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Conducting and Reporting Paint Data Query (PDQ) Searches

ABSTRACT

In recent years, the Royal Canadian Mounted Police (RCMP) has included a paint layer search exercise with the release of the Paint Data Query (PDQ) updates. This exercise is a useful means of evaluating a paint analyst's ability to conduct a PDQ search, compare search results between analysts in a laboratory system, and allows laboratories to assess what is considered to be sufficient documentation for a technical review of the analyst's search parameters for reporting results. This article describes one approach to conduct, report, and prepare a PDQ search for review using the quiz spectra that accompanied the 2018 release.

Keywords: Paint Data Query, Make-Model-Year, Spectral Search Libraries

INTRODUCTION

The frequency of casework suitable for and requiring a make-model-model year automotive paint search of original equipment manufacturer (OEM) paint systems using the Paint Data Query (PDQ) database can be sporadic in many laboratories. A lack of regular engagement can make it challenging to maintain proficiency in effective use of the database. The Royal Canadian Mounted Police (RCMP) provides detailed training in Canada for any new or current PDQ partner laboratories; however, the best way to gain the necessary tools to remain proficient is regular use of the database. Therefore, the recent introduction of a user search quiz within the past several PDQ updates has been well received by partner laboratories looking to practice and maintain effective PDQ search skills.

The FBI Laboratory's forensic paint examiners each independently participated in the 2018 user search quiz to evaluate proficiency in the use of PDQ as well as to evaluate and discuss what constitutes sufficient search documentation to facilitate technical review. It is FBI Laboratory practice to conduct the technical review of PDQ searches from the documentation rather than to repeat searches using the database; therefore, the assembled documentation of the searches needs to be sufficient to follow the search parameters used and the results each search yields.

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The exercise sample set, an approach that can be used to search the PDQ database, the documentation collected for the search and necessary for technical review, as well as the results and the report wording are all discussed in the following sections. This paper is meant to serve as an example of how PDQ was used in one practitioner's laboratory. It is not meant to serve as a procedure for the use of PDQ nor to take the place of PDQ training by the RCMP, which is much more extensive.

Background

PDQ evolved from the premise that automotive manufacturers contract with paint suppliers based on a number of business metrics to include: compatibility of the paint with the manufacturer's equipment, plant capabilities to adapt for recycling and/or repair work, business model, accessibility for a set number of assembly plants, ability to meet plant demand for paint, and paint quality. Manufacturers can negotiate supply contracts with paint suppliers on a mutually agreeable schedule such that the assembly plant may use a single paint supplier for all paint layers, or several suppliers for the different layers, or varying suppliers per layer as contracts are renegotiated. This variability in supplier and the resulting compositional changes in individual paint layers have proven to be forensically advantageous because they often allow for a given paint layer system to be attributed to a particular assembly plant. This information can be used to generate make-model-model year investigative leads for an unknown paint chip based on interpretation of the chemical components of each layer and a spectral search of those features in an original equipment manufacturer (OEM) automotive paint spectral library designed for that purpose [1,2].

This approach to developing lead information in hit-and-run investigations was developed by the RCMP as an in-house project back in the mid-1970s. This early work resulted in a series of publications in the Canadian Society of Forensic Sciences Journal [3-5]. Following the successful proof of concept of this research and with the development of more modern personal computers, PDQ was eventually created and introduced in the 1990s. Once the technology and infrastructure were in place to share the database, a more robust sample population scheme was implemented. Early contributors included forensic laboratories in Canada (e.g., RCMP, Centre of Forensic Sciences in Toronto) and the United States (e.g., FBI Laboratory, state laboratories in Florida, Georgia, Virginia, and Washington). Today, any PDQ partner laboratory can participate in PDQ, with the majority of the entries sought for the database intended to reflect the types of vehicles available within North America. In order to best capture the range of paint formulation combinations that might exist at a given plant, the PDQ Maintenance Team attempts to enter at least one red, one black, one white, and one other basecoat color (e.g., neutral such as silver or beige, blue, green) to the database for each model year produced. Therefore, these colors for recent model year vehicles are the most desirable that a partner laboratory can acquire for the database.

The requirements for becoming or maintaining a PDQ partnership include a laboratory's affiliation with a duly sworn law enforcement agency and signing a non-disclosure agreement with the RCMP. Then, in exchange for access to the database, a PDQ partner laboratory is required to annually submit a minimum of 60 OEM automotive paint samples of sufficient size for analysis as well as retention as physical exemplars.

The RCMP also maintains a partnership agreement with a commercial spectral search databasing company to provide PDQ partner laboratories access to a commercially available spectral searching platform. This software offers an alternative means of searching the PDQ spectral libraries in addition to the text-based approach available directly through the PDQ program.

To conduct a text-based search, known as a Layer System Query (LSQ) within PDQ, the PDQ Maintenance Team provides users with "PDQ IR Reference Sheets" which are based on classification schemes of the most common/major infrared peaks expected to be found in OEM automotive paints. These sheets are labeled as the "Diagnostic Peaks of Common Binders/Resins" and the "Diagnostic Peaks of Common Pigments and Extenders" and were created from information detailed in publications by early PDQ developers such as Rodgers, et al. [3-5] and users such as Ryland [6,7]. These foundational references are a great resource to identify compounds and combinations of compounds commonly observed in OEM automotive paints from the 1970s to the present day. Familiarity with the characteristic peaks of the common automotive paint binders and pigments is essential to successful navigation and use of PDQ for make-model-model year range searches.

To begin an LSQ search, all diagnostic peaks within a spectrum should be evaluated according to the PDQ IR Reference Sheets, or some other resource that contains information regarding peaks commonly associated with an OEM automotive paint layer [3,4,7]. PDQ general guidance includes not assigning search significance to minor peaks that might cause excessive filtering of database hits. The PDQ Maintenance Team also advises partner laboratories to avoid peak assignments for color pigments used in a basecoat since that can also filter out reasonable hits in the database that may be from the same plant but contain a different basecoat color.

Data Set

For the 2018 search quiz, the PDQ Maintenance Team selected a 5-layer OEM paint system and provided the following spectral data files: OT3 (clear coat); OT2 (clear coat with metallic flake); OT1 (white basecoat); OU1 (white primer surfacer); OU2 (medium gray electrocoat, or ecoat for short). Figures 1 through 5 are scanned reprints of the spectrum of each layer. Peak assignments were added after download of the spectra to facilitate spectral interpretation.

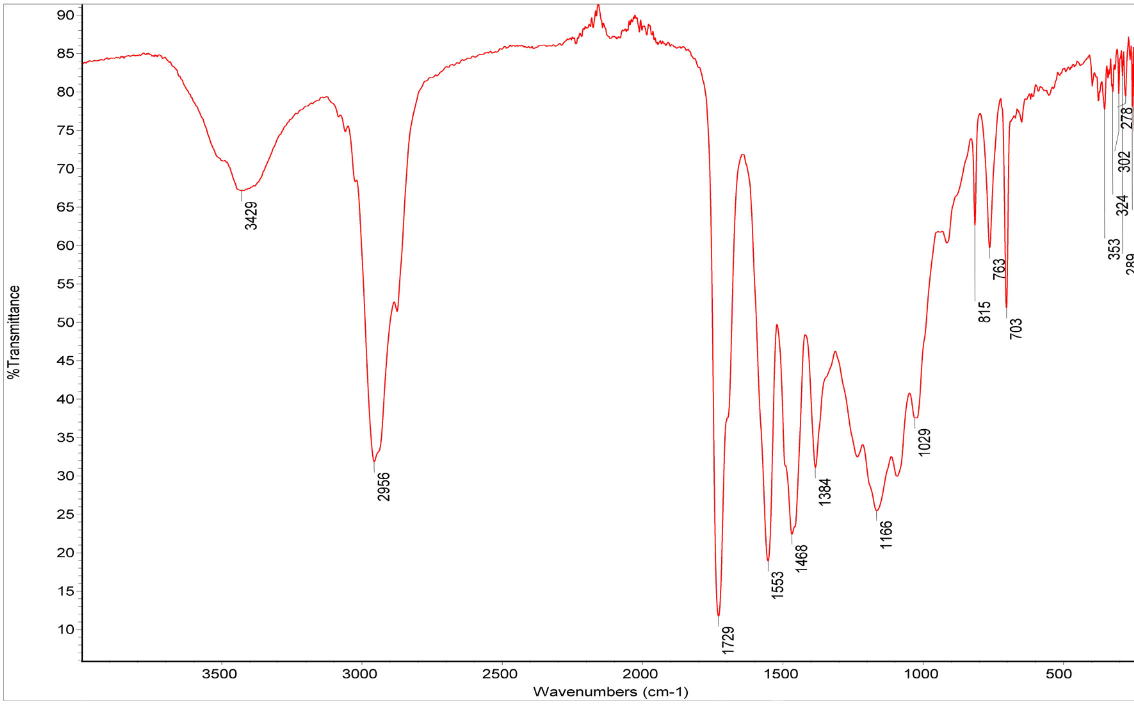

Figure 1: Spectrum of OT3, the topmost clearcoat layer

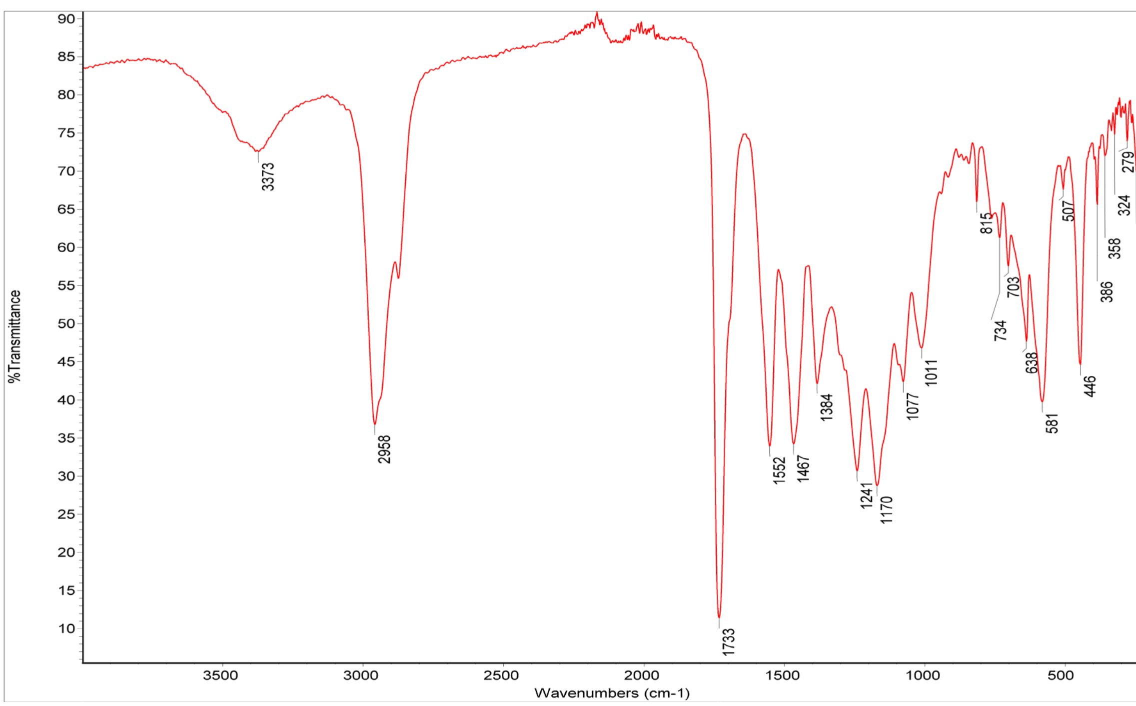

Figure 2: Spectrum of OT2, the effect clearcoat layer

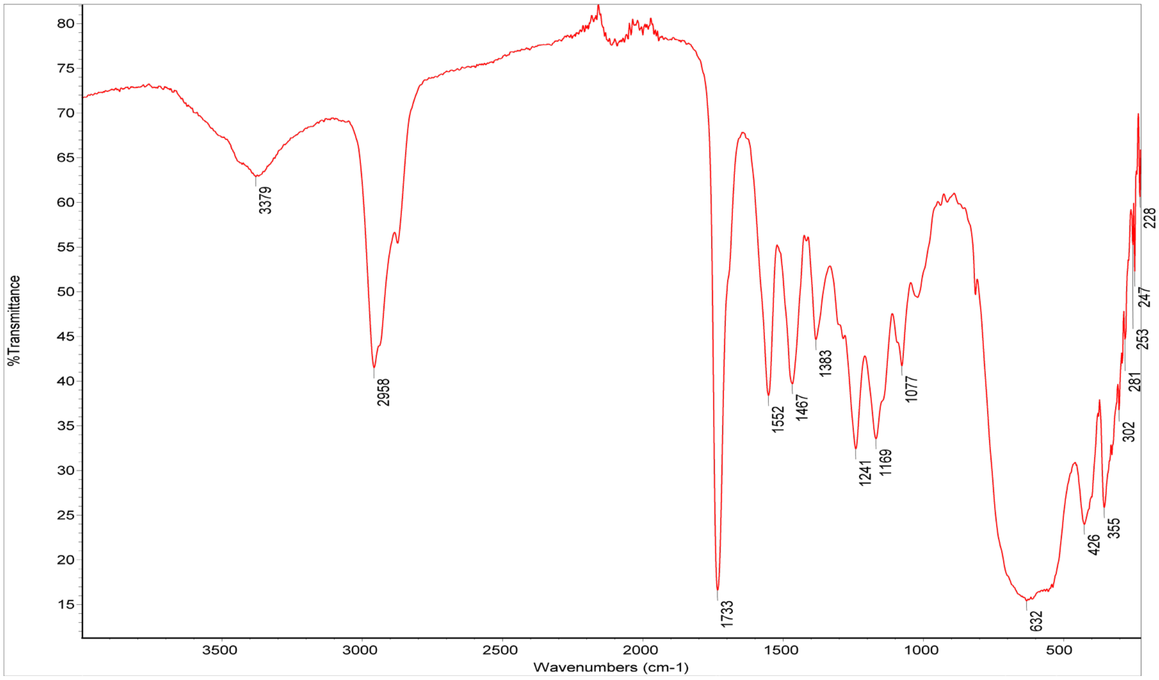

Figure 3: Spectrum of OT1, the white basecoat layer

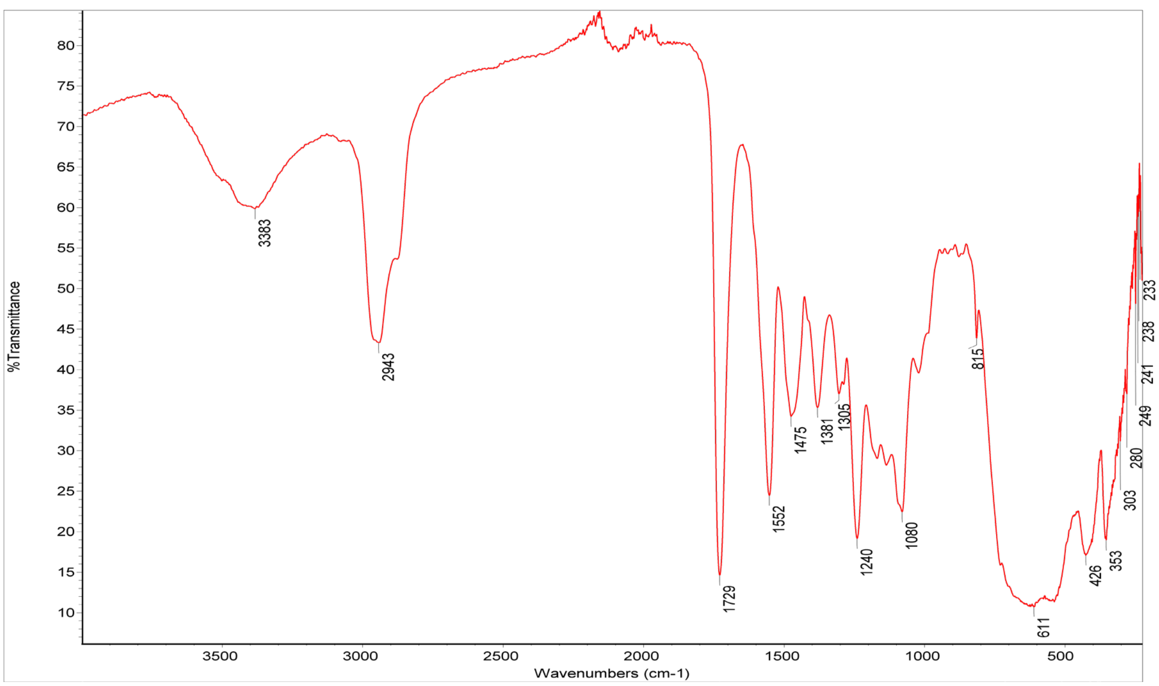

Figure 4: Spectrum of OU1, the white primer surfacer layer

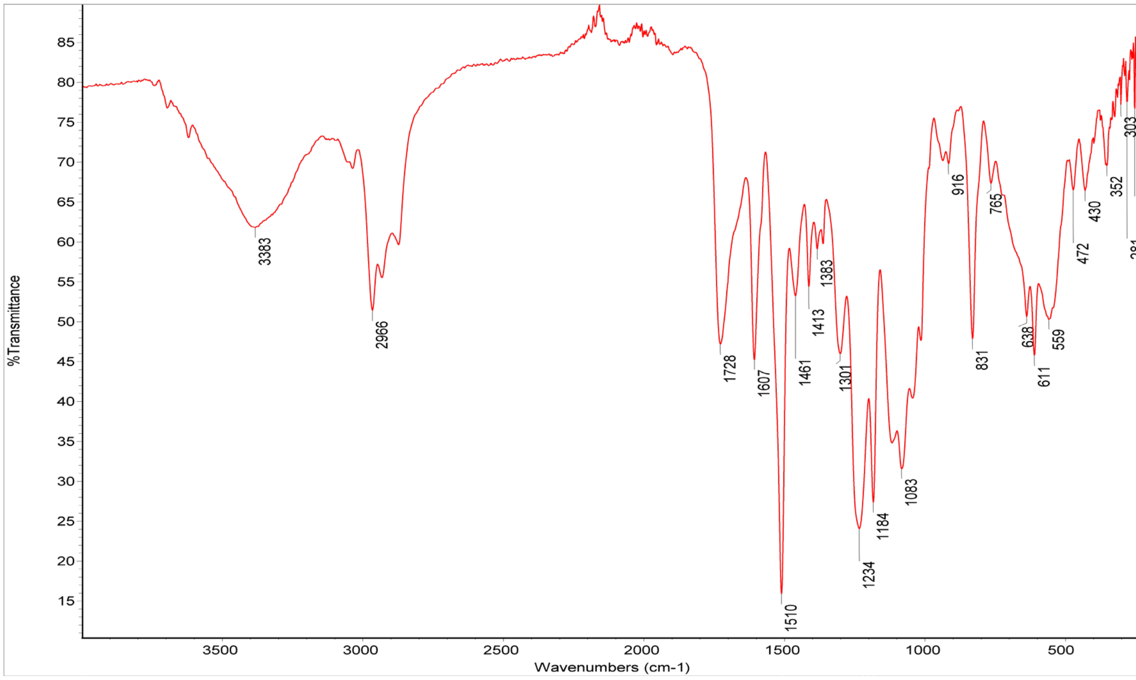

Figure 5: Spectrum of OU2, the medium gray electrocoat layer

Each spectrum was then coded using the PDQ IR Reference Sheets, as follows:

OT3: ACR MEL STY PUR
OT2: ACR ALK MEL PUR STY
OT1: ACR MEL
OU1: ALK IPH MEL OXI TIO
OU2: EPY PUR SIL ALS KAO OXI TIO SUL BAS [not $Zn_3(PO_4)_2$]

Table 1 depicts these assignments in a format similar to that displayed on the PDQ IR Reference Sheets such that it includes which wavenumbers correlate to the components observed in the spectra.

Table 1: Peak assignments made for each paint layer after labeling of PDQ spectra

Layer	**Component**	**PDQ Coding**	**Key peaks (cm^{-1})**
OT3	Acrylic	ACR	1729, 1468, 1384, 1166
	Melamine	MEL	1553, 815
	Styrene	STY	763, 703
	Polyurethane	PUR	1693 (shoulder on C=O), (1468)
OT2	Acrylic	ACR	1733, (1467), 1384, (1241), 1170
	Melamine	MEL	1552, 815
	Styrene	STY	763, 703
	Polyurethane	PUR	1685 (shoulder on C=O), (1467)
	Alkyd	ALK IPH	1733, 1467, 1241, 1077, 734
OT1	Acrylic	ACR	1733, 1467, 1383, 1241, 1169, 1146

	Melamine	MEL	1552, 812
	Polyurethane#	PUR	1690 (shoulder on C=O)
	Alkyd#	ALK OPH	(1733), (1383), 1077
	Titanium dioxide#	OXI TIO	Broad suppression from 740 – 550
OU1	Alkyd	ALK IPH	1729, 1475, 1381, 1305, 1240, 1129, 1080, 729
	Melamine	MEL	1552, 815
	Titanium dioxide	OXI TIO	Broad suppression from 730 – 550
OU2	Epoxy	EPY	1728, 1607, 1510, 1383, 1234, 1184, 831
	Polyurethane	PUR	1692 (shoulder on C=O), 1461, 1301, 1129, 729
	Titanium dioxide	OXI TIO	Broadening from 740 – 500
	Barium sulfate	SUL BAS	1083, 638, 611
	Kaolin	SIL ALS KAO	3696, 3618, 1041, 1010, 936, 916, 540

() wavenumbers could be representative of multiple components contributing to the peak
\# coded to acknowledge presence but not used in PDQ coding searches

An LSQ search should be constructed to target the minimum number of chemical components that could be found in the layer to focus on reasonable hits without excluding too many possibilities. Therefore, per PDQ Maintenance Team guidance, titanium dioxide was not coded in the search of the basecoat because not all basecoats are white and therefore would not contain this pigment. Similarly, the presence of an alkyd (or a particular alkyd) could be color dependent in that certain alkyd/pigment combinations are preferable within a formulation; therefore, this component is also not generally coded for the basecoat. Likewise, polyurethane in the basecoat was not coded because it appears to be present as a minor component. Therefore, not coding for it would still allow PDQ hits of the same type to be captured while not excluding hits that might also be good candidates based on other layers within the overall paint system.

Layer System Query Search & Results

LSQ searches can be run for a single layer or successively with each subsequent layer searched from the hits present for the previous layer. PDQ generally advises not to search the basecoat (OT1) through the database as not all colors are represented. However, since this particular basecoat was one of the colors PDQ routinely attempts to capture for every make-model-model year (MMY), an attempt was made. Using the layer sequence and chemistry above, an LSQ search was performed and the following number of hits was returned for each sequential layer:

OT3: 1537 hits
OT2: 641 hits
OT1: 641 hits (indicating no additional hits could be excluded between OT2 versus OT1)

OU1: 366 hits
OU2: 102 hits

The PDQ Maintenance Team later advised that a tri-coat was chosen in the hopes that users would use an OT* search term rather than separating out each layer individually, particularly since the chemistry of OT2 versus OT1 did not yield additional filtering of hits. Further, adding in an OT3 search term focused the hits on tri-coat systems, which could obscure basecoat/clearcoat samples from the same plant [8].

However, conducting the search as described yielded a possible 102 vehicles in the PDQ database. From this list of 102 possible hits, Table 2 shows the manufacturer, assembly plant, and number of vehicles/hits per plant. This tabular representation of the hit list allows an analyst to quickly surmise which manufacturer/plant combinations contain the largest number of hits that align with the questioned sample. A low number of hits does not necessarily equate to a low probability if there are not a lot of vehicles containing this type of formulation represented in PDQ. It is important to remain mindful that PDQ is not a population database. It is meant to provide the greatest possible range of chemical variation by attempting to include basecoats such as a black, red, white, and one other color vehicle per line per plant per model year.

Table 2: Results of LSQ search using text-based coding of spectra

Manufacturer	Assembly plant(s)	# of vehicles#	MY range+
BMW	2	1 each	2011, 2016
Ford	2	1, 6	2011-2017
Fuji (Subaru)	1	4	2013-2016
General Motors (GM)	2	4, 5	2014-2016
Honda	6	2,3,1,3,1,9	2003-16
Hyundai	3	3,2,2	2000-2014
Kia	1	5	2013-2016
Mazda	2	5	2013-2015
Nissan	2	2	2012
Tesla	1	1	2016
Toyota	3	2,1,1	2011-2014
Volkswagen	4	2,1,12,1	2000-2017

# denotes number of vehicles per plant
+ denotes model year range for all plants

From this table, Honda and Volkswagen have the highest number of assembly plants returned as well as the most vehicles represented at a given plant, compared to the other manufacturers in the hit list. These factors make these manufacturers appear favorable because the list also includes manufacturers such as Ford, GM and Toyota, which are known to have wide representation within the PDQ database yet contain a relatively low percentage of hits within this list.

However, when spectra for vehicles from Honda's Marysville, OH plant (Accord and Acura, predominant for the model year window) as well as Volkswagen's Puebla, Mexico plant (Beetle, Jetta, Tiguan) were evaluated against the quiz spectra, the spectra from neither plant compared favorably to the spectra for the 5-layered paint system. The same was true for the other plants represented. Therefore, the search parameters could have been too vague (or too specific) for one or more layers. Accordingly, a different search methodology was needed. One way to continue an LSQ search would be to eliminate a search for vehicles with a tri-coat finish and concentrate the top layer search on an OT* type layer. However, the approach chosen at this point was to switch to a spectral comparison methodology where the search could be more focused on spectral features rather than text-based spectral coding.

Combination Spectral and Name Search Results

Through an agreement between the RCMP and Bio-Rad®, PDQ partner laboratories can access the PDQ spectral libraries via their personal licenses of the Know-It-All™ software. Searching the PDQ libraries in this manner provides a visual way to quickly gauge how well an unknown paint layer's spectrum aligns with a layer in the database. Using the Property/Name search features in combination with the spectral libraries allows the analyst to filter by layer, manufacturer, plant, model year, or vehicle type. As each layer is searched, the resulting hit list can guide the search parameters for searches on subsequent layers.

With this approach, it is often prudent to begin spectral/name searches with the clearcoat or primer surfacer layers because the variability will be driven by chemical composition/supplier differences rather than by color alone.

As an example of a starting point to this search approach, a spectrum is loaded for searching against the entire PDQ library, where only the top 200 hits would be initially requested. The search algorithm recommended by PDQ is a 1st derivative Euclidean distance fit, and the results are displayed in a tabular format as well as in a spectral overlay display. The spectral overlay depicts each spectrum as a different color and contains a legend to allow the analyst to differentiate the unknown and the library spectra. The hit list table is arranged according to the Hit Quality Index (HQI), which depicts the best fit spectra in descending order. It also contains the PDQ ID for each spectrum, the partner lab code and sample number assigned by PDQ, the layer's chroma (e.g., N for neutral for a clearcoat), and the manufacturer, plant, and model year for the layer.

The software allows the analyst to export the hit list into a separate word processing format where the table columns can be edited, a header and page numbers can be added, and extra space is available for notes regarding the suitability of fit for the library hit versus the unknown layer. The spectral overlay for each hit versus the unknown layer can be copied and pasted into a word processing format for further comparison and commentary on the goodness of fit. The combination of the hit list with notes on the comparison of each hit to the unknown layer as well as the overlays of interest are used to document the results of each layer search. These formats are useful for a technical review of the search parameters and the results of each search conducted.

Spectral Search of 1st Layer – OT3 (Clearcoat)

For this layer, the Property search tab was used to conduct a Name search where the terms "OT" and "CLEAR" were used to filter the database entries that would be searched against the spectrum for OT3. This paint system contains an extra topcoat layer because it is a tri-coat, which is not necessarily unique to any manufacturer or plant, nor is it the only topcoat system that a given manufacturer or plant would produce. Therefore, the search has to remain broad enough to capture spectra that are OT2 layers.

Based on these search parameters, the first page of the top 200 hits are displayed as Table 3 below.

Table 3: First 30 hits of the top 200 hits for the spectral search of "OT" and "CLEAR"

	HQI		Tag	DB	ID	Name	Spectrum
1	934.32	0	Z_PDQ	56349	UARL00122	OT2 CLEAR	N HYU ALA 2011
2	932.05	0	Z_PDQ	61963	UFLO00613	OT2 CLEAR	N HON ALL 2012 MET CC
3	928.73	0	Z_PDQ	63938	UWIM00018	OT2 CLEAR	N HON GRN 2013 MET CC
4	926.12	0	Z_PDQ	60859	UVAC00452	OT2 CLEAR	N HON ELS 2013 MET CC
5	925.87	0	Z_PDQ	65151	UVAC00567	OT2 CLEAR	N GEN ORI 2017 MET CC
6	924.55	0	Z_PDQ	63953	UWIM00022	OT2 CLEAR	N HON GRN 2014 MET CC
7	923.88	0	Z_PDQ	54788	UVAC00356	OT2 CLEAR	N HON GRN 2012
8	923.29	0	Z_PDQ	46984	USCC00420	OT2 CLEAR	N HYU WST 2011
9	922.95	0	Z_PDQ	61887	UCTM00040	OT2 CLEAR	N HON ALL 2012 MET CC
10	922.33	0	Z_PDQ	32106	UMAB00006	OT2 CLEAR	N HYU ALA 2008
11	922.07	0	Z_PDQ	57531	UNYJ00104	OT2 CLEAR	N HON ALL 2012
12	921.75	0	Z_PDQ	25016	UCAD00142	OT2 CLEAR	N HYU ALA 2011
13	921.39	0	Z_PDQ	63826	UWAS00264	OT2 CLEAR	N HYU ALA 2014 MET CC
14	921.24	0	Z_PDQ	62442	UMNP00254	OT2 CLEAR	N HYU ALA 2014 MET CC
15	920.70	0	Z_PDQ	59822	UCOD00158	OT2 CLEAR	N HYU ASN 2013 MET CC
16	920.69	0	Z_PDQ	63887	UWAS00280	OT2 CLEAR	N KIA WST 2012 MET CC
17	919.91	0	Z_PDQ	54050	UGAA00255	OT2 CLEAR	N HON MAY 2012
18	919.64	0	Z_PDQ	59974	UKYF00259	OT2 CLEAR	N HYU ALA 2015 MET CC
19	919.52	0	Z_PDQ	54162	UMOK00044	OT2 CLEAR	N KIA WST 2011
20	918.65	0	Z_PDQ	61894	UCTM00042	OT2 CLEAR	N HYU WST 2012 MET CC
21	918.65	0	Z_PDQ	23936	UAZP00831	OT3 CLEAR	N KIA WST 2012
22	917.68	0	Z_PDQ	24709	UCAD00064	OT2 CLEAR	N HYU ALA 2007

23	917.42	0	Z_PDQ	53689	UCAD00202 OT3 CLEAR	N	HYU WST 2011
24	916.62	0	Z_PDQ	63899	UWAS00283 OT2 CLEAR	N	HYU ALA 2012 MET CC
25	916.40	0	Z_PDQ	63856	UWAS00272 OT2 CLEAR	N	KIA WST 2013 MET CC
26	916.13	0	Z_PDQ	45455	USCC00026 OT2 CLEAR	N	HYU ALA 2008
27	914.62	0	Z_PDQ	61979	UFLO00617 OT2 CLEAR	N	HON GRN 2013 MET CC
28	914.22	0	Z_PDQ	60871	UVAC00455 OT2 CLEAR	N	HYU ALA 2012 MET CC
29	913.55	0	Z_PDQ	63811	UWAS00260 OT3 CLEAR	N	HYU ALA 2015 MET CC
30	913.44	0	Z_PDQ	64678	UNCR00479 OT2 CLEAR	N	HON LCN 2014 MET CC

As Table 3 indicates, the Hyundai (HYU) plant in Montgomery, Alabama (ALA) and the Kia/Hyundai plant in West Point, Georgia (WST) as well as several US-based Honda plants dominate this list along with one entry for General Motors (PDQ code, GEN). Hit #200 on this list had an HQI of 861, indicating that there could well be more hits in the database that would appear to be a good candidate using this spectral algorithm. However, after hit #115, the visually consistent spectral hits became more spread out and the absence of the polyurethane shoulder on the carbonyl peak was the most frequent indicator for discrimination of these later hits.

Figures 6a-c contain examples of spectral overlays for a few of the top hits on the list displayed in Table 3. Notations in the captions indicate how the assessment of the "goodness of fit" would be documented within the case notes.

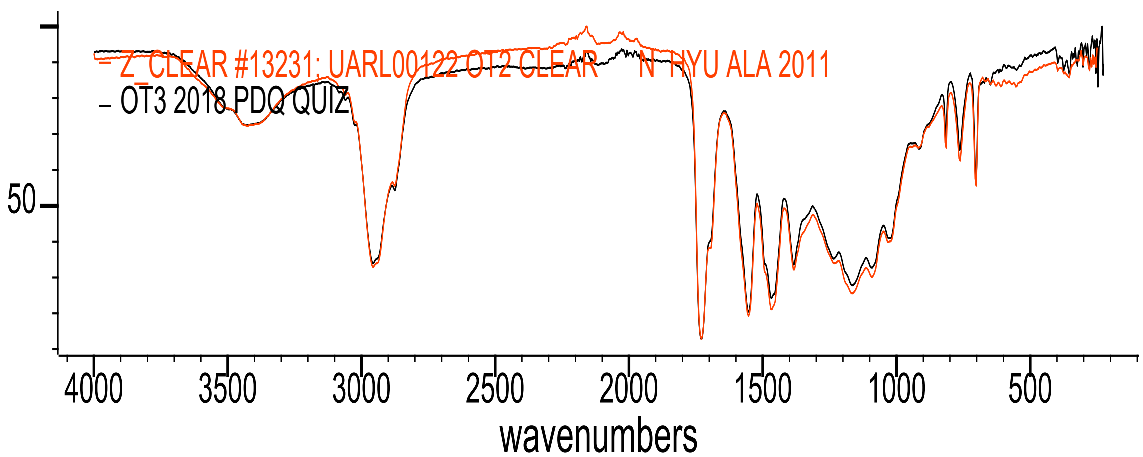

Figure 6a: Hit #1, good agreement

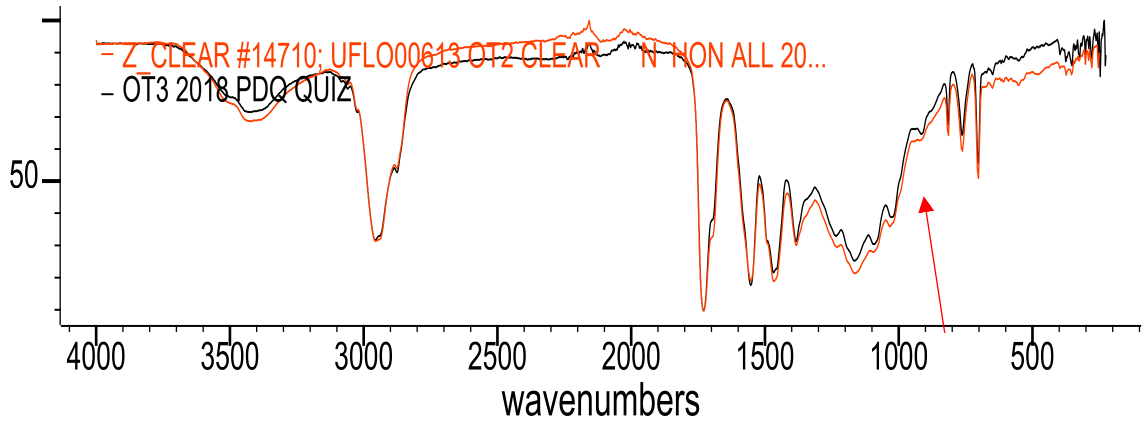

Figure 6b: Hit #2, differences noted at ~ 908 cm⁻¹ (see arrow)

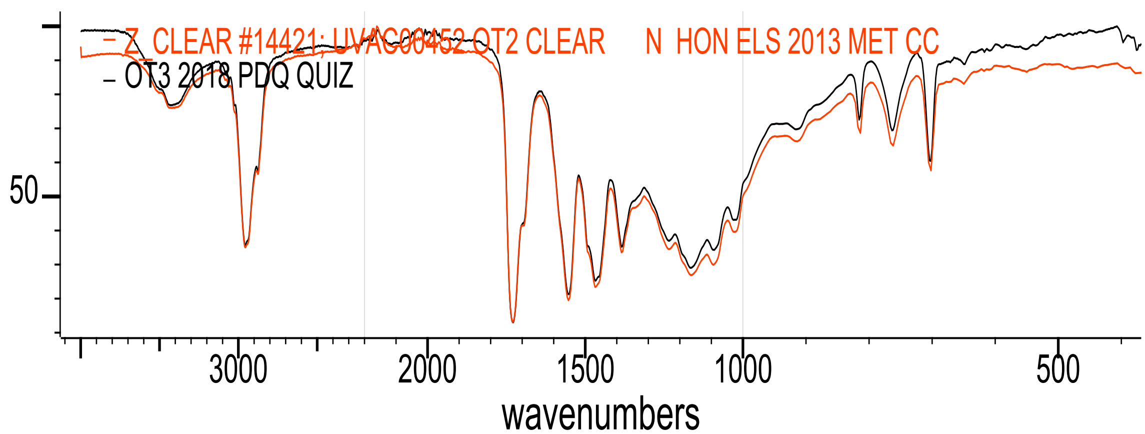

Figure 6c: Hit #4, good agreement

Regarding documentation of this search, all of the top 200 hits were printed and each PDQ sample on the list was annotated to indicate concurrence to the sample spectrum or to document which features eliminated it as a viable hit. Additionally, the spectral overlays for some of the top entries in the list were printed out to indicate commonality of compared spectral features. This approach allows a technical reviewer to review what features were used in the comparison in addition to evaluating the correspondence of the spectra.

Spectral Search of Another Layer – OU1 (Primer Surfacer)

For this second search, the same spectral search criteria as described above were used. For the Property search, the Name term was “OU” to allow for layer systems with additional underlayers such as anti-chip primer layers that could yield an “OU1” and an “OU2” above the electrocoat (“OU3” if anti-chip primer was present).

The HQI for the top hit was 896 for this search, not as well correlated by the search algorithm as for the clearcoat. This seemingly weaker correlation could be a function of the pigments and extenders suppressing the IR signal, a greater tolerance by the paint manufacturer for heterogeneity in an underlayer, or reasons not related to any one circumstance. Often a high HQI does translate to good spectral agreement between the PDQ hit and the sample, but it should not be used exclusively as a basis to include or exclude a specific hit or number of hits within a search.

The top five hits in this search were all from the US-based Kia and Hyundai plants and were good fits for spectral overlays with the OU1 layer from the quiz. Table 4 displays the first page of the top 200 hits for this spectral search and Figures 7a-c contain examples of spectral overlays for a few of the top hits on this list as well as an entry that was considered to contain features that could discriminate it from the quiz paint layer (i.e., Hit #10: FOR DEA 2005). For subtle differences such as this one (e.g., a possible concentration difference or the absence of a corresponding peak), replicates of the case spectra or examples of other PDQ samples from this plant for this layer and other layers would be needed to fully evaluate and document exclusion of this plant.

Table 4: First 30 hits of the top 200 hits for the spectral search of "OU"

	HQI	Tag	DB	ID	Name		Spectrum
1	896.35 0	Z_PDQ	60800	UVAC00437	OU1 N	9.3	KIA WST 2014 MET PS
2	879.55 0	Z_PDQ	59702	UCAD00298	OU1 N	8.8	HYU ALA 2015 MET PS
3	876.54 0	Z_PDQ	59878	UCOD00171	OU1 N	9.0	HYU WST 2013 MET PS
4	856.75 0	Z_PDQ	63812	UWAS00260	OU1 N	8.8	HYU ALA 2015 MET PS
5	847.80 0	Z_PDQ	62460	UMNP00258	OU1 N	9.0	HYU ALA 2013 MET PS
6	846.54 0	Z_PDQ	42734	UOKO00236	OU1 N	9.0	FOR DEA 2004
7	841.73 0	Z_PDQ	46633	USCC00329	OU1 N	9.3	GEN FLI 2008
8	841.37 0	Z_PDQ	56848	UCAD00226	OU1 N	9.0	GEN FLI 2012
9	838.37 0	Z_PDQ	23853	UAZP00811	OU1 N	9.0	GEN INE 2007
10	838.25 0	Z_PDQ	16885	CONT01751	OU1 N	8.5	FOR DEA 2005
11	838.19 0	Z_PDQ	64293	UAZP01115	OU1 10Y	9.0	GEN FLI 2015 MET PS
12	837.76 0	Z_PDQ	38950	UNYH00136	OU1 N	9.0	FOR STT 2003
13	837.34 0	Z_PDQ	23202	UAZP00653	OU1 N	8.8	FOR DEA 2006
14	837.05 0	Z_PDQ	50546	UVAC00254	OU1 N	9.0	FOR DEA 2002
15	836.63 0	Z_PDQ	25004	UCAD00139	OU1 N	9.0	GEN FLI 2009
16	832.08 0	Z_PDQ	16444	CONT01642	OU1 N	7.5	HYU ALA 2007
17	831.84 0	Z_PDQ	65020	UVAC00532	OU1 10B	6.0	HON LCN 2014 MET PS
18	829.68 0	Z_PDQ	20314	UARL00058	OU1 N	9.5	GEN OS1 2005
19	828.82 0	Z_PDQ	23235	UAZP00661	OU1 N	8.0	FOR DEA 2006
20	828.44 0	Z_PDQ	26250	UCAR00275	OU1 N	8.8	FOR LOU 2003
21	827.62 0	Z_PDQ	60764	USCC00575	OU1 N	8.8	HYU ALA 2014 MET PS
22	827.62 0	Z_PDQ	62629	UNCR00455	OU1 N	9.0	GEN FLI 2013 MET PS
23	827.25 0	Z_PDQ	50538	UVAC00252	OU1 N	9.0	FOR LOU 2002

24	826.98	0	Z_PDQ	58461	UVAC00392 OU1 N	9.0	GEN FLI 2013
25	826.69	0	Z_PDQ	56908	UCAD00241 OU1 N	9.0	GEN FLI 2012
26	825.88	0	Z_PDQ	63312	USCC00611 OU1 N	8.8	HYU ALA 2016 MET PS
27	825.87	0	Z_PDQ	58513	UVAC00406 OU1 5PB	7.0	TOY CBG 2011
28	825.60	0	Z_PDQ	61270	AVCM00880 OU15PB	5.0	FOR CNE 2013 MET PS
29	825.47	0	Z_PDQ	31369	UKYF00153 OU1 10B	6.0	GEN OS1 2002
30	825.39	0	Z_PDQ	61507	CONT02037 OU1 N	9.3	HYU WST 2013 MET PS

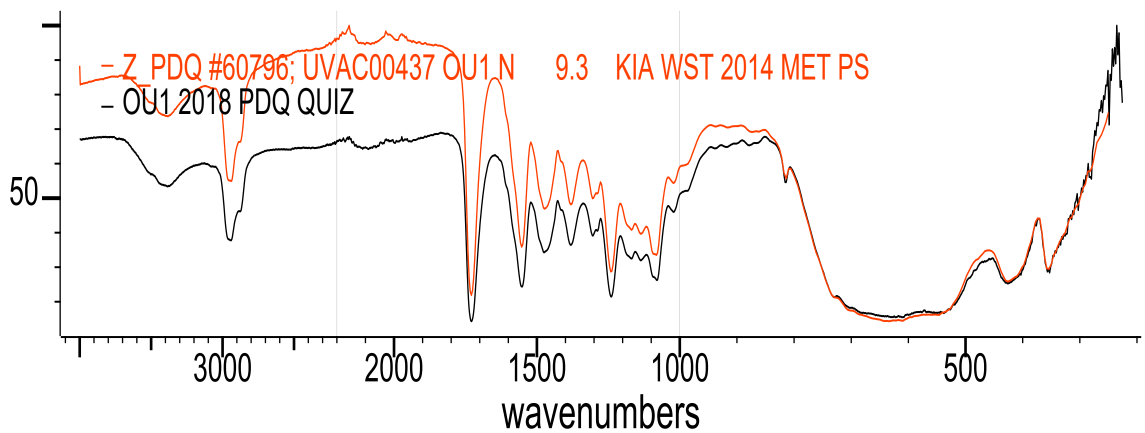

Figure 7a: Hit #1, good agreement

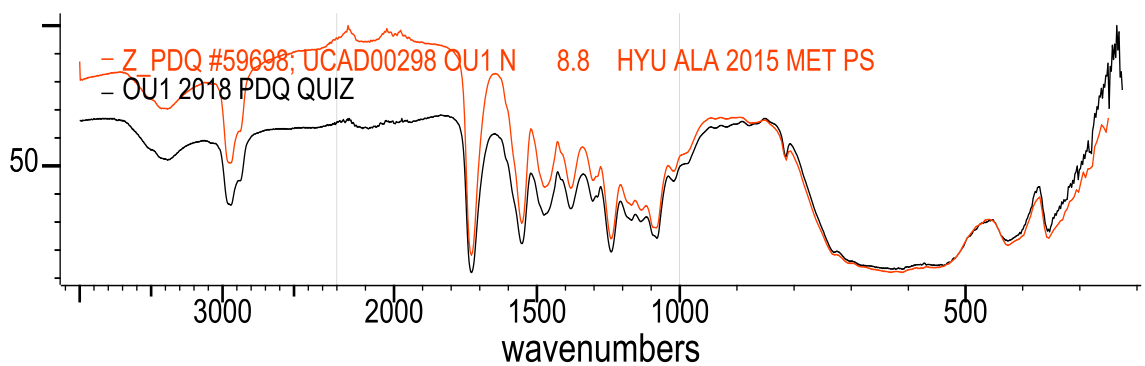

Figure 7b: Hit #2, good agreement

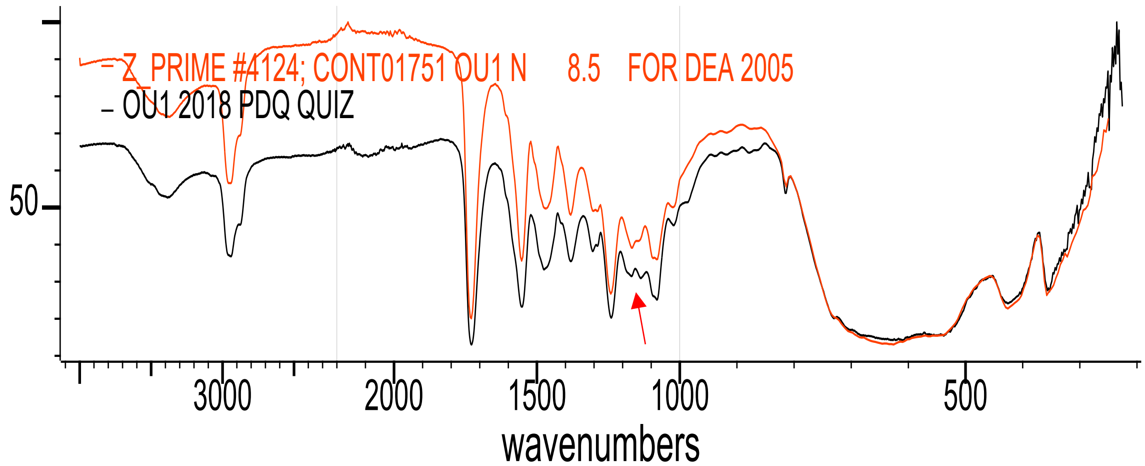

Figure 7c: Hit #10, differences noted at 1150 cm-1 (see arrow)

Spectral Search Indicators After Two Independent Layer Searches

Table 5 provides a summary of the best hits for the individual searches for OT3 and OU1. From this data, it became evident that combining the information generated from both searches indicated the Hyundai plant in Montgomery, Alabama (ALA) and the Kia plant in West Point, Georgia (WST) were strong contenders for the origin of the quiz data.

Table 5: Summary of the Search Results for OT3 and OU1

OT3			OU1		
Make	**Plant**	**Model Year(s)**	**Make**	**Plant**	**Model Year(s)**
GEN	FOR	'15	N/A+		
	FAI	'16			
HON	GRN	'12,'13	N/A+		
	ALL	'12			
	MAY	'07,'10, '12-'14			
	ELS	'09			
HYU	ALA	'06-'11, '13, '15	HYU	ALA	'13-'16
	WST	'11, '12, '17			
	ASN	'14			
KIA	WST	'11-'16	KIA	WST	'13, '14, '16
	WHA	'14			

+ refers to no good hits for this manufacturer, which led to exclusion

A third independent search was conducted in the same manner using the OU2 electrocoat layer and adding in Name search properties for "KIA". A fourth search was conducted using this layer and the name property "HYU". However, the electrocoat layer is generally supplied by a single paint supplier to most manufacturers and tends to vary in concentration of extender pigments more than in the absence or presence of these pigments or with respect to binder changes. Therefore, it was unsurprising that the top 200 hits in these searches were not vastly different or discriminating between the two plants, between model years, or from the quiz sample. As with the previous searches, the spectral search hit list with comments regarding how each set of spectra compare as well as some examples of spectral overlays were retained as documentation of the searches and the conclusions drawn from each search that was executed.

Refining the Spectral Search for Manufacturer/Plant/Model Year

Based on these results, additional spectral/name search combinations were run for each manufacturer/plant combination that resulted from the combined results of the OT3 clear coat and OU1 primer surfacer searches.

Hyundai Plant

Using the OT3 clearcoat spectrum in combination with search parameters of "HYU" and "ALA" and "OT" and "CLEAR", 98 clearcoat records were located in PDQ, 83 of which were on metal substrates. None of the plastic substrate hits were a good fit for OT3. This is to be expected given the chemistry for OT3 (see Figure 1) where the strong presence of melamine is indicative of a much higher cure temperature than would be suitable for a plastic substrate. Of the 83 clearcoat hits from a metal substrate, only 12 were a good fit for the OT3 spectrum. These 12 hits spanned a model year range of MY 2007-2015.

Using the spectrum for the OU1 primer surfacer layer in combination with search parameters of "HYU" and "ALA" and "OU", 154 records were located in PDQ. Hits 81-154 on the list were all OU2 layers (i.e., containing a predominantly epoxy binder) and therefore not the appropriate chemistry to compare to OU1. From the top 80 hits on the list, only 5 were considered a good fit for the OU1spectrum. These hits ranged from MY 2013 (2 hits), 2015 (2 hits), and 2016 (1 hit). Since the number of hits returned could just as easily be a function of how many like samples were entered into PDQ as opposed to how many are actual good fits, the model year range was expanded to 2011-2016.

This decision regarding model year range can be somewhat arbitrary and not easily validated or confirmed given that manufacturers (or their paint suppliers) can change formulations, suppliers, and tolerances for a given layer at an undefined interval. Limitations to the conclusions can be added to a report to mitigate a reader's attempt to narrowly focus on reported model year ranges. Further, the PDQ Maintenance Team recommends adding one year to either end of a suspected model year range in order to maximize the potential to capture like vehicles not represented in the database.

Kia/Hyundai Plant

An independent spectral/name search combination was then run for the Kia/Hyundai plant in Georgia. As an example, using the spectrum for the OT3 clear coat along with the search parameters of "KIA" and "WST" and "OT" and "CLEAR", 54 records were located in PDQ, 46 of which were on metal substrates. Of the 46 hits, hits 1-25 were not obviously different from the OT3 spectrum. Spectral overlays of these 25 indicated that only 10 were viable considerations in relation to OT3. These 10 hits spanned a model year range between 2011-2016.

Then, using the spectrum for OU1 along with the search parameters of "KIA" and "WST" and "OU", 78 records were located in PDQ where only the top three hits were not obviously different from the OU1 spectrum. These hits ranged from MY 2014 (2 hits) to 2015 (1 hit).

Summary of All Search Results

Using this information in concert with the MMY tables from the periodical Automotive News that PDQ supplies with the database updates each model year, it was readily apparent that Hyundai and Kia shared a line at the West Point, Georgia facility during this model year window. Revisiting the goodness of fit of the spectral overlays, the Hyundai plant in Montgomery, Alabama, was considered the best fit for the OT3 layer. However, in conjunction with the inability to eliminate the KIA WST plant for both clear and primer surface layers, the shared presence of HYU at WST made the KIA/HYU WST plant a good candidate for the PDQ quiz sample.

The PDQ Maintenance Team advised that the actual sample originated from a 2013 Kia Sorrento from the West Point plant, but that the Montgomery, Alabama (ALA) plant also had some good candidates. It should be noted that both plants returned hits for this model year range on the original LSQ search that was conducted and opinions on both would be thoroughly documented in the case notes along with reasons to include or exclude for the final report discussion (see Table 2).

After this work was completed and evaluated by the PDQ Maintenance Team, a second FBI paint analyst also completed the quiz using a similar spectral comparison approach to independently identify a viable hit list, which yielded a slightly different model year range. These findings indicated that this approach worked well for both analysts who self-report a greater comfort level with spectral overlay comparisons than with text-based searches. The exercise provided an opportunity to compare search methodology as well as the documentation each analyst found helpful as a technical reviewer. From this exercise, a more consistent approach to both PDQ searches and technical review could be discussed and implemented.

Wording for the MMY Report

One of the biggest challenges in working an investigative lead case is in deciding how broadly or narrowly to word the results in order to best assist the contributor in pursuing viable leads.

The FBI Laboratory's Paints and Polymers team uses a verbal scale to provide context to the conclusions reported for these types of cases.

Had this been a case, the following report wording would have been used along with inclusion of the complete Interpretation Scale to provide the reader with context for the range of conclusions that could be reported for this type of request.

> Based on resources available to the FBI Laboratory, Item 1 is a 5-layered original equipment manufacturer (OEM) automotive paint chip, consisting of a white metallic tri-coat as the basecoat color. This paint is consistent with originating from a 2011-2016 vehicle produced from the West Point, Georgia plant that produces both the Kia Sorrento and the Kia Optima as well as the Hyundai Santa Fe (*Classification* - see Interpretation section).
>
> **Interpretation**:
>
> The following descriptions are meant to provide context to the conclusions reached in this report. Every type of conclusion may not be applicable in every case nor for every material.
>
> *Identification*: The analytical data provides reliable information to specify a particular chemical or product.
>
> *Classification*: The analytical data does not support an identification of a specific chemical or product but does provide reliable information to include the substance within a class of materials. The phrase "consistent with" may be used in this context.
>
> *Indication*: The analytical data suggests a particular type of material but does not support a classification or identification. The terms "possible" and "similar to" may be used in this context.

Depending on whether corollary information could be added based on other resources (e.g., paint supplier refinisher pages to provide color code information, size of the paint chip, substrate indicators such as a galvanized paint layer, fiberglass, or fascia), additional information could be provided to assist the reader in targeting their search. Conversely, factors that would be informative to the reader such as limitations of the database population could also be addressed in the body of the report or in a separate section as needed to provide context to the results. Limitations could be expressed with a statement such as "A search for a suspect vehicle should include, but not be limited to, the vehicle types named in this report."

CONCLUSIONS

The Paint Data Query database is a powerful tool to assist in developing investigative leads in hit-and-run casework. It should not be considered to be a comprehensive population database and it is not always possible to ascertain if the resulting hit list captures the full range of makes, plants, and model years for which a particular paint layer system would have been available within North America. However, it is the model most trace examiners acknowledge as what a successful database for commercial products should aspire to become, and it is a resource that only gains value as it continues to be populated with a wide range of samples from its many global partners. The best approach to mining the database for its wealth of information can be a subject of some debate, but it remains a reality that only with continued use and practice can an analyst best become proficient in conducting MMY searches.

Participation in the PDQ quiz can be used as a training or competency exercise as well as an internal proficiency test if a laboratory deems such testing to be appropriate for their analysts. The quiz is also a useful tool to re-check an analyst's competency prior to casework if the frequency of case submission is sporadic.

Further, this type of exercise provides laboratories with the ability to develop best practices for search documentation and technical review parameters to ensure consistency between analysts over time. Specifically, with respect to this type of search and its reporting, documentation should be sufficient to ensure the following can be evaluated by a technical reviewer:

- Appropriate data has been collected for each paint layer as applicable
- The peaks or components of interest that were used or considered important for a comparative search
- The actual parameters used for a given search
- The results of the search
- The results of evaluation of each hit returned from a given search
- Next steps derived from the results of a given search
- Additional resources used to further narrow the search results (e.g., Automotive News, paint manufacturer refinisher pages, internet)
- Conclusions that will be reported to include limitations of the search results

The guidance provided for report writing and interpretation has been used in FBI Laboratory casework involving PDQ searches, other types of make-model-year searches involving plastic automotive part sourcing, and polymer classification requests for unknown fragments. Should a PDQ search result in submission of paint from a suspect vehicle for comparison, a different interpretation scale would be used to report out the results. Further examples of the use of these interpretation scales for paint or polymer materials can be found at https://fbilabqsd.com/.

This is publication number 20-60 of the FBI Laboratory Division. Names of commercial manufacturers are provided for identification purposes only, and inclusion does not imply endorsement of the manufacturer, or its products or services by the FBI. The views expressed are those of the authors and do not necessarily reflect the official policy or position of the FBI or the U.S. Government.

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