Process Control—The Glue of Color Management

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The implementation of digital color management started in 1993 when Apple Computer introduced ColorSync as part of their operating system. Shortly after this the ColorSync Consortium – now the International Color Consortium, or ICC was formed to get a broader acceptance of color management. Digital color management has evolved substantially since 1993. The current version of ColorSync is 4.x and is a key color management enabling technology of the Macintosh operating system. The Microsoft Windows operating systems also uses an enabling technology for color management known as Image Color Management (ICM). Along with developments in color profiling software the acceptance of color management methodologies has become universally accepted, some 14 years after the first implementation of color management in the microcomputer's operating system.

In addition, to the success of the ICC in creating an open standard for color communication, the ability to use spectrophotometry to accurately measure color data has advanced the acceptance of modern color management methods. At the 2006 IPA Color Proofing Roundup an experiment was conducted to test the ability to match visual ranked proofs and colorimetrically matched proofs. These results, although not quantified using rigorous statistical methodology, did suggest and has been accepted by the color community at large that "It is OK to go by the numbers" for color assessment [1].

The intent of this paper is not to address the success or debate the current status of color management; the intent is to address the next evolution of color management, which is the control of color once it is established. Color management methodology established the definition of a desired color space today, often as an ICC profile. There are many applications that can be used to confirm the definition of this space to ensure that the profile has been created accurately. The process usually requires the creation of a visual representation of the color space, often via a proof or press sheet that further confirms the accuracy of that color space to the end user. Up to this point, the process has only confirmed that the user is able to produce color within the desired space. What is missing in this equation is documentation to demonstrate that the desired color space is indeed being reproduced accurately and consistently over time. To accomplish this requires the implementation of process control.

Process control is defined by Southworth [2] as "any evaluation of control technique for keeping a process consistent after it has been optimized". Further he defines Statistical Process Control (SPC) as "a method of using analytical techniques and tools to interpret data derived from process measurement". Since it has been established that a spectrophotometer can accurately capture color data and represent that data as a colorimetric value that is highly correlated to the human visual perception of color [1], it makes sense to go to the next step and implement SPC, which becomes the glue of color management that ensures the color management system is working properly.

The science of SPC predates color management by several decades and is a natural application of mathematics and probability to color management. SPC is the study of the normal variability of a system, in our context, a color system. The typical measure of variability of a color system is usually expressed as a Delta E (ΔE). As Sharma [3] indicates, “In practice, it is very useful to be able to specify the difference between two colors by a single numerical value. A measure of color difference is ΔE”. To be confident in the application of SPC for controlling a color system requires that several conditions be met concerning the data from that system, in our case the ΔE values. These requirements are: [4]

- There is symmetry about the mean
- The scores that make up a normal distribution cluster about the middle
- The range of scores is unlimited

In addition, to be confident of the SPC system, when the initial mean and standard deviation are determined a large enough set of data must be collected to be representative of the system to be monitored. From a purely statistical sense, this number is approximately 25 observations once the process is in control. From a practical sense though it if often necessary to collect a much greater sample size to account for all of the normal variability in the environment of the system that is desired to be monitored and controlled.

Once the required data is collected it is then analyzed and a mean (μ) and Standard Deviation (STD) are calculated to form a run or control chart. A run chart is used to plot production observations to determine characteristics of the process in daily operation. A run chart has an Upper Control Limit (UCL) and a Lower Control Limit (LCL). During normal operation of the system being monitored the collected data will fall within the two limits, on either side of the mean. The key to using a run chart for SPC is to watch the data plotted on the run chart and to interpret this data to make inferences about the operation of the monitored system. The objective is to use the data to prevent a system from ever going out of control. This is possible because the UCL and LCL is calculated based upon μ ± (3) STD. From a statistical perspective, three times the STD indicates that if the process variable, in the case of a color system the ΔE, goes beyond the UCL value, then the process is out of control with the probability of 99.97% and corrective action is warranted. The idea with SPC though, is to watch the data and introduce corrective action prior to exceeding a ΔE value greater than the UCL by watching the trend of the data. As a system is in operation it will often exhibit a trend toward the UCL prior to going out of control, this is the time to intervene. Intervention can be either manually or automatically triggered depending on the sophistication of the monitoring process adopted and the criticality of the system. Figure 1 is a typical run chart.

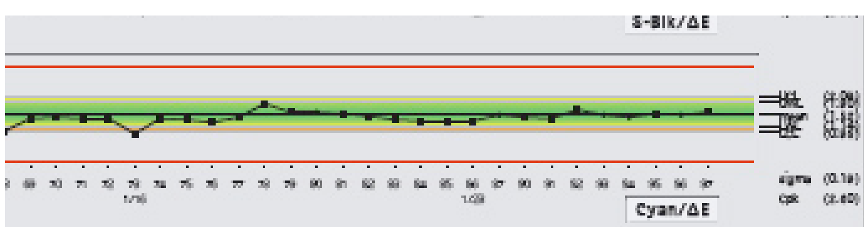

Figure 1. Typical Run Chart

The challenge becomes determining the corrective actions that are required. This knowledge comes from studying the data over extended periods of time and correlating the data signatures with actual events. Companies that are in the business of process control are invaluable in analyzing these data signatures and translating them into practical interventions.

Another issue involves the consideration of SPC limits and those limits that might be imposed based upon industry or custom specification. When the control limits of the system are less than the imposed specification then the issue isn't problematic since the system capability exceeds the specification. When the SPC limits are greater than the specification then further study needs to be conducted to investigate the process capability. A useful statistic to study this is the Cpk, which measures a process's ability to create products within specification limits.

This paper has discussed the issue of color management and the need to not only establish an accurate color representation but to also require that the system produces color that accurately produces this color representation over time from one print to another. SPC makes this possible by monitoring the color data, which indicates when the system drifts and with an experienced interpreter, allows for corrective action such that defective products are never produced.

References

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Author Biography

Ronald Dahl received his BSIT and MSIT from the University of North Dakota (1977, 1978) and his Ph.D. in Industrial Technology from Iowa State University (1984). He spent 20 years as a university professor, most recently at Arizona State University in Tempe. His work has focused in the graphic arts with emphasis on color and its control and reproduction. He is currently VP of Sales for ColorSciences, Austin, Texas; a company that provides color process control software to the graphic arts industry.