The Status of Status Densitometry

John Lind*, Greg Radencic*, and John P. Sweeney**

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Abstract: The standardization of graphic arts densitometry, namely Status-T, has been a great success, by any measure. However, there is still confusion in the graphic arts regarding Status Densitometry, use of polarization filters, and with new instrument manufacturers and new measurement techniques, questions regarding inter-instrument agreement have been raised.

This study is a survey of commercially available instruments, including densitometers, and spectrodensitometers, to determine the current status of Status T Densitometry. A number of materials, including ink on paper samples, T-Ref Standard Reference, SWOP Hi-Lo Ink references, and representative color proofing samples, are measured with the nine instruments in the study.

The purpose is to demonstrate the differences in Status Densitometry that one might encounter in a typical graphics arts production environment, where densitometric data is communicated.

Observations about the agreement of instruments, and whether performance is adequate are shared. Suggestions for further study are made.

Scope

This study includes the following:

a. Density Measurements
b. Comparative instrument specifications discussion
c. Analysis of the data
d. Conclusions and comments

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* Graphic Arts Technical Foundation
** Graphics Microsystems, Inc.

Terms and definitions

For the purposes of this study, the following terms and definitions apply. There are a number of commonly used terms used in connection with the subject of densitometry, such as repeatability and stability, and their use in this report at consistent with applicable international standards.

3.1 **True value** (of a quantity)
value consistent with the definition of a given particular quantity.

NOTE: The value that would be obtained by a perfect measurement. True values are by nature indeterminate. The indefinite article "a", rather than "the", is used because there may be many values consistent with the definition of a given particular quantity.

3.2 **Conventional true value** (of a quantity)
value attributed to a particular quantity and accepted, sometimes by convention, as having an uncertainty appropriate for a given purpose

NOTE: Sometimes called **assigned value**, **best estimate** of the value, **conventional value** or **reference value.**

3.3 **Measurand**
particular quantity subject to measurement

3.4 **Repeatability** (of results of measurement)
closeness of the agreement between the results of successive measurement of the same measurand carried out under the same conditions of measurement

3.5 **Systematic error**
mean that would result from an infinite number of measurements of the same measurand carried out under repeatability condition minus a true value of the measurand

3.6 **Error (of indication) of a measuring instrument**
indication of a measuring instrument minus a true value of the corresponding input quantity

3.7 **Stability**
ability of a measuring instrument to maintain constant its metrological characteristics with time

3.8 **Bias (of a measuring instrument)**
systematic error of the indication of a measuring instrument

3.9 Traceability

property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties

3.10 Calibration

set of operations that establish, under specified conditions , the relationship between values represented by a material measure or a reference material, and the corresponding values realized by standards

3.11 Reference material (RM)

material or substance one or more of whose property values are sufficiently homogeneous and well established to be used for the calibration of an apparatus, the assessment of a measurement method, or for assigning values to materials

3.12 Certified reference material (CRM)

reference material, accompanied by a certificate, one or more of whose property values are certified by a procedure which establishes traceability to an accurate realization of the unit in which the property values are expressed, and for which each certified value is accompanied by an uncertainty at a stated level of confidence

NOTE: Also known as a **Standard Reference Material (SRM).** In the Graphic Arts, the Idealliance / GCA T-Ref is the recognized CRM for verifying Status-T densitometry conformance

3.13 Coverage factor

k

numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty

NOTE: A coverage factor, *k*, is typically in the range of 2 to 3.

3.13 Combined standard uncertainty

***u* c**

standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances or covariances of these other quantities weighted according to how the measurement result varies with changes in these quantities

NOTE: The coverage factor is chosen based on the level of confidence desired. A coverage factor (k) of 2 generally will result in a level of confidence of approximately 95%, and a coverage factor of 3 generally will result in a level of confidence of approximately 99%. This association of confidence level and coverage factor is based on assumptions regarding the probability distribution of measurement results.

3.15 Expanded uncertainty

U

quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of values that could reasonably be attributed to the measurand

NOTE: Expanded uncertainty is the product of the combined standard uncertainty (u) and the chosen coverage factor (k).

3.16 Measurement uncertainty

parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

NOTE 1: For the purposes of this test and report, each component of the uncertainty is assumed to have a normal distribution.

NOTE 2: The result of a measurement is only an approximation or estimate of the value of the measurand and thus is complete only when accompanied by a statement of the uncertainty of that estimate.

Determination versus Verification of Densitometric Instrument Performance

In a manufacturer's determination of performance specifications, individual manufacturers establish test methods using traceable reference materials, under defined environmental conditions, and conduct testing in a repeatable, traceable laboratory setting. The purpose is to maintain a test environment such that the densitometers evaluated yield results that may be expected by users. The end results are published performance specifications that can be used to compare various instruments and verify performance of installed instruments.

It should be understood that published performance specifications are determined for specific instruments of a particular class, type or model. When comparing instruments of different make, class, or model, it is important to understand not only the published performance specification of each instrument, but the constraints of each, which include illuminate type, aperture size and shape, all of which contribute to uncertainty.

Vogelsong, in his 1990 TAGA paper "*Capability studies of densitometers and densitometry*" reports that two densitometers calibrated to the same set of physical reference standards will agree within 1α 68% of the time and within 2α 95% of the time. Since standards generating is a process, the value of α_T (total standard deviation of the densitometric process) must be expanded to include the variability of the calibration standards manufacturing process, which is typically ¼ of densitometric errors.

Note: Vogelsong served as Chairman ANSI IT2-218 Subcommittee on Densitometry, and chaired the T-Ref development committee.

In this study, the instruments were not calibrated to the same physical reference, but rather to their supplied reference, to better simulate densitometer us in production application, where instruments are typically at different locations, and calibration to a single reference is not practical.

The following four items include assumptions, and discussion of key sources of variation when comparing two instruments of different classes.

1. For comparison of two instruments of different make and model, the combined standard uncertainty of both instruments must be determined, and taken into consideration. One cannot assume that one of the two instruments yield a true value, or conventional true value, as both are subject to bias and variability.

2. The time difference between measurements contributes to the difference (delta) in mean density values between the two instruments. A major contributor to this effect is change in moisture content, as the dry sheets or signatures may pick up moisture, or lose moisture, depending on ambient conditions. There can be a measurable effect on measured density values due to changes in surface characteristics over time.

In the case of this study, however, the measurements were taken over a short period of time, under controlled laboratory conditions. The measurands (samples) remained in the laboratory for the duration of the study, so the temporal effect can be considered insignificant.

3. Instrument aperture size, or effective measurement area, could account for some portion of the differences between the reported mean density values.

4. Traceable CRM (Certified Reference Materials) should be used in determining instrument performance. In this study, a T-Ref was used a primary measurand. While the other graphic arts materials also measured in this study are not CRM's, they were chosen as representative to what is measured in standard print manufacturing environments.

In the determination and verification of instrument performance, carried out by instrument suppliers in the manufacturing process, and by users in the field, the use of traceable CRM's is critical.

Description of Test Procedure

1. Each instrument was calibrated using the supplied calibration reference.
2. Each instrument was then checked against its own calibration reference to verify calibration.
3. Each sample (measureand) was measured 5 times without moving the instrument, and the data recorded.
4. Each sample (measureand) was measured again, this time removing and replacing the instrument, and the data recorded.
5. Statistical analysis of the data was performed.

All measurements were performed in the Preucil Print Analysis Laboratory at GATF, Sewickley, PA, utilizing instruments provided for use at GATF by their respective manufacturers.

All measurements were taken in accordance with ANSI/CGATS.5, and backed with GCA Backstop material, which meets the requirements of CGATS for backing material. Specifically this is a black, or spectrally non-selective, materials, to minimize show through.

A sample size of 5 for comparative measurement by handheld instruments was selected based on the range of standard deviations encountered. For this report, the mean density values reported are from the 5 consecutive measurements, where the instrument was not replaced.

The following measurands were selected as representative of the range of graphic arts materials typically measured with densitometers in graphic arts production.

1. GCA T-Ref
2. SWOP Hi-Lo ink reference, SWOP Inc.
3. Offset Print Sample, Gloss Coated paper
4. Offset Print Sample, Matte Coated
5. Offset Print Sample, Uncoated
6. Offset Print Sample, Newsprint
7. Off-press Photomechanical Proof, Matchprint Commercial
8. Offpress Digital Inkjet Proof

A statistical analysis of the resulting measurement data and several "goodness of fit" tests were then performed. The analysis and tests performed followed “standard” statistical methods, valid when measurement devices, sampling methods, measurement targets, and measurement processes are identical between sample sets, and only the samples themselves are expected to vary.

The following instruments were used in this study.

1. X-Rite Model 939, Serial # 150, 4mm aperture, T Response
2. X-Rite Model 530, Serial # 1133, 3.4mm aperture, T_x Response
3. X-Rite Model 530, Serial # 1133, 3.4mm aperture, T Response
4. Gretag D196, Serial # 20150, 4mm aperture, T Response
5. Gretag D19C, Serial # 10692, 4mm aperture, T / Polarized
6. Gretag SpectroEye, Serial 10439u, x aperture, T Response
7. Gretag D196, Serial # 17561, 4mm aperture, T / Polarized
8. Ihara 730, Serial # 72905, 3mm aperture, T Response
9. Tobias IQ 150, Serial # ih2009, 3.4 aperture, T Response

It should be noted that while most instrument manufacturers have similar format for published performance specifications, it is not standardized, and the test methods used to determine performance vary by manufacturer.

Experimental Procedure Differences

When performing any kind of statistical analysis of two disparate sample sets, many fundamental assumptions are made. The assumption is made that the two sample sets were collected by the same sampling procedure, in approximately the same time frame. The assumption is made that both sample sets are part of a normal distribution of samples.

In the case where multiple instruments of the same type, model, or class are being compared, the same sampling procedure and same measurement process can be utilized. After having established repeatability and stability for a statistically valid sampling of instruments of a particular class, type or model, it is appropriate to compare test results to the published performance specification for that single class of instruments.

Different Instrumentation

- The most obvious difference is that which is being validated; i.e. that the measurements provided by both types of instruments are in agreement with each other, within the limits of measurement uncertainty.
- Some instruments employ different illuminant types. Each instrument has a different sampling aperture size and shape.
  Some instruments in the study are filter instruments, others are spectrophotometer based. These constraints contribute to measurement agreement uncertainty.
- Each instruments should have measurements verified with a CRM (T-Ref).

All of these conditions contribute to measurement agreement uncertainty. For more information regarding the measurement and quantification of uncertainty, see ISO-15790 (ANSI CGATS.11).

Data Summary and Comments

Measurement Delta vs. T-Ref Value		**Black**	**Cyan**	**Magenta**	**Yellow**
Target values		1.68	1.29	1.39	1.04
X-Rite 939		0.02	0.01	-0.01	0.01
X-Rite 530 Tx		0.01	0.01	0.02	0.02
X-Rite 530 T		0.00	0.01	0.00	0.00
Gretag D196(unpolarized)		0.00	0.01	0.00	0.00
Gretag D19C(polarized)		0.00	0.00	0.02	0.01
Gretag SpectoEye		0.03	0.00	0.01	0.00
Gretag D196 (polarized)		0.01	-0.01	-0.02	-0.02
IHARA		0.00	0.01	-0.01	**0.06**
Tobias IQ 150		-0.02	0.01	0.01	-0.01

It is interesting to note that when measuring the T-Ref, only one instrument failed, and only with the blue filter, yellow density measurement. All instruments measured their respective calibration references within tolerance.

Instruments equipped with polarizing filters passed the T-Ref verification, although by definition, a polarized instrument is not Status-T.

SWOP HIGH minus LOW		**Black**	**Cyan**	**Magenta**	**Yellow**
X-Rite 939		0.16	0.16	0.14	0.14
X-Rite 530 Tx		0.16	0.16	0.13	0.14
X-Rite 530 T		0.13	0.16	0.15	0.15
Gretag D196(unpolarized)		0.15	0.16	0.14	0.15
Gretag D19C(polarized)		**0.28**	0.20	0.17	0.17
Gretag SpectoEye		**0.28**	0.20	0.17	0.15
Gretag D196 (polarized)		**0.27**	0.18	0.19	0.14
IHARA		0.14	0.14	0.13	0.13
Tobias IQ 150		0.13	0.15	0.14	0.15

The SWOP High – Low is an ink on paper reference is designed to establish for a particular instrument, the allowable density range for press proofing for publications. Note the higher black density range when measured with polarizing filter.

Gloss Coated		Black	Cyan	Magenta	Yellow
X-Rite 939		1.70	1.46	1.56	1.07
X-Rite 530 Tx		1.71	1.44	1.59	1.08
X-Rite 530 T		1.69	1.45	1.58	1.06
Gretag D196(unpolarized)		1.68	1.48	1.60	1.04
Gretag D19C(polarized)		1.94	1.57	1.71	1.13
Gretag SpectoEye		1.94	1.54	1.69	1.11
Gretag D196 (polarized)		1.91	1.54	1.69	1.07
IHARA		1.68	1.47	1.55	1.08
Tobias IQ 150		1.66	1.45	1.60	1.05
	Min	1.66	1.44	1.55	1.04
	Max	1.94	1.57	1.71	1.13
	Range	0.28	0.13	0.16	0.09
	Mean	1.77	1.49	1.62	1.08
	1α	0.12	0.05	0.06	0.03

Matte Coated		Black	Cyan	Magenta	Yellow
X-Rite 939		1.59	1.41	1.49	1.05
X-Rite 530 Tx		1.61	1.39	1.48	1.07
X-Rite 530 T		1.59	1.4	1.49	1.04
Gretag D196		1.63	1.43	1.49	1.02
Gretag D19C (polarized)		1.94	1.57	1.7	1.11
Gretag SpectroEye		1.92	1.56	1.67	1.11
Gretag D196 (polarized)		1.87	1.55	1.66	1.08
Ihara		1.59	1.41	1.42	1.06
Tobias IQ 150		1.57	1.39	1.51	1.02
	Min	1.57	1.39	1.42	1.02
	Max	1.94	1.57	1.7	1.11
	Range	0.37	0.18	0.28	0.09
	Mean	1.70	1.46	1.55	1.06
	1α	0.16	0.08	0.10	0.03

Matte Coated		Black	Cyan	Magenta	Yellow
X-Rite 939		1.59	1.41	1.49	1.05
X-Rite 530 Tx		1.61	1.39	1.48	1.07
X-Rite 530 T		1.59	1.4	1.49	1.04
Gretag D196		1.63	1.43	1.49	1.02
Ihara		1.59	1.41	1.42	1.06
Tobias IQ 150		1.57	1.39	1.51	1.02
	Min	1.57	1.39	1.42	1.02
	Max	1.63	1.43	1.51	1.07
	Range	0.06	0.04	0.09	0.05
	Mean	1.60	1.41	1.48	1.04
	1α	0.021	0.015	0.031	0.021

Matte Coated – Status-T instruments only. (Polarized instruments excluded).

UnCoated		Black	Cyan	Magenta	Yellow
X-Rite 939		1.18	1.02	1.15	0.89
X-Rite 530 Tx		1.26	1.03	1.18	0.90
X-Rite 530 T		1.22	1.01	1.15	0.89
Gretag D196(unpolarized)		1.21	1.00	1.16	0.89
Gretag D19C(polarized)		1.59	1.17	1.40	1.07
Gretag SpectoEye		1.61	1.17	1.39	1.04
Gretag D196 (polarized)		1.57	1.15	1.38	1.00
IHARA		1.23	1.03	1.15	0.94
Tobias IQ 150		1.20	1.00	1.16	0.85
	Min	1.18	1.00	1.15	0.85
	Max	1.61	1.17	1.40	1.07
	Range	0.43	0.17	0.25	0.22
	Mean	1.34	1.06	1.24	0.94
	1α	0.19	0.08	0.12	0.08

NewsPrint		**Black**	**Cyan**	**Magenta**	**Yellow**
X-Rite 939		0.94	0.84	0.80	0.77
X-Rite 530 Tx		0.94	0.85	0.82	0.80
X-Rite 530 T		0.92	0.85	0.80	0.77
Gretag D196(unpolarized)		0.92	0.83	0.79	0.77
Gretag D19C(polarized)		1.12	0.99	0.92	0.94
Gretag SpectoEye		1.15	1.01	0.94	0.96
Gretag D196 (polarized)		1.22	1.01	0.95	0.95
IHARA		0.99	0.87	0.82	0.85
Tobias IQ 150		0.97	0.84	0.79	0.76
	Min	0.92	0.83	0.79	0.76
	Max	1.22	1.01	0.95	0.96
	Range	0.30	0.18	0.16	0.20
	Mean	1.02	0.90	0.85	0.84
	1α	0.11	0.08	0.07	0.09

Matchprint Proof		**Black**	**Cyan**	**Magenta**	**Yellow**
X-Rite 939		1.77	1.32	1.38	0.95
X-Rite 530 Tx		1.76	1.29	1.38	0.97
X-Rite 530 T		1.76	1.32	1.38	0.95
Gretag D196(unpolarized)		1.76	1.32	1.41	0.91
Gretag D19C(polarized)		1.85	1.32	1.48	0.93
Gretag SpectoEye		1.84	1.34	1.43	0.95
Gretag D196 (polarized)		1.82	1.36	1.46	0.94
IHARA		1.79	1.35	1.38	0.98
Tobias IQ 150		1.74	1.27	1.44	0.95
	Min	1.74	1.27	1.38	0.91
	Max	1.85	1.36	1.48	0.98
	Range	0.11	0.09	0.10	0.07
	Mean	1.79	1.32	1.42	0.95
	1α	0.04	0.03	0.04	0.02

Ink Jet Proof		**Black**	**Cyan**	**Magenta**	**Yellow**
X-Rite 939		1.66	1.32	1.47	1.00
X-Rite 530 Tx		1.66	1.32	1.45	1.01
X-Rite 530 T		1.64	1.33	1.46	0.99
Gretag D196(unpolarized)		1.73	1.37	1.52	0.98
Gretag D19C(polarized)		1.81	1.38	1.61	0.96
Gretag SpectoEye		1.80	1.38	1.58	0.99
Gretag D196 (polarized)		1.73	1.38	1.61	0.96
IHARA		1.68	1.33	1.45	1.03
Tobias IQ 150		1.63	1.33	1.52	1.03
	Min	1.63	1.32	1.45	0.96
	Max	1.81	1.38	1.61	1.03
	Range	0.18	0.06	0.16	0.07
	Mean	1.70	1.35	1.52	0.99
	1α	0.07	0.03	0.07	0.03

Measurement Comparison Conclusions

Examination of the comparison results indicate that there are some large apparent differences between the sample set mean values for certain measurands.

The critical question then becomes, “Are the differences significant with respect to the instruments used, the measurement procedure implemented, and the uncertainties involved?” In other words, “how good is good enough?”

As mentioned previously, when comparing measurement sets generated by two unlike instruments, with differing experimental procedures, it is necessary to allow for each contributor to the measurement uncertainty. Each instrument has a measurement uncertainty associated with its operation. There are many uncertainties associated with the measurement procedure, including, but not limited to, measurement of different swatches, temporal displacement, and differing sample set sizes. Each of these uncertainties should be quantized and included in the analysis as described in the ANSI national standard CGATS.11.

Unfortunately, characterizing most of these uncertainties is a very difficult task, without the resources of a national standards laboratory, and rigorous methodology. For this reason, instrument manufacturers typically rely on certified standards to provide performance information. The use of a certified reference offsets the necessity to try and determine which (if either) instrument generates the “true measured value”, and to rigorously characterize each and every uncertainty in the measurement process.

In many cases the instruments may measure the same sample at opposite ends of the allowable range for agreement. The apparent disparity between measurements can be larger than what would be expected when comparing measurements of a sample made by the same instrument or instruments of the same type, but the measurement values are still said to be in agreement.

The published allowable tolerance associated with the certified reference material used for this comparison is 0.02 D or 2%, whichever is larger. This tolerance should be associated with whatever instruments are used to provide measurement data. When comparing two unlike instruments using this standard, the allowable tolerance therefore becomes larger than the allowable tolerance for a single instrument. Use of the larger tolerance to provide the criteria for instrument agreement then integrates, to some degree, the additional measurement uncertainties that cannot be easily determined.

Using this industry standard approach to instrument agreement criteria, any two instruments that measure within .04D, or 4%, could be considered to agree, and two instruments within a class, (same make and model), should measure within .02D, or 2%.

Summary and Conclusion

Whereas eight of the nine instruments in this study measured the certified reference material (T-Ref) within the tolerance specified by the certification laboratory, then the instruments can be said to be in agreement. However, the data clearly shows large difference in mean density when a variety of typical graphic arts materials are measured.

Instruments from the same manufacturer were in better agreement across the range of materials, and it is recommended that the same class of instrument be used within a single shop, organization, or enterprise if possible.

It is also recommended that in the case where Densitometric data is to be communicated between parties, that a sample of the materials to be measured be circulated and measured with all instruments in use in the enterprise. Always include instrument make, model, and aperture size when communicating data.

The data shows the effect of polarization is not predictable across the range of measurands, particularly proofs. The use of polarization filters, by definition, is not a Status response instrument, and their use should be approached with caution.

Note the difference of delta density when comparing the same model instrument, Status-T and polarized, when measuring the two off-press proofs in this study.

In conclusion, the move to standard Status Densitometry has been successful, and of great benefit the graphic arts. With proper care in calibration, verification with a CRM, and testing with actual production materials, Status Densitometry values can be confidently used in communicating densitometric print characteristics, and establishing print specifications and guidelines.

All of the instruments in the study are easy to operate, require no warm-up or special configuration, which is a tribute to the instrument manufacturers.

Opportunities for Further Study

It is intended that this survey of densitometers will be repeated periodically as new instruments are introduced to the market.

With the rapid increase in the use of off-line scanning and on-press instruments for closed-loop color in the pressroom, this study should be expanded to include these instruments.

Where the purpose of this study is to show the degree of inter-instrument agreement between various instruments one might encounter in a production setting, there is also the need to study other instrument performance measures such as repeatability, and performance relative to published performance specifications.

With the industry moving to standard reference printing conditions, such a ISO-12647-2, ANSI CGATS TR-001 and TR-004, and as ICC color-managed workflows are adopted, a comparison of colorimeters and spectrophotometers, comparing colorimetric data, is needed.

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