power	No quantitative data available
Consequences for subsequent analyses	Non-destructive, can be re-analysed using the same technique. May be problematic for analysis by other techniques (glued to a sample stub). If using a high-vacuum SEM, carbon coating of the sample is required.
Strengths	Qualitative elemental analysis using an energy dispersive X-ray detector (EDS) typically has a limit of detection down to 500 ppm, spatial resolution down to 100 nm, elements above Z=4 are detectable. Elemental mapping is possible. Point-to-point resolution depends on the SEM type and can be below 1 nm, useful for imaging of pigments or other paint components or multi-layer structures.
Limitations	When using a low-vacuum SEM, the spread of the electron beam (skirt effect) has to be considered. Semi-quantitative analysis by EDS, although theoretically possible, is difficult for paints, due to the inhomogeneous nature of the inorganic materials in paint and requires sample grinding and polishing.
Equipment	Scanning Electron Microscope equipped with X-ray detector (EDS) for elemental analysis.
Other remarks	For the simultaneous detection of some elements (e.g. Ti and Ba) a wavelength dispersive X-ray detector (WDS) is beneficial.
Guideline	ASTM E2809 *Standard Guide for using Scanning Electron Microscopy/X-ray Spectrometry in Forensic Paint Examinations* [18] EPG-GUIDELINE-004 *Guideline for the forensic examination of paint by SEM/EDS* [19]

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Method	**Micro X-Ray Fluorescence (µXRF)**
Description	µXRF provides information about the elemental composition of a paint sample by detecting characteristic X-ray emission that occurs after excitation by a high-energy X-ray beam. The results are presented in the form of a spectrum depicting the X-ray intensity as a function of its energy. The analysis can be performed in air, helium or vacuum and provides qualitative and semi-quantitative elemental information. The excitation spot size depends on the X-ray optics and lies typically between 50 µm and 1 mm.
Input	Paint samples For obtaining semi-quantitative results the sample should be prepared (see guideline).
Output	Simultaneous multi-element (Na to U) composition of paint samples characteristic of inorganic components such as additives, pigments, aluminium flakes, mica, etc.
Discriminating power	No quantitative data available
Consequences for subsequent analyses	Non destructive
Strengths	Sensitive to heavier elements (down to 0.1 wt%) in contrast to SEM/EDS which is more sensitive to the lighter elements. Depth of penetration is higher as compared to SEM/EDS. Relative ease of use.
Limitations	Elements detectable with Z > 10 (depends on materials)
Equipment	µXRF spectrometer
Other remarks	none
Guideline	ASTM D5381 *Standard Guide for X-ray Fluorescence (XRF) Spectroscopy of Pigments and Extenders* [20]

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Method	X-Ray Diffraction (XRD)
Description	X-ray diffraction (XRD) characterizes crystalline materials by providing information on crystal structure and phase composition. Diffraction peaks are produced by constructive interference of a monochromatic beam of X-rays diffracted at specific angles from each set of lattice planes in a sample. A database search of X-ray diffraction patterns enables the phase identification of a large variety of crystalline samples.
Input	Solid paint samples
Output	X-ray diffraction pattern: periodic atomic arrangements in the material (lattice parameters of the crystalline phase by peak positions and distribution of atoms within the lattice by peak intensities). The identification is done by comparing the diffraction pattern with commercially available (e.g. PDF-4 or COD) or internal diffraction database or exceptionally by structural refinement of the components (Rietveld refinement).
Discriminating power	no quantitative data available
Consequences for subsequent analyses	Non-destructive
Strengths	Fast, minimal or no sample preparation requirements
Limitations	Imaging/Mapping: Mapping is possible with special equipment. Cannot be used for analysing amorphous or liquid materials.
Equipment	X-ray diffractometer
Other remarks	None
Guideline	ASTM D5380-93 (2021*) Standard Test Method for Identification of Crystalline Pigments and Extenders in Paint by X-Ray Diffraction Analysis* [21]

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Method	**Pyrolysis Gas Chromatography – Mass Spectrometry (PyGC/MS)**
Description	Paint samples can be flash-heated in an inert atmosphere (pyrolysis). At relatively low temperature, additive compounds are liberated from the paint, separated by GC, and semi-quantitatively detected by MS. At higher temperature, the binder polymer is broken down, resulting in smaller fragments of the paint, that can be separated and identified by transfer to a GC/MS. This information permits a thorough description of the binder polymer.
Input	Paint sample, 10 - 50 µg. Derivatization required depending on the type of binder (determined by FTIR).
Output	Detailed characterization of the binder system. Information on organic additives.
Discriminating power	> 95 % for automotive clear coats [22]
Consequences for subsequent analyses	Destructive
Strengths	High information content on organic composition, very useful for binder identification and paint comparison work. Very small amount of sample required, typically 10 - 50 µg depending on type of material and equipment.
Limitations	Expertise required in setting up the instrument. Repeatability is not optimal. Instrument maintenance and troubleshooting is time intensive.
Equipment	Programmable pyrolysis unit, compatible GC/MS
Other remarks	Several analyses needed to check reproducibility. Relatively time consuming.
Guideline	SWGMAT *Standard Guide for using Pyrolysis Gas Chromatography and Pyrolysis [Gas Chromatography-Mass Spectrometry in Forensic Paint examinations*. [23] EPG-GUIDELINE-005 *Guideline for the forensic examination of paint by Pyrolysis Gas Chromatography – Mass Spectrometry* [24]

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Method	Chemical Tests and Low Temperature Ashing
Description	A number of comparative tests of paint samples by treating them with chemicals, studying their dissolution behaviour and/or behaviour on heating.
Input	Paint samples in different forms (multilayer paint chips, smears, spray paint droplets, etc.)
Output	Visual features like colour change, dissolution, etc.
Discriminating power	Depends on the number of reagents used, no quantitative data available
Consequences for subsequent analyses	Destructive
Strengths	Permits a preliminary assessment, fast and associated with little effort and resources, permits serial examination (screening).
Limitations	Destructive, experience and training necessary, interference caused by impurities, documentation is difficult (video), clear definition of the visual features as caused by the reaction required.
Equipment	Stereo microscope with incident light, chemicals, scalpel and needle, microscope slides
Other remarks	None
Guideline	S.G. Ryland, T.A. Jergovich, K.P. Kirkbride, *Current Trends in Forensic Paint Examination* [25] J.M. Home, D.K. Laing, S. Richardson, *The discrimination of small fragments of household paint using chemical tests* [26]

Other methods could be suitable in certain situations. Their use should be substantiated and they should not be applied unless properly validated. Validation guidelines can be found in QCC-VAL-002 [27]

5.5 Selection of methods

Methods detailed in the previous section should be considered as fit for purpose, but the limitations and the potential benefits of each method should be assessed depending on the type of paint.

The choice of appropriate methods for a particular paint analysis problem depends on a number of criteria that are described hereafter.

5.5.1 Availability

The availability of methods is dictated by two conditions: the availability of operational and validated equipment, and the availability of personnel trained and authorized to perform the method.
All methods that fulfil these conditions can be considered when evaluating the next criterion.
If certain methods are not available they may be outsourced to another laboratory.

5.5.2 Scope

The choice of methods depends on the amount of detail needed. High information content methods are usually more time-consuming.

Not all analyses need to be pushed to maximum detail in all cases.

In investigative examinations the speed of response is generally more important than the strength of evidence. As an example, a request for car make identification would not aim at defining the exact paint batches as contained in the database, which would exclude all similar and potentially significant candidates.

On the other hand, in full evidence examinations comparing traces with a reference paint, the interpretation is more important than the speed of response. In these cases it is required to

compare to a particular batch, so such examinations should be conducted to the point of detecting significant differences or to the non-differentiation by all techniques selected.

Usually in casework there is a need of compromise between the amount of detail needed in the context of the case, and the urgency of the request.

5.5.3 Samples

Further choices depend on the samples submitted.

The nature of the samples may render certain methods less appropriate.

The number of samples may render certain methods less appropriate and will certainly influence the response time for the case.

The type of the paint samples may affect the discriminating power of some methods used in routine and additional methods should be considered.

5.6 Prioritization and sequence of examinations

Once the appropriate methods to be applied in the case have been chosen (see method overview section), the scientist has to decide on the sequence in which to apply them. This sequence is generally defined by:

5.6.1 The destructiveness of the method

This aspect is particularly important when measuring very small samples that could be destroyed completely when applying certain methods. In these cases, a destructive method should either not be used or used as the last analysis on that particular sample.

5.6.2 Potential information content

The combination of techniques available that offers the greatest potential for identifying or discriminating between the samples should be used, taking into account the sample size and the desirability of leaving some material available for any possible future examination.

Identification of the paint type should be made by reference to authenticated reference samples or data provided in a standard text, peer reviewed publication or standard database.

Comparison of paint samples should consider the following features: layer structure (colour, sequence, relative thickness, and morphology), surface features, adherent material, and the results of all analytical techniques applied.

5.6.3 Influence on subsequent methods

Some methods have negative consequences on the outcome of subsequent methods. This can influence reference samples as well. Information is available at the method overview section and in the various method guidelines.

5.7 Documentation

Selection, prioritization and sequence of methods shall be documented and substantiated in the case file.

5.8 Case Review

A case review protocol including the motivation of the choice of methods shall be implemented.

A technical review is carried out in order to assure the appropriate methods and procedures have been used. It includes review of the data and results and the assessment of their significance. It also checks the case file is properly documented.

The protocol assures the review of critical findings by a competent peer. Findings are considered critical if, either:

- They make a significant contribution to the findings in the case;
- It would not be possible to confirm them at a later time (e.g. no sample left for re-analysis);
- They are subject to possible differences in interpretation by different reporting scientists or analysts.

The case review shall be documented in the case file.

6. VALIDATION AND ESTIMATION OF UNCERTAINTY OF MEASUREMENT

6.1 Validation

Validation is instrument specific and is treated in individual laboratory validation documents, see QCC-VAL-002 [27].

6.2 Estimation of uncertainty of measurement

The estimate of uncertainty is treated in individual laboratory validation documents.

7. QUALITY ASSURANCE

7.1 Proficiency Testing/Collaborative Exercises

Proficiency tests and/or collaborative exercises should be used to test and assure the quality of the forensic examination of paint. A lists of external PT providers is available from the ENFSI website [28]. The EPG periodically organizes PT/CE tests on forensic paint analysis.
Results of these tests, their evaluation and corrective/preventive measures originating therefrom, are to be documented by the participants.

The document "*Guidance on the conduct of proficiency tests and collaborative exercises within ENFSI*" [29] provides information for the ENFSI Expert Working Groups (EWGs) on how to organise effective proficiency tests (PTs) and collaborative exercises (CEs) for their members.

7.2 Quality Controls

Quality Controls used in the method and/or process and relevant criteria used therein should be recorded.

7.3 Data Collection for control, monitoring and trend analysis

Data collection for the purposes of assuring the method/process should be documented and an outline given on how this could be presented (e.g. control charts).

7.4 Risk assessment

Risk assessment is an integral part of quality management as expressed in ISO 17025:2017. The laboratory shall consider risks and opportunities associated with both its impartiality and its laboratory activities, so that it can achieve its purposes and objectives in the intended way and can prevent (or reduce) undesired impacts and potential failures.

The evaluation needed in this respect does encompass the complete process from the introduction of the case up to reporting. It should therefore be based on a thorough scrutiny of the process and the actions that comprise it.

The risk factors to be considered depend on the organisation of the laboratory and the equipment used and should be based on the local SOPs. Some of the more prominent risk factors to be assessed:

- Unwarranted deviation from the field of competence
- Loss of traceability of samples and sub-samples
- Representativity of samples
- Lack of detection of significant traces
- Threats to sample integrity
- Loss of trace samples (e.g. during transport from one equipment to another)
- Inversion of samples
- Manipulation errors and cross contamination
- Uncontrolled measuring parameters including equipment failure
- Failure of detection of layers
- Bias in interpretation of findings
- Peer review ability to detect errors

This list is not comprehensive and should be regarded as an initial guide to monitor the processes conducted in your laboratory. This should include regular review by team members who are trained and experienced the various process steps involved in any paint examination.

Once risk factors have been identified and their potential impact assessed, the laboratory can define actions to address these risks (and opportunities), implement them and evaluate their effectiveness. The actions shall be proportional to the potential impact on the validity of laboratory results.

Risk assessment is a continuous process as external and internal risk factors tend to evolve both in likelihood and impact. While the laboratory is free to choose the evaluation method to be used, it must ensure its consistency both amongst disciplines and in time.

8. HANDLING ITEMS

Proper care shall be taken to ensure an uninterrupted chain of custody for items or samples that provide elements of evidence.

8.1 At the scene

Not applicable, this best practices manual is aimed at laboratory based examinations and does not provide recommendations for working at the scene.

8.2 In the laboratory

Comprehensive item, sample, sub-sample and trace labelling shall be performed to ensure that the provenance of results is unequivocally linked to the item submitted to the laboratory. It is recommended to perform an inventory check on a periodic basis in order to ensure tracking is maintained.

Anti-contamination measures are to be implemented on all levels necessary, including the appropriate need of protecting other evidence types when performing search, recovery, sampling or testing. (see sections 4.4, 5.2 and 5.3 of this manual).

Appropriate storage conditions have to be maintained in order to avoid loss, mix-up, deterioration or contamination of the paint materials involved.

9. INITIAL ASSESSMENT

The review of case requirements was treated in sections 5.1 and 5.2 of this manual in accordance to the logical sequence of actions depicted in ILAC G19 [1] and QCC-CAP-003 [6].

10. PRIORITISATION AND SEQUENCE OF EXAMINATIONS

In this manual the documented choice of methods plays a crucial role. Their prioritisation and sequence is a logical extension to this choice and is therefore treated in the methods section 5.5 – 5.6.

11. RECONSTRUCTION

Not applicable, this best practices manual is aimed at laboratory based examinations and does not provide recommendations for reconstruction activities.

12. EVALUATION AND INTERPRETATION

12.1 Differentiation between samples

In general, a set of methods is needed to perform a full comparison of a questioned sample and a reference paint. These methods should enable comparing the physical characteristics as well as the organic and inorganic composition of the paint layers.
This set of methods and their sequence is decided upon at the onset of case treatment according to section 7 of this manual.

At each point in this sequence a decision is made wheather the questioned sample can or cannot be differentiated from the reference paint.

The questioned sample cannot be differentiated if its data fall within the range determined from multiple measurements of the reference paint and if there are no significant differences between the items. In this situation the analysis sequence is continued.

If, on the other hand, the questioned sample exhibits at least one significant difference from the reference paint, the analysis sequence is discontinued and a statement ‘dissimilar’ is issued. By ‘significant difference’ is meant:

- The difference is reproducible;
- It concerns a characteristic of the reference paint that is not exhibited by the questioned sample;
- The difference is not related to co-measured adjacent layer(s);
- The difference is not explained by a known contamination (e.g. support).

If the questioned and reference paint exhibit differences that warrant doubt whether they are significant or not, the analysis sequence is continued.

In ASTM documents the term ‘exclusionary difference’ is used. This term is not used here because it implies more than observation and measurement, giving opinion on the evidential weight.

12.2 Degree of similarity

At the end of the analysis sequence, the experimental data need to be evaluated in order to assess the level of similarity or difference between samples, typically between trace and

reference. This degree of similarity shall be formulated in a clear and transparent way and be based on defined criteria. These shall take into account:

- The type of paint examined;
- The type of measured characteristics (group characteristics or individual);
- The combined discriminating power of the sequence of techniques used;
- Known contaminations or contributions of extraneous material to the measured characteristics;
- Inherent inhomogeneity of the paint.

This degree of similarity can be expressed using a predefined scale :

- Physical fit (highest level of similarity) with many characteristics,
- Indistinguishable in uncommon characteristics (very high level of similarity, corresponds to a class of small size)
- Indistinguishable in common characteristics (high level of similarity but belongs to a sizeable class)
- Similar with limitations (level of similarity decreased due to high occurrence rate, incomplete analysis, contamination, insufficient size to assess heterogeneity)
- Inconclusive
- Dissimilar (at least one significant difference).

12.3 Evaluating the evidential significance

In the next step, a statement must be provided to answer the client's request. This statement shall be unbiased and avoid misinterpretation by a non-scientific reader. It shall be formulated in a clear and transparent way and be based on defined criteria, taking into account:

- Competing propositions that support the neutrality of the statement and ensure the absence of bias;
- The context and particular circumstances of the case, in so far as they have been established objectively and the information is given to the expert;
- Information available in relevant databases;
- The background variation detected by the sequence of techniques used;
- Whether a one- or multi-layer transfer is involved;
- Whether a one- or two-way transfer is involved.

The Bayesian approach [30 - 32] provides a means of accounting for the influence of these factors. At least two competing hypotheses are considered, one favouring the prosecution allegation (H_p) and the other favouring a defence position (H_d). These propositions can be formulated at source level (do the samples originate from the same source or not) or at activity level (has a certain action occurred or did another specific action occur). A likelihood ratio (LR) is estimated as the ratio of the probability of the findings given hypothesis H_p, to the probability to obtain the findings given hypothesis H_d. In presenting evidence, the LR is usually expressed in terms of a standard verbal scale of strength of evidence indicating the extent to which the findings support either H_p or H_d. If the findings do not favour either H_p or H_d, then these should be considered as neutral (i.e. inconclusive with a LR =1). The scientist should confine his/her evaluation to the probability of the evidence using the two competing propositions under consideration and the estimation of a LR.

At present, lack of some of the necessary background data means that the estimate of the likelihood ratio is partially subjective, limiting an exact LR calculation. Even so this estimate can still be used as a guide to place the findings on a verbal scale of probability [32 - 35].

Alternative interpretation models may be considered but these should be validated. Moreover, the use of such a model should be communicated clearly and with transparency to the courts.

It is normally not possible to state that specific recovered paint originated from a particular object to the exclusion of all others. Paint is a mass-produced material, so paint could therefore

originate from another object coated with identical paint. In exceptional cases a physical match can be established [36].
Nevertheless paint, especially if more layers have been transferred in a two-way transfer, can be very characteristic and in some cases can provide very strong evidence.

Some paint types, e.g. white household wall paints, are so widely distributed that in many case circumstances they could be considered of little evidential value.

One of the main features involved in paint comparisons is colour and layer structure: smeared layers of paint therefore may hamper transfer examinations and should be considered while interpreting the findings.

Provided the necessary additional information is obtained, also an interpretation at activity level can be made.

12.4 Paint frequency databases

Paint frequency data can be very valuable in the assessment of paint evidence. They should be as comprehensive as possible and cover characteristics such as the apparent colour, layer sequence and/or morphology. Data collections that are currently available to EPG paint examiners to estimate paint frequencies include:

- European Paint Collection at the BKA and IRCGN (EUCAP);
- The FRCAP/FRPLAST databases maintained in France;
- Various collections with colour data for car paints;
  - PPG Color Tool (www.ppgpaintit.com);
  - AKZO Nobel Mixit ColorWeb Application (www.mixitcloud.com);
  - Glasurit Color Tool (https://coloronline.glasurit.com);
  - BASF-RM (https://color-explorer.rmpaint.com)
  - Axalta color tool (https://www.spieshecker.com/au/en_AU/colours/colour-tools/colour-search.html#.YjSpaK9KhPY)
- Paint Data Query (PDQ) databases maintained by Canadian RCMP;
- Various collections of spray and tool paints as part of the EPG spectral libraries set;
- Data collections maintained within individual laboratories.

12.5 Paint surveys

In addition to the estimate of frequency of occurrence of the specific types of paint in the case, there are many other factors which should be taken into account, for example:

- The proportion of paint types in the general paint population within the appropriate geographical area and a knowledge of which types can be stated to occur infrequently within this population;
- The relative frequency with which different paint types are used to coat various objects;
- The background variation i.e. the variation of the characteristics of paints in the background population, i.e. that have similar appearance as the questioned sample but are not related to crime.
- Published data [37 – 44] demonstrate that by using the most discriminating (combination of) analytical techniques it may be possible to single out individual paint samples out of a limited random population sample.

13. PRESENTATION OF EVIDENCE

The overriding duty of those providing expert testimony is to the court and to the administration of justice. As such, evidence should be provided with honesty, integrity, objectivity and impartiality.

The expert's findings and opinion are normally provided in the first instance in written form, as a report or statement of witness, for use by the investigator and/or the prosecutor/court. Oral evidence, in addition, may be required subsequently.

The results shall be peer reviewed prior to release.

13.1 Written reports

Written reports should include all the relevant information in an accurate, clear, concise, objective, structured and unambiguous manner as required by the relevant legal process.

Minimum contents include:

- A unique case identifier;
- The name and address of the laboratory and identification of the person authorizing the report;
- The name and contact information of the customer/client;
- The purpose of the examination, as agreed with the customer/client;
- Information as received on the case as well as on (results of) prior investigations and statements;
- Identification of the method(s) used;
- A description, unambiguous identification and, if necessary, the condition of the item(s);
- The date of receipt of the item(s);
- The date(s) of performance of the laboratory activities;
- The date of issue of the report;
- The results including when appropriate the units of measurement;
- Additions to, deviations or exclusions from the method;
- Clear identification if results are from external providers;
- Opinions, interpretations and conclusions. Interpretations and conclusions will normally be in separate chapters in the report than the results so as to be transparent on factual results and the interpretation by the expert.

Opinions, interpretations and conclusions expressed in reports shall be based on the results obtained from the tested item(s) and shall be clearly identified as such. They should only be expressed by personnel authorized to do so. Opinions on paint transfer and persistence, paint frequency etc. should be confined to what can be supported by documented studies.
Subjective or speculative information should be avoided wherever possible.

13.2 Oral testimony

Persons expected to present oral testimony should have received instruction and/or mentoring in the procedural requirements of the particular criminal justice system in which the evidence is to be presented.

Only information obtained by the examinations carried out should be presented, unless specifically directed by the court. Expert witnesses should refrain from responding to questions that take them outside their field of expertise unless specifically directed by the court, and even then a declaration as to the limitations of their expertise should be made.

14. HEALTH AND SAFETY

Materials dealt with in forensic casework can be inherently hazardous and/or often found in hazardous circumstances that are not always known or communicated to participants in the process. There is an obligation on those involved in the forensic process to ensure the safety of anyone handling materials that are inherently hazardous or rendered hazardous by the scientific examinations performed (e.g. a scalpel blade enclosed in the item packaging).

In setting up any process in the laboratory, consideration must be given to these issues and it is suggested that as a minimum the following should be considered:

- An assessment of the hazards upon reception and handling of the item(s) and how to minimise these;
- An assessment of the risks involved in all the scientific processes in the laboratory;
- The required safety measures should be taken;
- Any appropriate protective clothing and equipment for all processes involved in the examination of paint;
- The mechanism for documenting and communicating the risks associated with any stage of the process and especially where materials may be brought into the public domain (e.g. courts).

15. REFERENCES

[1] ILAC G19:08/2014, Modules in a Forensic Science Process

[2] ISO/IEC 9000:2015, Quality management systems – Fundamentals and vocabulary.

[3] ISO/IEC 17020.2012, Conformity assessment – Requirements for the operation of various types of bodies performing inspection

[4] ISO/IEC 17025:2017, General requirements for the competence of testing and calibration laboratories

[5] ASTM E1492-11 (2017), Standard Practice for receiving, documenting, storing and retreiving evidence in a forensic science laboratory

[6] QCC-CAP-003-002 Performance based standards for forensic science practitioners, ENFSI, 2004.

[7] QCC-CAP-006-001 Guidance on the assessment of competence for forensic science practitioners, ENFSI, 2011.

[8] EPG-GUIDELINE-001 Guideline for the initial inspection, search and recovery of forensic paint evidence, version 1, 2021

[9] P.R. DeForest. 2002. Foundations of Forensic Microscopy. In Forensic Science Handbook, Vol I Chapter 5, ed. R. Saferstein., Englewood Cliffs, NJ.: Prentice-Hall.

[10] N. Petraco and T. Kubic. 2003. Color Atlas and Manual of Microscopy for Criminalists, Chemists and Conservators, 1st Ed., Boca Raton, FA: CRC Press.

[11] D.K. Laing et. al. 1982. The discrimination of small fragments of household gloss paint by microspectrophotometry. Forens. Sci. Intern. 20: 191-200.

[12] ASTM E2808-21 Standard Guide for Microspectrophotometry and Color measurement in forensic paint analysis

[13] H. Xie, S. Chie Ching, W. Ying Leong, A. Y. Teo. 2019. Analysis and discrimination of white architectural paint from high-rise public housing buildings in Singapore. 25th EPG Working Group Meeting, Prague 2019.

[14] W.Y. Soong, K.Y. Goh, H. Xie, T.B. Lim. 2020. Assessing the automotive paint evidence in Singapore via population and discrimination studies. Forens. Chem. 21: 100289.

[15] EPG-GUIDELINE-002 Guideline for the forensic examination of paint by Fourier-transform infrared spectroscopy, version 1, 2021

[16] A. Michalska, A. Martyna, G. Zadora. 2019. Raman spectroscopy in blue car paints examination. 25th EPG Working Group Meeting, Prague 2019.

[17] EPG-GUIDELINE-003 Guideline for the forensic examination of paint by Raman spectroscopy, version1, 2021

[18] ASTM E2809-13 Standard Guide for using Scanning Electron Microscopy/X-ray Spectrometry in forensic paint examinations

[19] EPG-GUIDELINE-004 Guideline for the forensic examination of paint by SEM/EDS, version 1, 2021

[20] ASTM D5381-93 (2021) Standard Guide for X-ray Fluorescence (XRF) Spectroscopy of Pigments and Extenders

[21] ASTM D5380-93 (2021) Standard Test Method for identification of crystalline pigments and extenders in paint by X-ray diffraction analysis.

[22] B. Plage, A.D. Berg, S. Luhn. 2008. The discrimination of automotive clear coats by pyrolysis gas chromatography/mass spectrometry and comparison of samples by a chromatogram library software. Forens. Sci. Intern. 177: 146-152.

[23] SWGMAT Standard Guide for using Pyrolysis Gas Chromatography and Pyrolysis Gas Chromatography-Mass Spectrometry in forensic paint examinations, issue 1. 2014. JASTEE 5,: 22-33.

[24] EPG-GUIDELINE-005 Guideline for the forensic examination of paint by Pyrolysis Gas Chromatography - Mass Spectrometry, version 1, 2021

[25] S.G. Ryland, T.A. Jergovich and K.P. Kirkbride. 2006. Current Trends in Forensic Paint Examination. Forensic Sci. Rev. 18:97.

[26] J.M. Home, D.K. Laing and S. Richardson. 1983. The discrimination of small fragments of household paint using chemical tests. J. Forensic Sci. Soc. 23:43-47.

[27] QCC-VAL-002 Guidelines for the single laboratory validation of instrumental and human based methods in forensic science, issue 1, 2014. https://enfsi.eu/wp-content/uploads/2017/06/Guidance-QCC-VAL-002.pdf

[28] https://enfsi.eu/docfile/overview-external-pt-ce-providers_11-2018/

[29] QCC-PT-001 Guidance on the conduct of proficiency tests and collaborative exercises within ENFSI, issue 1, 2014. https://enfsi.eu/wp-content/uploads/2017/07/QCC-PT-001-_-Guidance-on-PT-CE.pdf

[30] B. Caddy Ed., 2001. Forensic Examination of Glass and Paint, London: Taylor & Francis.

[31] J. Hellman, K. Legate, G.L. Vardy, E. Lindsay and G. Edmondstone. 2004. An assessment of the evidential value of automotive paint comparisons, J. Can. Soc. Forensic Sci. 37(3):147-153.

[32] S. Willis, A. Ligertwood, J.J. Molina, C. Berger, G. Zadora, A. Nordgaard, B. Rasmusson, L. Lunt, L. & C. Champod, A. Biedermann, T. Hicks, F. Taroni and X. Zhu. 2015. ENFSI guideline for evaluative reporting in forensic science.

[33] F. Taroni, C.G.G. Aitken and R. Garbolino. 2001. De Finetti's subjectivism, the assessment of probabilities and the evaluation of evidence: a commentary for forensic scientists. Sience Justice 41: 145-150.

[34] A. Nordgaard, R. Ansell, W. Drotz and L. Jaeger. 2012. Scale of conclusions for the value of evidence. Law, Probability and Risk 11:1-12.

[35] R. Marquis, A. Biedermann, L. Cadola, C. Champod, L. Gueissaz, G. Massonnet, W.D. Mazella, F. Taroni and T. Hicks. 2016. Discussion on how to implement a verbal scale in a forensic laboratory: benefits, pitfalls and suggestions to avoid misunderstanding. Sci. Just. 56:364-370.

[36] K. Walsh and A. Gordon. 2001. Pattern matching of a paint flake to its source, J. Assoc. Firearm Toolmark Exam. 33(2):143-145.

[37] P. Buzzini, and G. Massonnet. 2004. A market study of green spray paints by Fourier transform infrared (FTIR) and Raman spectroscopy. Science and Justice, 44:123-131.

[38] S. Bell, L.A. Fido, S.J. Speers, W.J Armstrong and S. Spratt. 2005. Forensic analysis of architectural finishes using Fourier transform infrared and Raman spectroscopy, Part II: White paint. Applied Spectroscopy 59:1340-1346.

[39] D.M. Wright, M.J. Bradley and A.H. Mehltretter. 2011. Analysis and discrimination of architectural paint samples via a population study. Forensic Science International 209:86-95.

[40] C. Muehlethaler, G. Massonnet and P. Esseiva. 2011. The application of chemometrics on Infrared and Raman spectra as a tool for the forensic analysis of paints. Forensic Sci. Int. 209:173-182.

[41] E. Dolak and R. Weimer. 2015. The physical and chemical characterization of multipurpose architectural paint. J. Am. Soc. Trace Evid. Exam. 6:21-43

[42] M. Maric, W. van Bronswijk, K. Pitts, S.W. Lewis. 2016. Characterisation and classification of automotive clear coats with Raman spectroscopy and chemometrics for forensic purposes. J. Raman Spectrosc. 47:948-955

[43] K.J. Kruglak, M. Dubnicka, B. Kammrath, V. Maxwell and J.A. Reffner. 2019. The evidentiary significance of automotive paint from the Northeast: a study of red paint, J. Forensic Sci. 64: 1345-1358.

[44] J.M. Duarte et al. 2020. Discrimination of white automotive paint samples using ATR-FTIR and PLS-DA for forensic purposes. Talanta, 240: 123154.

Recent research publications can be found in the periodic Interpol literature surveys, e.g.

M.J. Bradley, A. Hobbs Mehltretter and D.M. Wright. 2010. Examination of Paint 2007-2010. 16th Intern. Forensic Sci. Symp., Lyon, France: 113-181.

L. Heudt, G. De Roy, M. Lannoy and L. Köhler. 2013. Paint report 2010-2013. 17th Interpol Intern. Forensic Sci. Managers Symp., Lyon, Franse: 129:174.

J. Almirall. 2016. Paint and Glass 2013-2016. 18th Interpol Intern. Forensic Sci. Managers Symp., Lyon, France: 114-142.

J. Almirall, T. Trejos and K. Lambert. Paint and Glass 2016-2019. 19th Interpol Intern. Forensic Sci. Managers Symp., Lyon, France: 108-135.

J.M. Duarte et al. 2020. Automotive paint analysis: How far has science advanced in the last ten years?, Trends in Analytical Chemistry, 132:116061.

16. AMENDMENTS AGAINST PREVIOUS VERSION

Compared to EPG-BPM-001 Issue 001 (2009) this document has been completely revised:

1. The aims of the manual have been redefined;
2. Shift from fixed procedures to accountable choice by the responsible scientist
3. Inclusion of key ISO 17025:2017 requirements

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