Managing A Quality Digitization Practice in Cultural Heritage Institutions: Statistical Quality Control Tools and Techniques

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Abstract

The appearance of user-friendly, scientifically informative, standards-based digital imaging targets within the Cultural Heritage community presents opportunities for establishing achievable and verifiable image capture specifications, for streamlining digitization hardware selection and optimal use, and for monitoring critical steps in digital imaging workflows. The success of these standards based quality control tools and procedures will require appropriate selection and adoption, in concert with a serious commitment on the part of management to their use.

Crucial to this adoption effort is understanding the role that similar techniques have long played in those professional-level analog imaging and film processing facilities that were organizationally or physically set apart – "Black Boxed" – from the Cultural Heritage institutions that utilized their services and received their products. In this paper, we propose that Cultural Heritage institutions move to adopt industry standard statistical process control and quality improvement language, tools, and procedures. We propose this with some urgency because less rigorous and less effective quality measurement, monitoring, and process control & improvement procedures are currently being adopted by or developed in Cultural Heritage digital imaging and archiving facilities.

Quality Control Tools

The field of Statistical Quality Control and Quality Improvement is a rich and effective one.[i] Statistical quality control tools and techniques are rich in that their principles and practices are rooted in both statistics and management science. They are effective in that quality control tools and practices have been successfully employed in industrial, financial, medical, and government workplaces for more than five decades.

They have made it possible to move beyond merely *asserting* that one's products or services meet local or industry quality standards – essentially trading on one's reputation – to *providing proof* that a quality item or service exists. The effective application of quality-oriented process control and process improvement in Cultural Heritage digital preservation begins by placing them into the most mission-critical situations.

Techniques Usable By All – These techniques can be employed by both managers and technicians to verify the quality of archived Digital Items, the production processes that created them, and the delivery processes that service end-users. Managers can examine quality levels of entire repositories of Digital Items and identify inefficient or error prone production steps. Technicians can determine optimal equipment settings and differentiate between errors introduced by the digitizing technology, by the production process, and those introduced by the technicians.

Three Time-Tested Tools

In this paper, we will first address how one monitors *quality* when it is defined as pass-fail judgments of Digital Item[ii] properties or attributes. We then address the long-term challenges of workflow process monitoring and the elimination of undesirable sources of variation. We finally focus on the critical project start-up stage where vendors or internal digitization facilities are qualified via performance characterizations of their hardware and software systems.

Due to the relative novelty of these tools for the Cultural Heritage community, each example of statistical quality control tool use will be described in terms of (a.) preexisting parallels in analog imaging and film processing environments, (b.) its immediate benefit to production or evaluation processes, and (c.) possible long-term benefits to archival and access processes. Three statistical process control and quality improvement tools can be put to immediate use in Digital Library production, archiving and delivery environments:

- **Pareto Charts** - Pareto charts can be used to monitor service or production process nonconformance to specifications (defects[iii]), expressed in categorical form. They "identify and prioritize areas of concern, particularly any change from the status quo.[iv]"
- **Control Charts** – For digitization workflow process monitoring, improvement, and general process problem solving. One species of control chart, the Run Chart, permits the study of data over a specified period and support process tuning or the tracking of changes in an item's characteristics.[v]
- **Variability Charts** – For characterizing digitizing devices and for production process problem solving.

Tool I: Pareto Charts for Categorical Defect Monitoring

At various points during the production of Digital Items within or on behalf of a Cultural Heritage institution, these items are subject to some form of inspection. In one kind of inspection, a person or an automated process compares that item's *attributes* (bit depth, spatial resolution, descriptive & technical metadata, etc.) against a list of expected (or undesirable) item attributes. The inspector then makes a series of pass-fail judgments based on the comparisons (bit depth and resolution according to spec, descriptive metadata missing statement of responsibility, etc.). Conforming items proceed through routine production paths while nonconforming ones are rejected and handled via alternate process paths.

A Microfilm Inspection Example

Categorical process and product inspections like the above also take place during the analog process of microfilm production, except that *three* types of item inspection may occur:

- **Judgment Inspection** – As above, examinations of product attributes (scratches) or variables (maximum density) form the basis of pass-fail judgments.
- **Informative Inspection** – An expansion of judgment inspection, where information that led to the rejection of a microfilm reel (or, conversely, the acceptance of an film processing run[vi]) is sent back "upstream" to earlier stages in the production process. The information transfer is effected with the expectation that item rejection/acceptance data will (a.) lead to a reduction of the item rejection rate, (b.) lead to improved production efficiencies, or (c.) state for the record that all subsequent production steps followed specifications.
- **Source Inspection** – This task involves examining items at critical steps during their production, with the intent of catching operator or equipment-generated mistakes *before* they become defects that are incorporated into products. In microfilm processing, for example, technicians employ film processing control strips to establish that film processors are operating within *control limits* (i.e., that the film will be processed properly) before exposed film is run.[vii]

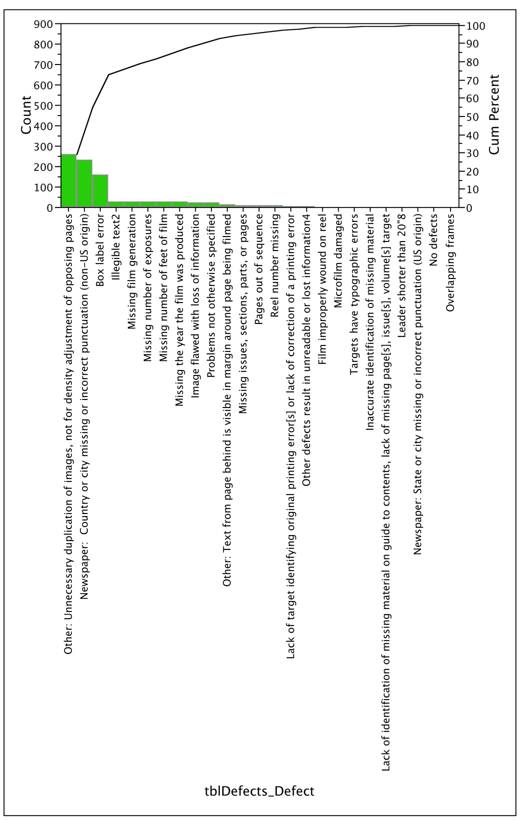

Figure I: Pareto Chart of Microfilm Inspection Codes

Even though an institution's document microfilming contract would specify that each reel of processed microfilm be delivered without measurable or visually detectable chemical or physical damage to the film, a Quality Control inspector working for that institution may nonetheless encounter deep scratches across several images on a reel. The inspector reasons that the microfilm reel possesses a defect, and assigns the appropriate defect code (whose label is "scratches or gouges") to the item. Based on the number and types of defects that are identified within the reel or batch, the reel or batch may be declared *defective* and rejected.

In this production scenario, pass-fail microfilm inspection results are periodically aggregated and analyzed to identify trends in production quality. To support this effort, a *Pareto Chart* is created to arrange pass-fail inspection information as a bar chart of defect counts superimposed over upon a defect cumulative percentage line chart. The Pareto chart shown in ***Figure 1*** presents microfilm inspection defect codes (including a "no defects" code) that were assigned to a sample set of microfilm reels processed by an outsourced quality control inspector.

The defect codes presented are a subset of a comprehensive list of 93 contractually specified nonconformances that have established by the institution that outsourced both the microfilming and its initial inspection. To further inform the film inspector's judgment inspection, the master defect list also includes a "level of error" value that indicating the seriousness of each defect. Quality control teams at differing points in the production process could (as the recipient of informative inspection data sharing) use Pareto charts (in combination with their knowledge of defect types and severity and the microfilm production process) to identify (a.) which *special cause* defects can be corrected by operators at various points in the production process, and (b.) which defects will require reengineering of microfilm production steps.

If any serious defects are present – those for which *no* occurrence is acceptable and which would occasion immediate rejection downstream – the special causes or process steps responsible would be targeted for immediate correction. Defects deemed less critical may be handled differently. In our example, quality control staff analyzing ***Figure 1*** would note that the most common defect ("Other: Unnecessary duplication of images, not for density adjustment of opposing pages") constitutes about 30% of the defects reported. They might then examine the microfilming process step(s) where camera operators are permitted/encouraged to take and retain more than one exposure of a page as needed. The team may decide that, given the low level of criticality accorded to the defect, and the minimal effect it will have on microfilm users, reengineering production process step(s) to reduce the occurrence of that particular defect is not worth the effort.

The goal of Pareto Chart analysis for quality control is to remove as many defects as possible from subsequent reports – given established quality limits and resource limitations. Removing that one low-level defect from consideration and the Pareto Chart, allows the Quality Control team to direct its attention to the remaining 70% of defects assigned for other reasons. Many human conducted or software-executed digital preservation production (or service delivery) steps can be very adequately framed in terms of pass-fail judgments of quality, completeness, timeliness, etc. They therefore lend themselves well to Pareto charting & analysis, and to subsequent process correction and/or improvement.

Downstream Uses – Archive operators further down the line from the producers can, by examining vendor-supplied or web accessible charts or tables of defect code distributions, verify for themselves candidate item or batch completeness, image quality, processing documentation, etc. These distributions could also have been generated from production metadata included in Submission Information Packages (SIPs).

Tool II: Run Chart Validation of Graphic Arts Photography "Rules of Thumb" and for General Process Monitoring

Many of the vanishing skills practiced in Black Box production environments served to eliminate process variation that could prove problematic later on. Using film processing control strips to monitor film developing was one way that photolabs assured their clientele that their work was being processed according to expectations. This information would be especially useful if a client complained that processed film color or contrast shifts were the fault of "the lab." Lab personnel could present control charts of film strips processed before, during, and after the client's work as proof of proper development. Before the lab reached that happy point in time, however, lab technicians would have had to characterize their film processor so that they understood how output from the film processor could depart from specifications. Achieving process control would have taken time, patience, technical skill, and supportive information from film, film processor and processing chemical manufacturers. They would have accomplished their goal by adjusting film processing parameters, processing control strips, measuring control strip values, examining the results grouped into meaningful categories, and repeating the cycle as many times as necessary.

The production of digital images is also subject to variations that may exceed the bounds of acceptability. While image properties like brightness, contrast, color balance, etc., are – unlike a film/processing step – now trivially adjustable, determining optimal camera lens settings to achieve the best resolution still poses difficulties for analog and digital imaging system operators.

As a case in point: maintaining image sharpness by judicious refocusing during image capture is an activity that – while assuring good image quality – slows down production rates. In response to the situation, many Graphic Arts photographers have developed focusing techniques – rules of thumb – that yield good quality results more efficiently. For example, one popular rule of thumb held that the photographer should frame, focus, and set exposure for the first page of a book as usual – but should *not* refocus the lens or change the lens aperture thereafter. Instead, the photographer focuses the camera image as needed by moving the *whole camera and lens* assembly up and down over the copy. One Control Chart can show very accurately what happens if this rule of thumb is not followed.

A Real-World Imaging Task as a Designed Experiment

Consider that a bound newspaper volume is to be digitized as quickly as possible by technicians possessing reasonably good digital imaging skills. The institution's bound volume of *Stars and Stripes* for November 1955 was placed on a overhead capture copy stand, illuminated normally, and the camera adjusted to a height such that the field of view/capture encompassed one bound page at time. A *Golden Thread*[viii] imaging target was placed on each page to provide image quality information for later analysis, and a set of sample images were captured.[ix] For purposes of this designed experiment, this rapid imaging procedure includes an error of practice in hopes that its consequences are detectable by one or more elements of the included quality control target.

Focus Short Cuts & Magnification Consequences – Under the press of production, imaging technicians avoided refocusing the camera between several page captures, hoping that the "depth of field" characteristics of the focused image would assure sufficient image sharpness. As the technicians shot their way through a book volume, and refocused the image, they made the common error of *refocusing the lens,* rather than *moving the previously focused camera body and lens up and down as a unit*. As each succeeding page of the bound volume was slightly further away from the camera lens than the previous one, refocusing the lens – as opposed to moving the whole camera to refocus the image – subtly changed the image magnification over the 3cm thickness of the bound volume. For thin pamphlets, this change in image magnification over the thickness of the item would not be apparent or of concern. But when thick books or newspaper bound volumes are imaged, the differences in image magnification can be significant – and would show up clearly in imaging target elements used to measure image dimensions.

The Designed Experiment – The imaging task was designed to produce digital image files that vary in lens-page distances for each shot. One element on a *Golden Thread* quality control target is a simple centimeter/inch scale. This scale can be used in an experiment that explores changes in image magnification under different conditions. Within each image captured, the length of a 10cm section on the target was measured and recorded. Changing the lens-page distance in this situation changed the magnification of the final image along with its overall sharpness. The bound volume's thickness was such that the images were not so out of focus as to preclude accurate measurement – possibly justifying the technician's hopes. If one uses a control chart called a *Run Chart*[x] and plots the magnification[xi] of the captured images in order of their capture, one can clearly detect a downward and an upward trend in image magnification over the 3cm bound volume:

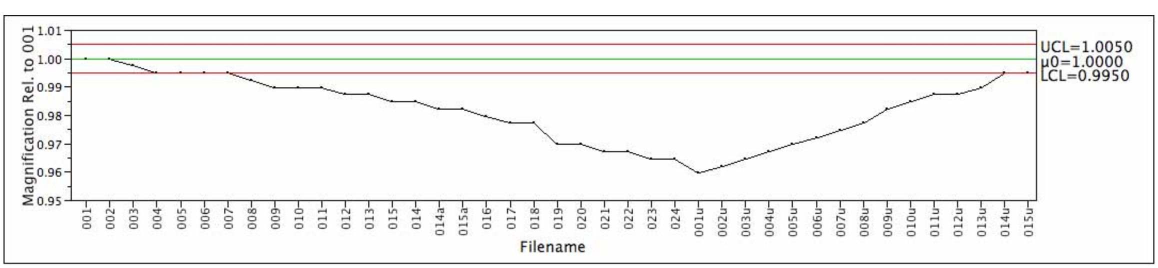

Figure 2: Run Chart of Target Magnification As Sampled Through The Full Thickness Of A Bound Newspaper Volume

Due to a less-than-optimal lens refocusing strategy employed over the thickness of the bound newspaper volume, several phenomena are detectable:

- The magnification of each captured image slowly decreases down to the last page in the volume (0024).
- When the lens is refocused on the last page captured (previously as image 0024) with images captured all the way up through the volume to the top page (image 015u is of the same page captured as image 001), the slow increase in image magnification is also visible in the Run Chart.
- The magnification of last unfocused image of the page at the back of the volume (image 024) is not the same as the focused image of that same page (image 001u).
- The magnifications of the two images of the top page in the volume (images 001 and 015u) are not the same.

Practical Application of Run Chart Results – We have seen from the Run Chart that the image magnification changed about 4% between the pages at the front of the volume and those at the back. For *Stars and Stripes,* this means that the 40.6 cm x 30.5 cm dimensions of the front page will be recorded by the camera as a smaller 39.2 cm x 29.4 cm back page.

If it was intended that each captured image should be printed out as a facsimile at the same size as the original (as it would be for duplex printing and/or binding), one can see how these variations could create extra work for printing and binding personnel. If the sizing of facsimile prints is keyed to the dimensions of the first bound page image, the top facsimile page will be approximately *1.4cm taller and 1.1cm wider* than the facsimile page printed from the last page image. Intervening facsimile page dimensions will fall, aggravatingly, in-between.

If the goal for imaging the bound newspaper volume is to enable the production of back-to-back facsimile page reproductions at the original print size, this variation in image size across an issue may result in some printed pages being rejected due to their misalignment with the image on the other side of a page. If not outright rejection of page images, the magnification differences will at least oblige the printer to fiddle with printed image sizes to make the pages align properly.

The 4% variation in page image magnification revealed above may or may not be important to the institution creating the resource, depending on the design quality levels established for their Digital Items. For newspapers, one can imagine not needing to align pages more accurately. For rare books, however – where facsimile reproduction quality standards are much higher – the story is quite different. Hardcopy output alignment issues aside, when a researcher wants to examine variations in the type used for printing across selected pages of the volume by comparing magnified views of the text on a row-by row basis, excessive variation in page magnification makes the comparison task more difficult. The result is a less-than-satisfied user of that digital content.

Causes and Solutions – The magnification variations encountered above would be considered *special cause* variation if the camera can be focused appropriately but had not been. Reduction or elimination of this kind of variation would simply require a change in imaging practice. If the camera arrangement cannot easily and accurately be corrected (i.e., a systemic process variation exists), then a reengineering of that imaging process step – acquiring a better camera stand – would be necessary.

Run Chart analyses of target-based measurements like image magnification can enable all three forms of inspection: Judgment, Informative, and Source. Just as in the case where control strips are inserted to monitor film processing, a target like the *Golden Thread* could be placed for capture alongside the item of interest. Imaging specialists could immediately (hopefully automatically) determine that critical variables like image magnification, color/tonal resolution, etc., are within *tolerances* established for the specified design quality level. Target data would thereby provide sufficient information for a "mistake proofing" mechanism at that point in the imaging process.

From the imaging and Run Chart exercise above, we have grounds to believe that image magnification variations could be reduced by adopting the hoary (but apparently very helpful) Graphic Arts Photography rule of thumb – a rule that applies equally to analog and digital imaging practice.

The Downstream View – While successful process control and improvement techniques will reduce the need to frequently and comprehensively analyze quality control targets during Digital Item production, target insertion will still play an essential role in downstream archiving and access operations. At archival ingest time, quality control target information can be acquired via random or continuous SIP sampling and verified against SIP producer quality claims (made at the institutional registry level and/or supplied as SIP metadata). At access time, image quality analyses like the above can be made by quality sensitive end-users using the appropriate target analysis application.

Tool III: Variability Analysis for Digital Imaging Device Characterization and General Problem-Solving

Variability analyses involve making measurements of a produce or process characteristic, and examining averages and standard deviations (variability metric) of those measurements.[xii] *Variability charts* show the variation of a measurement across a set of categories that may affect a measurement. The vertical axis of a variability chart represents a measurement of interest, and the horizontal axis the categories under examination. If one wanted to use variability charts to evaluate the performance of an overhead capture system before purchase, or to assure proper system function on a periodic basis, the relevant categories could be:

- Locations on a copy board whose area is fully imaged by the camera. The locations could be labeled top-left, top-right, center, bottom-left, and bottom-right.
- The three sensor elements of a color scanner (Red, Green, and Blue)
- Lens aperture settings expressed as categories (f/5.6, f/8, f/8-11, f/11, f/16, etc.) instead of continuous variable.
- Image post-processing options, categories of which could be aligned or unaligned, contrast corrected or uncorrected, sharpened or unsharpened, etc.

Variability analyses of imaging system performance could be performed using any measurement technique that yields a numerical value. Quantitative analysis of the data – whether to settle an image quality dispute or to decide on expensive technologies – benefits best from *ratio-level* measurements (evenly spaced measurement intervals with a true zero value) of imaging system performance. System Frequency Response (SFR) measurements[xiii] are of this type. For this device performance analysis, an ISO 16067-1 test target was placed at a series of locations on the copy board of a high-resolution color overhead capture system, with images captured at two lens aperture settings.

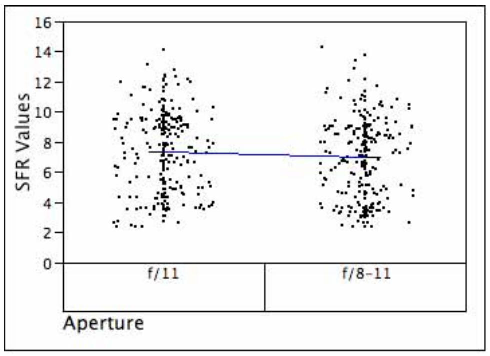

Figure 3: Variability Chart : RGB Resolution With Connected Lens Aperture Averages

Figure 3 presents a variability chart of System Frequency Response measurements of the target, indicating that of the two imaging system resolution measurement datasets being studied,[xiv] neither manages to achieve an 600 DPI equivalent average resolution (11.8 cycles/mm) across the whole copy board. From a cursory glance, the performance levels at both aperture settings average 400DPI (7.9 cycles/mm) or less. The system cost and the scanner manufacturer's performance claims suggest that actual system performance is below expectations.

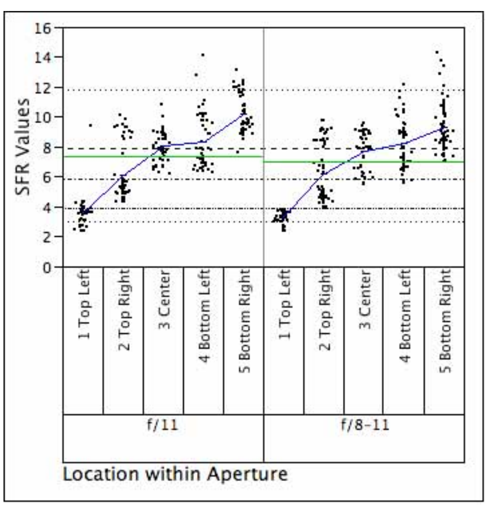

Figure 4: Variability Chart II RGB Resolution With Connected Location Resolution Averages And DPI Resolution Reference Lines

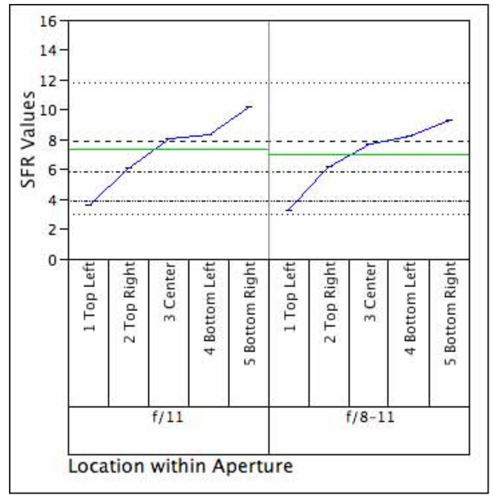

Figure 5: Variability Chart II Connected Location Resolution Averages And DPI Resolution Reference Lines

Variability Chart Conventions For Rapid Data Analysis

DPI Equivalent Resolution Reference Lines - To gain a better sense of imaging system performance, SFR measurements at different locations on the camera system's fully imaged copy board will be examined. Knowing that variability charts like ***Figure 4*** will be used for imaging device characterization, chart display features can be adjusted to improve interpretability. Horizontal lines are drawn at SFR values that equate roughly to the common notion of dots per inch resolution (DPI) [xv]. For ***Figure 4*** and the remaining graphs, the top two dotted lines represent 600DPI and 400DPI equivalent resolutions. The next line represents the average DPI resolution for the lens aperture setting. The bottom three dotted reference lines represent 300DPI, 200DPI, and 150DPI equivalent resolutions.

Now that SFR values in ***Figure 4*** have been separated into different categories based on location on the copy board, significant resolution variation can be seen at some board locations. At about 150DPI, the resolution in the top left corner seems *very* low, while the top right corner disappoints at about 350DPI. The remaining locations yield acceptable DPI-equivalent resolutions at or above 400DPI at both f/8-11 and f/11 lens aperture settings. Knowing that the plotted measurements are of the combined performance of red, green, and blue sensor channels, the analyst might wonder whether differences in color channel resolution may be the cause.

Averaged SFR Resolution Values And Connecting Lines – In ***Figure 4***, the SFR values measured by the target application plot as *16* SFR measurements for the R, G, and B channels at each copy board location. However, in order to speed and simplify interpretation at the next level of variability analysis, it will be useful to further streamline data presentation. The following graphical conventions are used where appropriate in ***Figures 4*** through ***8***:[xvi]

- The variability charts now include *averaged* SFR measures for each color channel.
- In ***Figures 5, 6a, & 6b***, the SFR measurements are replaced by the average SFR resolution at each channel and location.

- Averaged SFR measurements (e.g., in ***Figure 5***, the narrowest groupings are by copy board location: "1 Top Left" "2 Top Right," etc.) are connected by a solid connecting line so that the viewer can readily note significant resolution differences at each copy board location and lens aperture. The connecting lines also exist in ***Figure 4*** but are harder to see because of the many data points.

The Final Analysis: Exploring Color Channel Resolution

- We are now at our final level of device performance analysis. ***Figures 6a & 6b*** are variability charts that group SFR measurements by color channels at a specified copy board location:

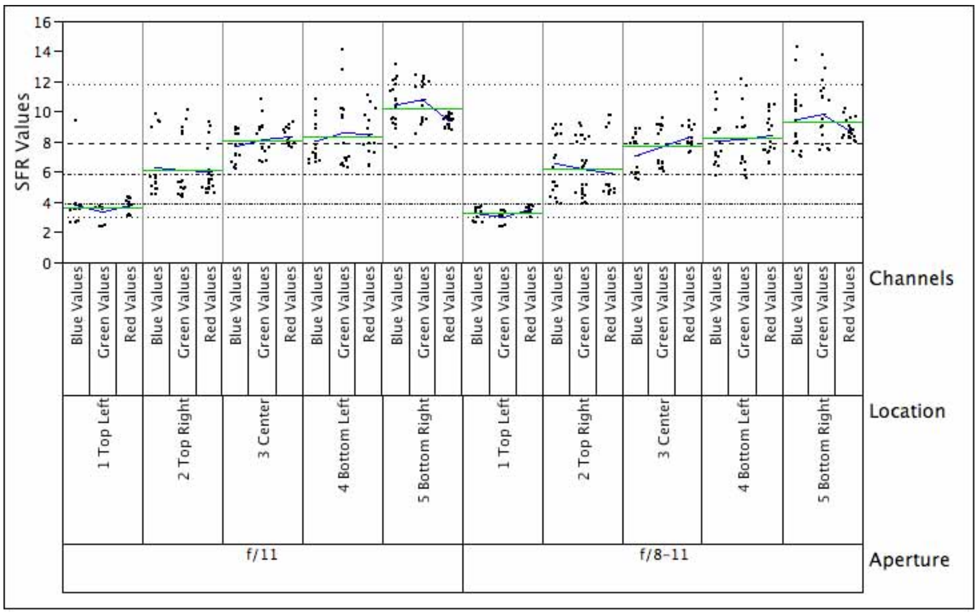

Figure 6a: Variability Chart III RGB Channel Resolution Values, Averaged RGB Lines, and Location Average & DPI Resolution Reference Lines

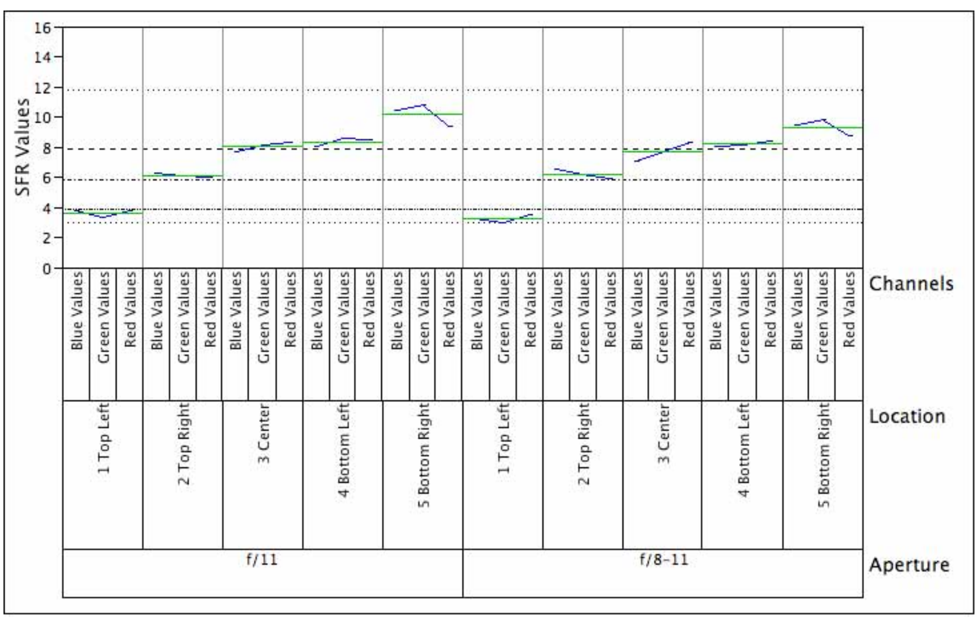

Figure 6b: Variability Chart III RGB Averaged RBG Channel Resolutions with Location Average and DPI Resolution Reference Lines

The analyst can tell whether color channel SFR resolution at any location on the copy board varies by noting whether the connecting line between a location's color channels is relatively straight and level or is relatively tilted and crooked. According to the charts, average SFR resolution differences can be detected for some SFR color channels at any given location – but none are so great as the resolution differences between copy board locations.[xvii] The SFR measurement pattern suggests that the lens system is misaligned. The plane of focus appears to be tilted in both horizontal axes, such that the top left corner is the most out of focus (ergo the low SFR), followed by the top right corner. The success of efforts to realign the system could be verified by repeating the variability analysis (which can actually be done very quickly when the data is in hand) with target data from the adjusted system.

Variability Analysis: The Most Critical Quality Control Tool

Quality oriented variability analyses of this type would be performed much less frequently than Pareto and Run Chart analyses – but variability analyses are the most crucial of the three presented. Variability analyses can be used in production level as well as in the repository or archive.

For the production-minded, decisions on hardware purchases, outsourcing, or of multimedia digitization capture settings depend on being able to make accurate measurements of digitizing device performance or of product/service quality, then determining how these measures would vary under required or desired production configurations. Variability analysis can ensure that (a.) a candidate digitizing technology *can actually achieve* a specified design quality level, (b.) that the consequences of adjusting steps in a Digital Items production process (whether in-house or externally) are well-understood in advance, and (c.) problems traceable to specific hardware, software, or process can be identified by a systematic exploration of system and process configurations. If needed to encourage process identification and improvement, the presentation of quality data like the above can be supported by statistical tests.

For the archive and repository-minded, variability analysis enables examination of quality measures of individual high-value items, of batches of items, items produced by a particular vendor or those submitted by a particular institution.

Making Statistical Process Control & Quality Improvement Work For You

In their volume on statistical quality control tools and technique deployment beyond factory environments, Snee & Hoerl note:

- The tools provide statistical and process improvement rigor, but do not require that ground-level practitioners be professional statisticians.
- The tools do not make improvements on their own. The actions of the people involved in the process make that happen.
- The tools must be properly integrated and used in the proper sequence within the institution.
- If leadership for process control and quality improvement program is lacking within the institution, the tools will not have a lasting effect.
- Tool use must be combined with product/content expertise in an “iterative fashion of generating, testing, and revising hypotheses” regarding the proper creation of products or services.[xviii]

For the quality control and process improvement regimen to succeed in Cultural Heritage Institutions, several specific conditions must be met:

- Quality control data capture takes place at appropriate *control points* – item production or service delivery process steps.
- Quality control data capture should be comprehensive and if possible automatic.
- There must be a management supported – if not mandated – effort to address quality control and process improvement issues at all levels of operation, ideally in the order of their significance to the institution. This effort must include relevant internal and external parties if they play essential roles in Digital Item production or service delivery.

The principal reason for employing quality control metrics and process improvement procedures in Cultural Heritage Digital Library and archive/repository operations is to support the identification and elimination of sources of variation in Digital Item production processes and within the Digital Items themselves. Adopting these tools will result in processes that are more efficient and reliable, and in Digital Items and delivery services of *provable quality*. Applying statistical quality control techniques to digital imaging workflows and to the verification of archived image quality will return to Cultural Heritage imaging environments the same type of quality control and process improvement capabilities that have long existed in professional-level silver halide based photographic studio and graphic arts photography environments. Cultural Heritage institutions can then more confidently and efficiently acquire, create, archive, enable discovery of, and deliver Digital Items in service to their client populations.

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Background

From Annotation and Storage to Data Creation and Quality Control

For several years, local, national, and international parties in the library, archive, and museum worlds have been intensively projecting and adapting their existing points of view and methodologies for managing analog information resources into the rapidly expanding digital domain of textual and multimedia content. This includes undertaking notably extensive efforts at setting standards for library/archive/museum resident digital data and metadata, and to a lesser extent establishing procedures for creating, modifying, enhancing, etc. the managed data and metadata.

Many Cultural Heritage institutions have – initially under the guise of reformatting or framing digital content acquired from publishers in the form of static or dynamically generated webpages – gone on to assume the mantle of data or content creators. This implies they have established *manufacturing* processes that involve the compilation of or creation of data (following editorial guidelines), creation of and aggregation of metadata from one or more sources, and the subsequent structuring of this information into Digital Items for later discovery, access, and use. The direct creation of Digital Items or the reformatting of existing materials has moved libraries, archives, and museums further away from stereotypical recipient, repository modes of the past into the multileveled realms previously inhabited by publishers, photographic studios, graphic arts reproduction facilities, and film processing laboratories.[xix]

What About Quality?

With the growing role that digital information is playing in society and the expansive role that many libraries, archives, and museums have chosen to play in providing digital information to local and global users, assuring the proper characteristics of discoverable, deliverable digital content becomes an affair worthy of serious attention. Once past the initial blush of institutional excitement experienced as they moved from their old roles into the domain of Digital Item production, many libraries, archives, and museums may now face – from within and without – questions regarding the reliability, efficiency and cost-effectiveness of their Digital Item creation processes. Given this emerging focus, it follows that the language and tools for (a.) measuring the *quality* (i.e., conformance to standards) of manufactured Digital Items and for (b.) monitoring and improving the reliability and efficiency of the processes that create those Digital Items be capable of addressing those questions in a convincing fashion.

The Good Old (Analog Imaging) Days: Quality Control in Silver Halide Environments

Silver Halide-based imaging, film processing, and printing practices have long ago reached a level of refinement where suitably motivated, trained, and equipped parties could accurately measure camera and lens/film performance, and operate under well established measurement-analysis-action regimes in order to reach and maintain high levels of quality in photography and in film and print processing.

These domains of photographic technology, knowledge, and skill may have been visible to and actively inhabited by photographic specialists in the better-outfitted Cultural Heritage institutions. More likely than not, many of these domains were hidden from view in commercially created and/or managed "Black Boxes" labeled "Professional B&W and Color Film," "Custom Film Processing Lab," or within commercial facilities that accepted "Camera-Ready Copy."[xx]

Outside of Cultural Heritage institutions, however, Black Box regimes of imaging media manufacture, image processing, and image reproduction – intent on serving the highly varied quality/cost/turnaround time requirements of a broad market of clients – have established (a.) design quality levels from which the client can select, and (b) inputs, outputs, operational processes, and quality metrics that yield the results expected by clients.

With the appearance of high quality digital imaging and reproduction systems – and their progressive migration from Black Box worlds into digital imaging facilities in Cultural Heritage institutions – many reasonably well understood and accommodated film-based Black Box systems have been replaced by very powerful digital imaging and reproduction systems. These new imaging, display, and hardcopy output devices do not always arrive into these institutions with the operational "profiles" that yield results similar to the analog photography regimes that they supplanted. In contrast to the preexisting, familiar, prespecified imaging systems whose critical operational parameters were either worked out in advance or quietly monitored by experienced external parties, the new digital technologies allow nearly all image parameters to be altered at will.

Notes

[i] Montgomery, Douglas. Introduction to Statistical Quality Control. 5th ed. New York:John Wiley & Sons. 2005. Snee, Ronald & Hoerty, Roger. Six Sigma Beyond the Factory Floor: Deployment Strategies for Financial Services, Health Care and the Rest of the Real Economy. Upper Saddle River NJ:Pearson Prentice-Hall. 2004.

[ii] The term "Digital Item" is used here because of its definition in terms of library/archive/museum concepts. ISO 21000.

[iii] As distinct from *defective* items or services, a status assigned by the application of management-approved rules to defect-laden items or services.

[iv] ReVelle, Jack B. Quality Essentials: A Reference Guide From A to Z. Milwaukee:ASQ Quality Press. 2004. p.125.

[v] ReVelle, p.163.

[vi] Standard microfilm processing procedure entails running control strips – film samples exposed under controlled conditions – and verifying processed strip readings against those form a preprocessed reference strip.

[vii] Examining a film processing control strip that accompanies a film run would fall under Judgment or Informative Inspection. If the film was not processed properly, the outcome of the inspection – a pass/fail judgment, etc. – might depend on whether the microfilm was internally exposed or was sent in from elsewhere. Unlike a digital imaging production system where the result of the image acquisition step can be immediately checked and corrected before proceeding, a microfilm processing step can only be monitored in a before & after the fact fashion.

The fact that a film processing process step must complete – often irreversibly – before results are known makes this process control case different from ***poka-yoke*** or "mistake-proof" production system elements that monitor – and stop if necessary – the production process if a nonconforming situation exists. Shingo, Shigeo. Zero Quality Control: Source Inspection and the Poka-yoke System. Cambridge MA:Productivity Press. 1986.

[viii] *Golden Thread* imaging targets are a series of image quality targets under development by Imaging Science Associates of Rochester, NY (ISA@rochester.rr.com). They contain elements for measuring spatial and tonal resolution, color accuracy, and image linearity. Versions are under development for measuring imaging device performance in general, as well as for placement alongside materials to be imaged during scanning production.

[ix] In the bound newspaper sample set, a page image and target are captured every 10 pages throughout the entire bound volume as imaged from front to back. The camera was refocused several times during this process – on pages it will be the image quality target's job to identify. Upon reaching the end of the volume, images were captured every 20 pages from the back of the bound volume to the front, without any refocusing.

[x] http://www.statit.com/support/quality_practice_tips/xbar-r_chart_in_control.htm. Figure 2

[xi] The magnification of each successive image defined in terms of its size relative to that of the first image captured

[xii] JMP Statistics and Graphics Guide v. 5.1. Cary NC: SAS Institute, Inc. 2003. p. 661.

[xiii] Following the ISO 16067-1 method, the target analysis application reposts SFR values at a specified criterion level of sensor response for each R, G, & B channel.

[xiv] Four shots each were made of a target located on the copyboard at 1-top left, 2-top right, 3-center, 4 -bottom left, and 5-bottom right, taken at lens apertures of f/8-11 and f/11.

[xv] SFR refers to detail available in the image, while DPI refers only to the sampling rate of the imaging device. It is possible to create an image with literally no detail in it – a SFR value of 0 – yet sample that image at 600DPI.

[xvi] In contrast to Tufte's art-historical approaches to creating statistical graphics, this chart follows graphical convention strategies established empirically to support enhanced "graphical perception" as recommended by Cleveland. Tufte, Edward R. the Visual Display of Quantitative Information. 2nd.ed. Cheshire CT:Graphics Press. 2001. Cleveland, William S. Elements of Graphing Data. 2nd ed. Murray Hill NJ: AT&T Bell Laboratories. 1995.

Following this strategy, an analyst comparing Red, Green, and Blue channel color resolution at a given copystand location does not need to estimate the values of each of the R, G, & B data points and proceed from there. They need only judge whether the blue line joining the three points is horizontal or jointed up, down, or in both directions.

[xvii] Excluding "extraneous" SFR measurement variation attributable to the target, the analysis application, etc.

[xviii] Snee & Hoerl (2004) p.249.

[xix] Cultural Heritage institutions have developed extensive production lines and procedures for managing acquired materials and have to a large extent internalized industrial approaches to management of their information resources as far as metadata-related and materials management operations go. Some production efforts have become quite expansive and have been assigned a high priority by the involved institutions.

[xx] When the label "Black Box" is applied to a system, it implies certain specified relationships with the "outside world" and obligatory structures and processes within the system's own boundaries. Inputs and outputs for Black Box systems determine the system's internal structure and function – and conversely, a Black Box system places obligations on those who wish to use them to provide the proper inputs. These systems have been effectively managed using statistical quality control procedures that reflect the factory-like environments typical of busy photo studio and photo processing facilities.