Color Convergence Under Closed-Loop Control

Steve Tiltman*, John Seymour*, and Jeff Krueger*

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Abstract

The subject of convergence of color to a target provided for a closed-loop color control system in the web offset printing environment has long been mired in a combination of subjectivity and variability. Subjectivity resulting from such things as differing human perception of good color, and variability coming from a wide array of circumstances and configurations, including the range of available cut-off or impression lengths utilized. For those involved in the development and use of such closed-loop color control systems, this subjective and variable base has been one on which foundations for measurement and comparison have been difficult to establish. Consider the statement 'it takes 3,000 copies to get good color' and its intrinsic lack of scientific credibility. How much paper is wasted during those 3,000 copies and what is an objective measure of good color?

For the purpose of this study, influence on measurement resulting from human subjectivity was eliminated through the introduction of the concept of Theoretical Good Color. This is when 80% of all ink zones on all ink fountains are within +/–0.10 density points of the target. Variability as a consequence of differing cut-off or impression lengths was removed by converting all lengths to meters. The elimination of these factors prepares the way for meaningful analysis as it places distributed closed-loop color control systems on equal footing.

A large collection of closed-loop color control system data was gathered from web offset presses produced by two major manufacturers, the presses were distributed around Europe and the USA, and encompassed a wide range of variability in press crews, press impression lengths, printing environments and printed work. The collected data was analyzed and studied with the intention of identifying the remaining variables which most influence the performance of a

* QuadTech

closed-loop color control system as it brings color from its starting condition to theoretical good color.

The analysis revealed two main influences on the length of substrate wasted as color converges on a target:

- The quality of the output produced by the presetting system used to set the ink fountain roller speed and ink key positions—referred to in the study as Preset/Ratchet Quality.
- The length of paper passing through the closed-loop measuring device between subsequent samplings of the printed product—referred to in the study as Measurement Period.

By manipulating these two influences on the speed of color convergence, it may be possible to exert significant control over the amount of wasted substrate.

Introduction

This study was conducted using a large collection of data generated from a range of presses, utilizing QuadTech closed-loop color control systems. The purpose was to identify and classify important factors affecting the performance of those systems as color is brought from its starting condition to good color. An objective measure of performance was created, facilitating comparisons between print runs in differing environments, and eliminating the inherent subjectivity of human perception of good color. We first describe a performance measurement methodology before detailing the results of the analysis and discussing the possibility of positively influencing the amount of wasted paper attributed to color makeready.

The Color Control System

The data used in this study was generated from QuadTech closed-loop color control systems. To aid in the discussions that follow, a brief overview of how these systems function is described below.

QuadTech's color control system, like other inline color control systems, utilizes a form of color measurement camera located in the web path. Generally, these cameras are positioned after the dryer and chill-rolls, assuming a heat-set application, but before silicone coating and slitting. The cameras take measurements of a color bar as the web passes the camera's field of view. Color bars are printed once for each image repeat. After taking a measurement at a specific position, the camera moves laterally to the next measurement location. Data acquisition continues until the full width of the color bar has been scanned, at which point the camera returns to the starting position to repeat the measurement procedure. The time required in measuring the color bar in a single pass and returning is referred to as the scan cycle. Figure 1 provides a simplified illustration of this process. In reality there are generally many more measurement steps than six and the color bar contains more patches than simply solid black, cyan, magenta and yellow as shown here.

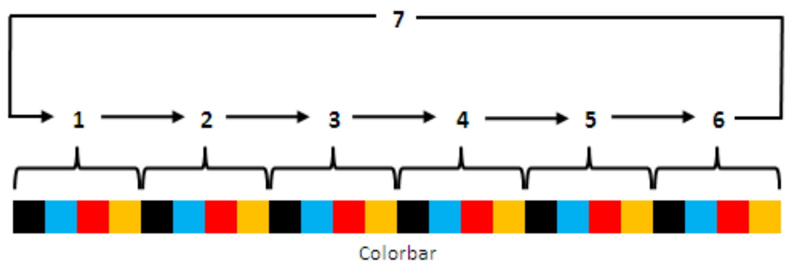

Figure 1. Simplified illustration of the scan cycle.

In simple terms, closed-loop systems utilize a reference point, a sensor to determine current output levels, and a controller to adjust the inputs of the system to match the desired reference point. In the case of the closed-loop color control system, after acquiring and processing color bar data, the system converts the measured data into adjustments of ink keys, blades, or pumps which control the feed of ink. There are multiple control algorithms to adjust the ink output in order to match the reference target. We have chosen to use the simplest control method, referred to as solid ink density control. This method utilizes solid ink density measurements from the color bar. Those measurements are then compared to a target density provided to the color control system. If the density value is too high compared to the target, the supply of ink is reduced, or if too low, the supply increased. Solid ink density control was used in this study as it provides the most straightforward basis on which to judge performance.

Normalizing Repeat Lengths

Given that it is common to discuss performance of a color control system, as well as many other aspects of makeready, in terms of copies or impressions, it becomes necessary to normalize each press in a comparative study with an equal unit of length. A challenge when considering the amount of paper wasted during a makeready is the range of repeat lengths in use. Repeat length, in this case, is the circumferential distance from one printed color bar to the next, as depicted in Figure 2. Cursory research revealed that repeat lengths today range from 400mm to 1,400mm. If Press A has a repeat length of 630mm and Press B 1,240 mm, attempts to compare performance between the two in terms of impressions is misleading. To illustrate the challenge, if each were to require 2,000 meters of paper to complete a color makeready, this would result in Press A wasting 3,170 impressions while Press B wastes just 1,600. When viewed like this, identical performance seems unequal. To normalize our approach to color makeready performance analysis, repeat lengths were converted from a repeat unit, in this case impressions, to its metric equivalent. For the purpose of measuring performance we focus solely on meters of paper.

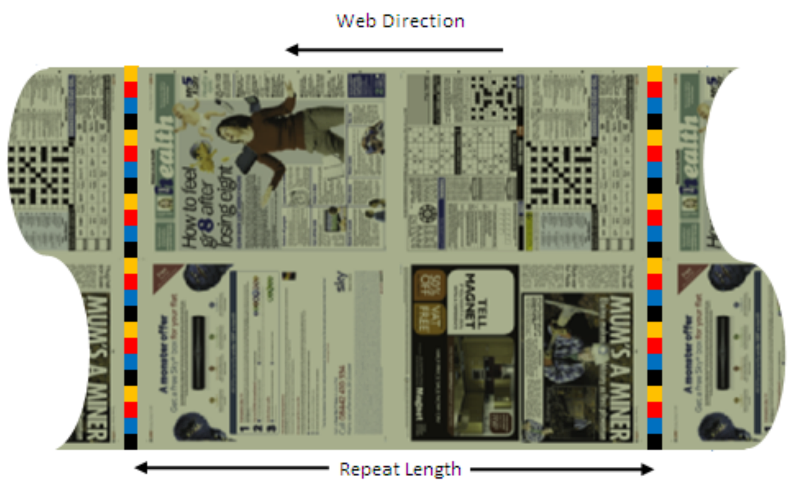

Figure 2. Repeat length.

Objective Good Color

It is well known that perception of color is rather subjective. Contributions to that subjectivity come from factors such as physiological differences from person to person, and the light source printed output is viewed under. For commercial work, that subjectivity also depends upon portions of the work itself, such as a specific advertisement, and even a specific portion of that advertisement. It is, therefore, not surprising that human opinion of when good color has been achieved is difficult to quantify with some level of confidence. Further to that point, even when using a closed-loop control system to perform makeready, there is no agreed upon objective measure. For this reason it is necessary to implement an objective measure of good color, referred to in this study as Theoretical Good Color. Theoretical Good Color is defined as the point at which the solid color bar patches in 80% of all ink zones of all colors are within +/–0.10 density points of the target. 80% has been selected empirically, with experience showing this to be the point above which improvement slows as the control systems ends aggressive control. Beyond this point the more difficult to achieve targets, such as very light coverage areas requiring a reduction in supply, are corrected often very slowly but eventually to the target. The density tolerance of +/–0.10 was selected as a reasonable estimate of a range within which color is considered to be commercially acceptable.

We acknowledge that it is something of a leap that the reader is asked to assume that *theoretical* good color is akin to good color. However, the intention here is to study the performance of the *control* system. The difference between theoretical and actual good color, which may be approved through a customer pass for example, is jointly the result of the color targets selected, the condition of the prepress processes, the press and ink. For the purpose of this study, it is necessary to rely on the targets given and not human perception of good color.

Measurement Method

With our two important variables of repeat length and good color accounted for, it is now possible to objectively discuss closed-loop color control system performance in terms of wasted paper. This is achieved through the use of what we have termed a Performance Profile, an annotated example of which can be seen in Figure 3.

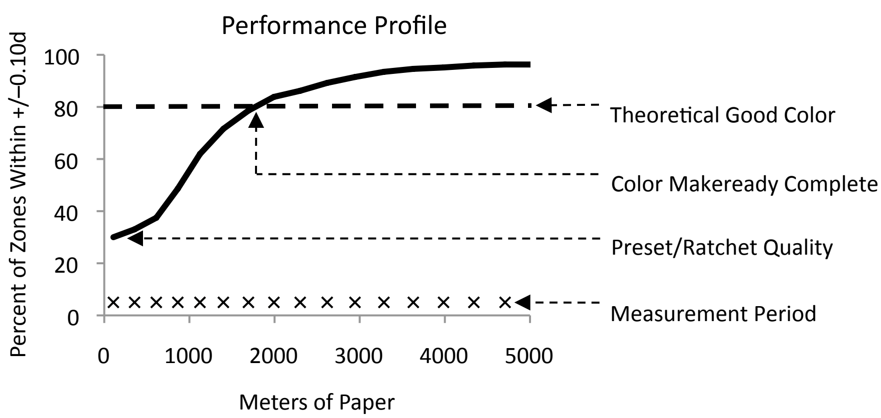

Figure 3. An example performance profile graph for a single press with 100 makereadies averaged.

A number of aspects of color control system performance can be interpreted from a performance profile graph. Two plots are shown on the graph and include the percentage of ink zones in tolerance, seen as the solid black line, and the measurement period, seen as the X plot. Each is further described below together with their associated components.

Percentage of Ink Zones in Tolerance

This plot indicates several aspects of both press and control system performance to the observer.

Preset/Ratchet Quality. Observing the vertical position of the beginning of the plot in relation to the y-axis, one gets an indication of the quality of the ink key presetting. From Figure 3, the preset/ratchet quality is approximately 30%. That is, on average, from the outset of a print run, 30% of the ink zones conform to the tolerance of +/–0.10 density points. Note: the selection of the name of this measure as preset/ratchet quality is an acknowledgement of the fact that the quality of the ink key presetting is dependent on both the positioning of the individual ink keys, determined by ink coverage in individual zones, and the initial speed setting of the ink duct roller.

Color Makeready. Color makeready is considered to be the period from the point at which the camera of the color control system locates and begins to take measurements from the color bar, to the point at which theoretical good color has been achieved. This period is shown in Figure 3 as the distance, in meters, from zero on the x-axis to the point at which the 80% theoretical good color line is crossed (as highlighted). Time zero on the x-axis is the moment the color control system camera located the color bar for the first time. Depending on other conditions and press activity, the point at which theoretical good color has been achieved may or may not determine the point at which the overall makeready is complete. For example, there may be color-to-color registration, cut-off or sidelay issues, over which the color control system has no control, affecting makeready, thus delaying good copy.

Correction Rate. The number of meters of paper required to take the percent of ink zones in tolerance from the starting condition (preset/ratchet quality) to theoretical good color (color makeready complete), also known as the color makeready, determines the correction rate, that being the number of meters of paper required for each 1% improvement towards theoretical good color. This could also be considered an approximation of the slope of the line (it is acknowledged that the plot is not a straight line).

Measurement Period

Shown in Figure 3 as a series of unequally spaced Xs, measurement period is a measure of the number of meters of paper to pass the color control system camera between each measurement during the color makeready. Measurement period has three contributing factors, discussed below:

Press Speed. The speed at which the press is running is the speed at which the web is passing the color control system cameras.

Web Width. As previously described and illustrated in Figure 1, the color control systems cameras function cyclically, taking measurements of a color bar before moving back to the starting point and repeating the process. For this reason, the width of the web in use has a significant bearing on the amount of time taken for a camera to complete one full scan cycle.

Camera and Transport Speed. The speed at which the camera is able to snap a portion of the color bar, process the data and move to the next location, as well as the speed at which the transport mechanism drives the camera from position to position, have a bearing on the amount of time the camera requires to complete a full scan cycle.

The combined influence of press speed, web width and camera and transport speed determine the amount of paper to pass the camera between each measurement in a single ink zone, therefore, the measurement period is a product of their interactions.

Analysis

Data resulting from 805 color makereadies, from 12 presses distributed around Europe and the USA, were processed using the performance profile method and the resulting data formed the foundation of this study. Data resulting from color makereadies that did not meet certain conditions were rejected as much as possible in order to remove influences on results from external factors, including:

- Print runs where the press stopped during the first 5,000 meters due to, for example, web breaks or folder jams.
- Print runs where the color control system was not started and kept in automatic mode.
- Print runs where press operators made adjustments to the target density values during the color makeready.
- Print runs where press operators altered ratchet settings during the color makeready.

Additionally, purely for ease of coding and analysis, print runs which used all of black, cyan, magenta and yellow on all surfaces were considered to the exclusion of any print runs utilizing special colors.

Color Makeready

The mean color makeready, resulting from our dataset of 805 color makereadies, is 1,687 meters. This result needs to be considered in the context of the histogram in Figure 4 which depicts a distribution that is not normal, ranging from the extremes of 382 to 4,733 meters.

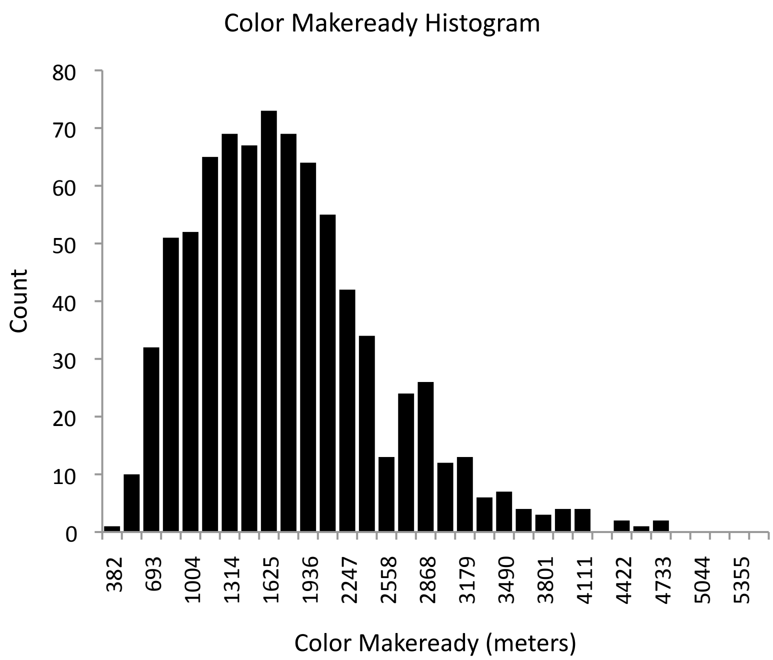

Figure 4. Histogram of color makeready results.

Table 1, which shows representative percentiles, indicates that 25% of color makereadies were completed in 1,126 meters or less, 50% completed in 1,586 meters or less, and 75% in 2,747 meters or less. At the high end of color makeready scale, we see that 90% complete in 2,747 meters or less and 95% in 3,108 meters or less.

Table 1. Representative percentiles for color makeready results (in meters).

Percentile	*25th*	*50th*	*75th*	*90th*	*95th*
Result	1126m	1586m	2072m	2747m	3108m

From both Figure 4 and Table 1 the median color makeready is determined to consume around 1,600 meters of paper. There is also a very large spread in this data warranting caution when comparing results between individual color makereadies.

Individual colors were compared to determine whether some tended to complete color makeready sooner than others. The results are shown in Table 2.

Table 2. Color makeready performance for individual colors (in meters).

	Mean	*Standard Deviation*
Black	1950m	1090m
Cyan	1811m	1002m
Magenta	1655m	951m
Yellow	1576m	972m

Observing the means in isolation, it appears that black takes the longest to reach theoretical good color, followed by cyan, magenta, and then yellow. Each ink takes roughly 100 meters less paper. However, there is a great deal of variability in the data, with standard deviations around 1,000 meters. With a large degree of variability and the fact that the dataset contains 805 color makereadies can a statistically valid comparison be made?

In order to determine whether a statistically valid comparison can be made, a Student's t-test analysis would be used. Unfortunately, this test assumes data from a normal distribution. An alternative test, which does not assume any particular distribution, is the paired binomial test. The color makeready values for black and cyan inks were paired, and a count was taken of the number of times that black took longer than cyan. With no real difference between the two, cyan would win about 402.5 times and black would win about 402.5 times. Of course, if cyan were to win 407 times, this would not be statistically remarkable. One could toss a coin 805 times and get heads 407 times, repeating the 805 coin tosses one could see 399 heads.

The result of counting heads in a coin toss is a binomial distribution. If the number of coin tosses is more than perhaps 20, and if the probability of heads or tails is close to 50%, then this distribution is well approximated by a Gaussian distribution. The mean of this distribution will be np, where n is the number of coin tosses (in this case, 805), and p is the probability of being counted. If we are trying to assess whether cyan and black are equally likely to win, then $p = 0.5$. The standard deviation of this distribution will be $\sqrt{n(1-p)p}$.

So, if cyan and black are equally likely to win, the number of times that cyan completes color makeready before black should come from a Gaussian distribution with mean of 402.5, and standard deviation of 14.2. If the actual count is outside of this range, then we can feel confident saying that one converges sooner than the other. Table 3 shows the t statistics for the various comparisons between pairs of colors. Since the *t* statistics are all well above 3.0, we can say that the results are statistically very significant.

Table 3. Paired binomial test of color makeready.

	Score	*t*	*Conclusion*
Black vs. Cyan	K 326, C 479	5.39	Black is slower
Cyan vs. Magenta	C 291, M 514	7.85	Cyan is slower
Magenta vs. Yellow	M 309, Y 496	6.58	Magenta is slower

Why is black the slowest? Ink coverage is a likely explanation. When coverage is very low, it can take a long time for an ink change to be realized. In these situations there is already a lot of ink in the ink train and it is being pulled out very slowly. Low coverage is like steering a boat while higher coverage is like driving a Maserati. If it takes a long time for the result of an ink key move to pass through the printing unit and appear on the paper, it will naturally take a long time for a color control system to get feedback on the results of an ink key move. Consequently, it will take longer to correct color errors.

While ink coverage varies broadly from job to job, there are some consistent trends. According to Kurt Miller, Ink on Paper manager with Quad Graphics, “Yellow is the most used color followed closely by Magenta as second. Third depending on levels of optimization are Black and Cyan running neck and neck.” If printers do not generally operate with high levels of Gray Component Replacement (optimization), then this would predict the results in Table 2.

In conclusion, it is likely that coverage has a marked effect on color makeready with higher coverage leading to reduced color makeready. Unfortunately, coverage did not form part of this study therefore data is not available to verify this hypothesis.

Preset/Ratchet Quality

Preset/ratchet quality was found to be, on average, 25%. In other words 25% of ink key zones were within the stated tolerance of +/–0.10d from the outset of a print run. Figure 5 depicts the histogram of preset/ratchet quality derived from the dataset analysis. Similar to the color makeready histogram of Figure 4, a significant amount of variability is observed.

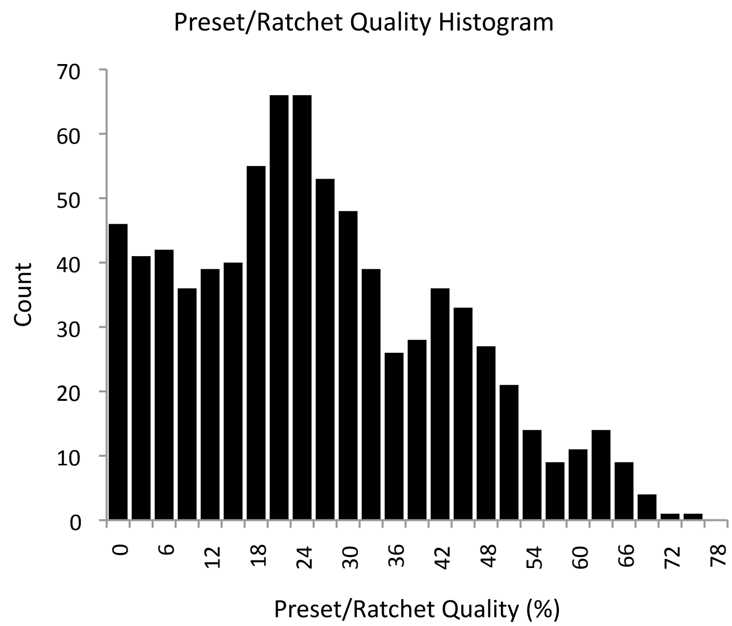

Figure 5. Histogram of preset/ratchet quality results.

Table 4 shows that 25% of preset/ratchet qualities are 12% or less, 50% are 23% or less, and 75% are 37% or less. At the high end of the scale, we observe that 90% of preset/ratchet qualities are 49% or less and 95% are 57% or less. We conclude from this that preset/ratchet quality is 50% or greater only 10% of the time.

Table 4. Representative percentiles for preset/ratchet quality analysis results.

Percentile	*25th*	*50th*	*75th*	*90th*	*95th*
Result	12%	23%	37%	49%	57%

Preset/ratchet quality was compared for individual colors to determine whether some presets are better than others. The results are shown in Table 5.

Table 5. Preset/ratchet quality performance for individual colors.

	Mean	*Standard Deviation*
Black	24%	22%
Cyan	22%	22%
Magenta	25%	23%
Yellow	25%	23%

Observing the means in isolation, it appears that presetting is approximately equal for black, magenta and yellow, but cyan scores slightly lower. Once again there is a great deal of variability in the data, evidenced by standard deviations roughly equal to the means and the spread of the not normally distributed histogram in Figure 5. To establish whether there are any statistically valid differences in the means, the paired binomial test was again carried out and the results are shown in Table 6.

Table 6. Paired binomial test of preset/ratchet qualities.

	Score	*T*	*Conclusion*
Black vs. Cyan	K 398, C 407	0.31	No significant difference
Cyan vs. Magenta	C 430, M 375	–1.94	No significant difference
Magenta vs. Yellow	M 416, Y 389	–0.95	No significant difference

Since the t statistics are all below 3.0 it can be said that the differences in preset/ratchet qualities between colors are not statistically significant.

Measurement Period

The mean measurement period, resulting from our dataset of 805 color makereadies, is 243 meters per scan cycle. On average 243 meters of paper pass by the color control system camera between consecutive measurements in the same lateral location. The histogram of the measurement period data can be seen in Figure 6.

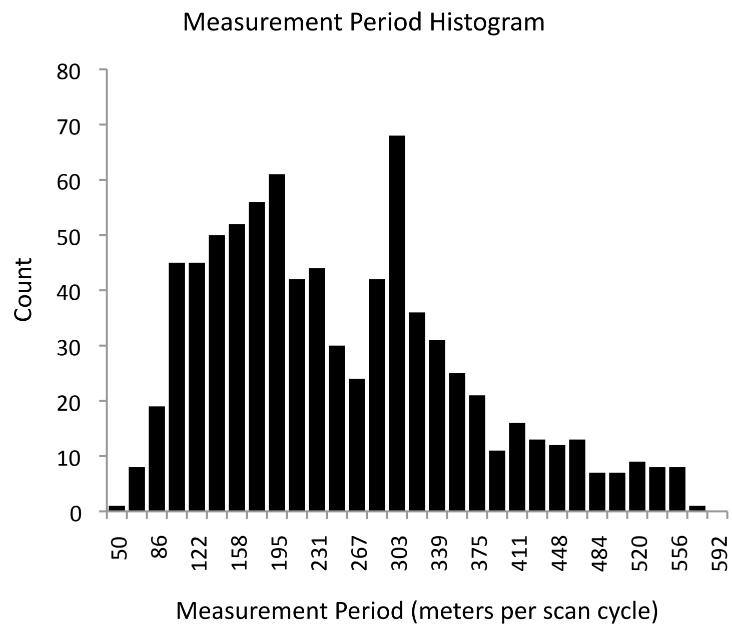

Figure 6. Histogram of measurement period results.

A remarkable observation from Figure 6 is the apparent double peaks at 195 and 303. This has occurred as a result of the presses used in the study falling broadly into two categories, narrow and wide web presses. It was not an intention of this research to focus on the effect web width has on makeready because, despite it being a factor in measurement period, it cannot be controlled.

Table 7 shows that 25% of measurement periods are 152 meters per scan cycle (mps) or less, 50% are 218mps or less, and 75% are 312mps or less. At the high end of the scale, it is observed that 90% of measurement periods are 410mps or less and 95% are 465mps or less. Measurement periods of greater than 400mps are the exception rather than the rule.

Table 7. Representative percentiles for measurement period results.

Percentile	*25th*	*50th*	*75th*	*90th*	*95th*
Result	152mps	218mps	312mps	410mps	465mps

Color Makeready Variability

Now we consider some potential sources of the apparently large variability in color makeready by examining the data in greater detail.

Figure 7 depicts a plot of color makeready against preset/ratchet quality and an applied best-fit linear trend. It appears the data is rather noisy and possibly not a particularly good fit for the trend. However, the correlation coefficient is –0.43 and when considering that there are 805 individual data points in the dataset, this result is respectable. The R^2 value was calculated to be 0.18, suggesting that preset/ratchet quality explains some 18% of the variability in our dataset.

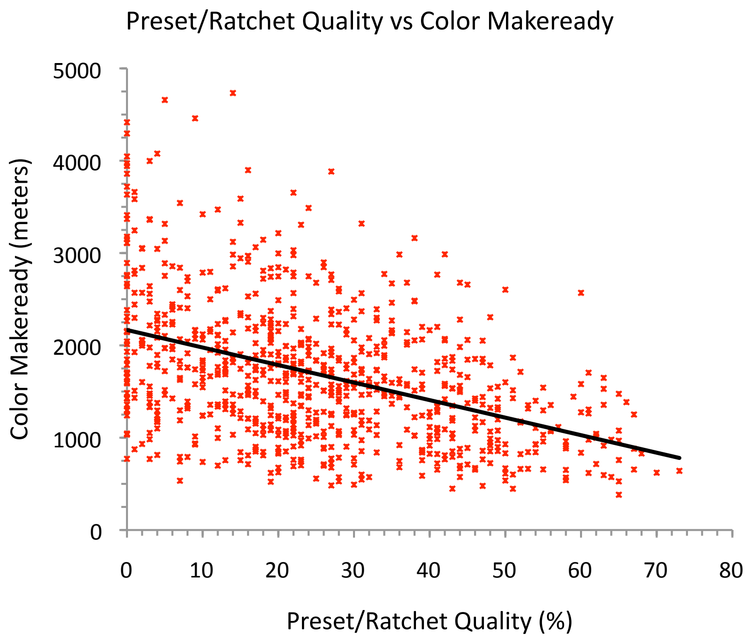

Figure 7. Scatter plot of preset/ratchet quality versus color makeready.

Next, observe the scatter plot shown in Figure 8, where once again we have applied a best-fit linear trend to the dataset. This time the trend in the data is perhaps a little more obvious to the naked eye, as borne out by the correlation coefficient result of 0.56 which results in an R^2 value of 0.31 (31%).

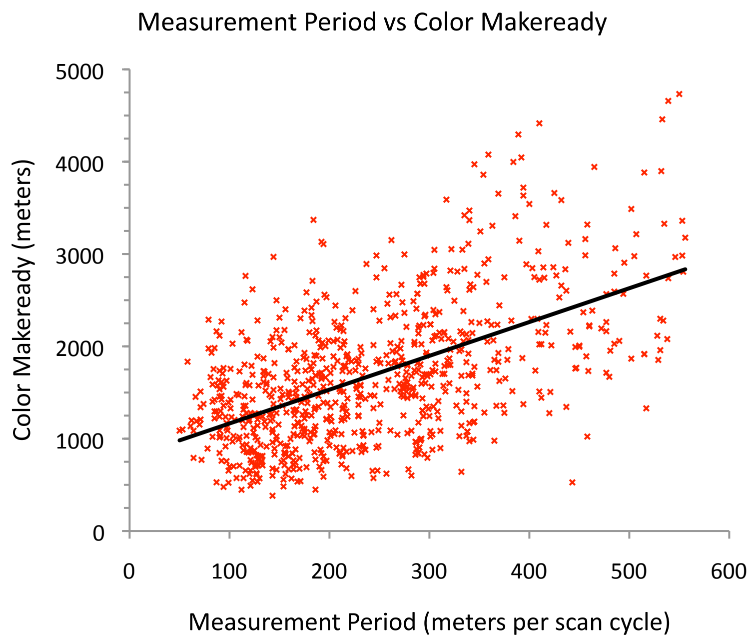

Figure 8: Scatter plot of measurement period versus color makeready.

We have established that some 18% of the variation in our mean color makeready result of 1,687 meters can be explained by preset/ratchet quality. A further 31% is explained by the influence of the measurement period. But what about the influence of the two variables combined? For this we employ a multiple regression approach with color makeready as a single dependent variable and preset/ratchet quality and measurement period as the predictor variables. Table 8 shows the results of this multiple regression with a confidence level of 95%:

Table 8: Multiple regression results for color makeready.

	Result
Samples	805
R^2	0.46

	Intercept	*Preset/Ratchet Quality*	*Measurement Period*
Coefficient	1,280	-17	3.45
Standard Error	56.19	1.16	0.17
Lower 95%	1,170	–19.32	3.12
Upper 95%	1,390	–14.78	3.79
t-Stat	22.78	–14.74	20.17
p-Value	5.84×10^{-89}	1.06×10^{-43}	1.63×10^{-73}

Observing Table 8, we note the following:

- The R^2 value of 0.46 indicates that 46% of the variation in color makeready is explained by the combined influence of preset/ratchet quality and measurement period.

- Taking the coefficients for the intercept, preset/ratchet quality and measurement period, we establish that color makeready is approximated by the function *1280 meters – 17(preset/ratchet quality) + 3.45(measurement period)*.

- The lower and upper 95% results indicate that the confidence intervals are:
    - 1,170 to 1,390 meters for the intercept;
    - –19.32 to –14.78 for the preset/ratchet quality; and
    - 3.12 to 3.79 for the measurement period.

  None of these ranges either span or are close to zero; therefore all the coefficients can be considered very significant. This result is further supported by the t-Stat results which indicate how many standard errors the coefficients are away from zero; a t-Stat between –2 and 2 would show that we should have little confidence in the predictive power of the coefficient. Conversely, the further these values are from the range –2 to 2, the more confidence we can have in the coefficient.

- The p-Values are so small they are effectively zero. This tells us that the null hypotheses, those being that neither the intercept, nor preset/ratchet quality, nor measurement period affect color makeready, can be confidently discarded. Note: any p-Value of less than 0.05 would have lead to the same conclusion and the fact that the actual p-Values are so much less than this threshold provides a significant amount of confidence in the result.

We have determined that 46% of the variability in color makeready can be assigned to the combined influence of preset/ratchet quality and measurement period. Having established two major influences on color makeready, the remaining influences are left for future investigation including the aforementioned variation in ink coverage.

Influences

Preset/Ratchet Quality Influence

It should be no surprise that preset/ratchet quality has an influence on color makeready. If we use the equation of a line, $y = mx + c$, as an analogy, equating the constant *c* with preset/ratchet quality and making *m* positive, then, predictably, increasing the value of *c* will in turn ensure that 80% is reached with fewer meters of paper having been wasted. This effect is demonstrated in Figure 9 which shows a performance profile graph of data from one of the presses used in our study. A selection of color makereadies with preset/ratchet qualities (PRQ) considered good, average and poor, were grouped before being averaged and plotted independently:

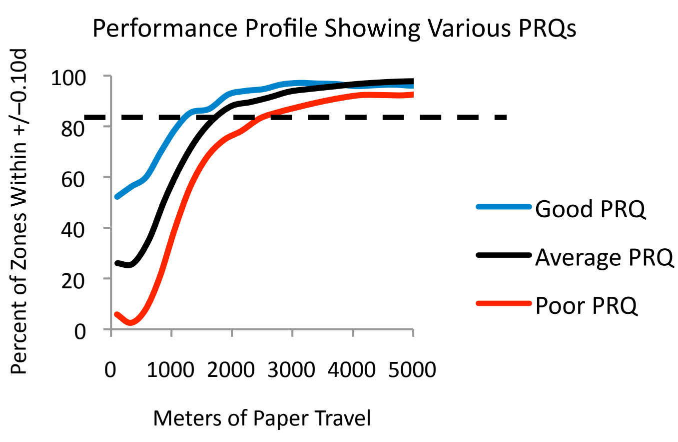

Figure 9. Performance profile demonstrating the impact on color makeready of various preset/ratchet qualities (PRQ).

Observing Figure 9, note the impact of improved preset/ratchet quality on the length of the color makeready, and therefore the meters of substrate wasted. When a color makeready was conducted with poor presetting, over 2,000 meters of paper were wasted in pursuit of theoretical good color, while the waste was closer to 1,000 meters when the presetting was good.

Measurement Period Influence

It has been demonstrated that measurement period has more of an influence than preset/ratchet quality on color makeready waste. In order to introduce a theory for why the measurement period has such an apparently high level of influence, we need to consider some additional background information regarding the presses under control and the design of color control systems.

Each individual ink key in a duct with segmented ink keys can be controlled independently of the other ink keys in the same duct. The range of movement of a key is generally from 0 to 100% open. Movements in a closing direction result in the reduction in the amount of ink fed in a zone, while movements in an opening direction result in an increase in supply.

When an ink key is commanded to change position, there is a delay from that moment to the time at which the result of the observable change in the print stabilizes. This delay results from a combination of:

- The time required for the ink key to change from position A to position B.
- The time for the resulting change in ink supply into the printing unit to propagate through the roller train to the blanket and finally onto the web.
- The time for the change in print to travel through the press.

The number of impressions required for this delay depends on several factors. Of these factors, most important are the size of the ink key move and the coverage of ink in the zone where the change is made. Move size and coverage are highly variable, making it very difficult to put an exact figure on the length of substrate required for any single ink key move to settle. To account for these setting periods, color control systems have configurable delays which are implemented after an ink key has been moved. A subsequent move should not be made on a particular ink key until the completion of that delay.

Additionally, the movement of an individual ink key not only impacts the zone which is directly fed by it but also its neighbors. Earlier research (Chu and Sharma, 1998) has shown that only about half of the ink delivered by an ink key actually ends up in that ink zone. By way of an example, this means an increase in the opening of ink key 10 will result in an increase in the supply of ink to zone 10, but will also generate an increase in the supply of ink in zones 9 and 11. Furthermore, some of the increase in ink zones 9 and 11 will be transferred over to zones 8 and 12, and so it continues. This complex interaction, coupled with varying ink coverage, as well as other factors, makes the design and configuration of closed-loop color control algorithms rather complex.

Because these types of color control systems operate with scan cycles, there is potential for the measurement device to be in an unfavorable location at the point in time when the resulting change in print from an ink key move has settled. Both the likelihood of this happening and the amount of resulting waste increase as the measurement period becomes larger.

We return now to the equation of a line analogy for color makeready which we first outlined at the beginning of the 'Preset/Ratchet Quality Influence' section. There we proposed that the constant *c* (in $y = mx + c$) is analogous to preset/ratchet quality. In view of what we have described above we now propose that the inverse of the measurement period is analogous to the *m* in our equation representing the slope. That is, as the measurement period decreases, the slope, therefore the correction rate during color makeready, improves.

Controlling Waste

We have learned that preset/ratchet quality and measurement period influence color makeready, and this leads us to ask the question of whether it may be possible control the amount of waste in some way. We propose that this is indeed possible, but keeping in mind that 54% of the variability remains unexplained at this stage, we must expect that any ability to exert control is restricted to control of the average and not any individual color makeready.

Using our equation of a line analogy for color makeready once more, we plot some approximations of color makereadies on performance profile graphs, as Figure 10, to demonstrate the effects.

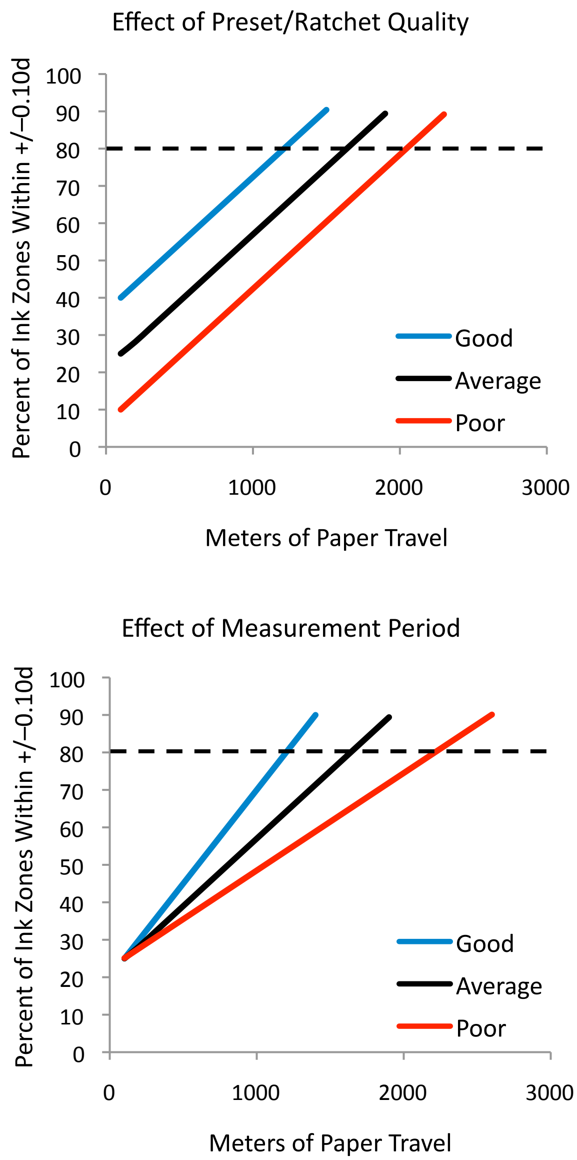

Figure 10. Demonstrating the result of controlling the color makeready influences of preset/ratchet quality and measurement period.

Figure 10 uses the average preset/ratchet quality, determined from our study to be 25%, as the starting point and independently applies two different scenarios to determine the effect on color makeready. This has been done to determine the approximated effect of controlling our analogous *c* and *m* variables, respectively.

While Figure 10 demonstrates the approximate effect one could expect from attempting to control the variables, it does not give a precise estimate of expected savings. For this we return to the approximated function established during the multiple regression:

1280 meters – 17(preset/ratchet quality) + 3.45(measurement period).

Using this function, we see that we may be able to save an average of 17 meters of paper per 1% improvement in preset/ratchet quality and an average of 35 meters of paper per 10 meters per scan reduction in the measurement period. To give an example using the average values determined during the study, if preset/ratchet quality were improved from 25% to 35% and the average measurement period reduced from 243 meters per scan to 193, then we might be able to save, on average, 350 meters of paper per color makeready.

Most presetting systems already have a built-in learning algorithm that requires operator input to activate data collection at an appropriate point during the print run. This data is used as the basis to improve subsequent presets. Measurement period, as we have described, is a product of the combined inputs of press speed, web width and camera and transport speed. How much control can we realistically expect to exert over these two influences?

Regarding preset/ratchet quality, Chu and Sharma (1998) state "Fountain calibration […] is the most obvious problem. In addition, several factors […] such as no coverage zones, dot gain, wet trapping, edge keys and target density vs. color matching […] may all affect the accuracy of the presetting." Further improvements may also be possible through enhancements to the learning algorithms of presetting systems, perhaps through connection to the wealth of color data available from a color control system.

On the subject of measurement period, of our three contributing factors there is one which cannot be controlled, the width of the web. However, contributions of press speed, and camera and transport speed, should be controllable. In the case of camera and transport speeds, there may be leeway for design advances allowing for improvements in the speed at which the scan cycle completes. Reducing press speed during color makeready has the effect of reducing measurement period and, as we have learned, this will have the subsequent effect of reducing the average color makeready waste. The immediate solution seems simple. Minimize press speed at makeready and reduce waste. This is not as practical as it would seem. The color control system is not the only component, or mechanism, on press which needs to perform efficiently under favorable operating conditions. Reducing speed to create this environment may negatively impact other run-time critical components. Therefore, measurement period can be optimized, under certain conditions, and its impact on waste reduction is possible, though restricted.

Conclusions

Using Theoretical Good Color and normalizing repeat lengths with meters eliminates subjectivity and variability. This also facilities the construction of Performance Profiles which provide useful insight to closed loop color control system and ink key presetting performance. Performance Profiles also enable comparison between distributed presses and systems.

Preset/Ratchet Quality and Measurement Period explain 46% of the variability in the amount of paper wasted as color is brought from its starting condition to theoretical good color. Increasing preset/ratchet quality and/or reducing measurement period may reduce the amount of paper wasted during color makeready. The fact that 54% of color makeready variability remains unexplained dictates that any reduction in waste will only be observed over the average and not any individual color makeready.

By using the equation *color makeready = 1280 meters – 17(preset/ratchet quality) + 3.45(measurement period),* it may be possible to approximate expected average color makeready waste.

Selected Bibliography

Chu, C, Sharma, A.
1998 "Validating a model-based ink key presetting system," TAGA.

Ho, C. N.
1992 "Waste minimization—an integrated approach," TAGA.

MacPhee, J.
1995 "A relatively simple method for calculating the dynamic behavior of inking systems," TAGA.

Pope, B, Sweeney, J.
2000 "Performance of an On-line Closed-loop Color Control System," TAGA.

Seymour, J, Tiltman, S, Nelson, A.
2010 "Closed loop color control in the work," TAGA.

Snedecor, G, and Cochran, W.
1989 "Statistical Methods," Iowa State University Press, pp. 121–124.

Chu, C. Sharma, A. Seymour, J.C.
2001 U.S. Patent 6,318,260 (November 20, 2001).

Lachajewski, S.
2000 U.S. Patent 6,142,078 (November 7, 2000).

Noffke, P. Younk, P. Moersfelder, B.
2009 U.S. Patent 7,627,141 (December 1, 2009).