# The Necessary Resolution to Zoom and Crop Hardcopy Images

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## Abstract

The objective of this study was to determine the necessary scan resolution for users to zoom and crop images by various amounts. The study image parameters followed a factorial design that consisted of a series of simulated scan resolutions, zoom/crop amounts, inter-polation methods, and print sizes. Observers rated perceived image quality and categorized all of the images as "Acceptable" or "Unacceptable." An objective metric based on system MTFs and the parameters outlined above was calculated. The results for acceptability categories showed similar patterns to the results for relative image quality ratings. The pattern of the objective MTF-based values compared quite favorably to the pattern of image quality ratings. As a result, the necessary resolution at a series of acceptability levels can be derived.

## Introduction

Recently, there has been great interest in the optimal scan resolution for digital imaging systems. Previous research suggests that image resolution impacts perceived image quality.[1-3] It is also indicated that there is an impact of interpolation method on objectively measured image quality.[4] However, these studies do not provide data for many other important variables that may alter perceived image quality due to resolution. Therefore, we chose to examine print size, zoom/crop amount, and interpolation method for various simulated film scanner resolutions.

The results of this study can provide specifications for film digitization systems. In addition, warnings can be displayed when a user does not have enough scan resolution for a desired zoom/crop amount and image quality level.

## Perceived Image Quality Experiments

### Observers

Nineteen Eastman Kodak Company employees who met the criteria for a "typical consumer" participated in this study. Observers who judge images as part of their job, or work on related products, were excluded from the study. They all had normal or corrected-to-normal visual acuity (20/30) as well as normal color vision.

### Experimental Design

To determine relative perceived image quality, a series of images were compared to a reference image. These images were generated by the parameters in fully within-subjects factorial designs. The levels of the variables were slightly different for 4 × 6" and 8 ×12" print sizes. The design for the 4 × 6" print size had 3 levels of scan resolution, 5 levels of zoom/crop amount, and 3 levels of interpolation method. The design for the 8 × 12" print size had 3 levels of scan resolution, 3 levels of zoom/crop amount, and 3 levels of interpolation method. The levels of the study variables were as follows:

<u>Scene:</u> Skipond, Parkbench, Hearth, Couple.

<u>Scan Resolution:</u> Base (512 × 768), 4 Base (1024 × 1536), 16 Base (2048 × 3072).

<u>Zoom / Crop Amount:</u> 4 × 6": 1X, 1.5X, 2X, 4X, 6X and 8 x 12": 1X, 2X, 6X. Zoom / crop amounts were calculated from the original scanned image.

<u>Print Size:</u> 4 × 6" (16 Base = 2048 × 3072) and 8 × 12" (2 * 16 Base = 4096 × 6144) at 508 dpi.

<u>Interpolation Methods:</u> cubic convolution, linear, and 32-bin linear. Cubic convolution and linear interpolation methods are described by Keys.[4] 32-bin linear interpolation is an integer approximation to linear interpolation, which restricts any new pixel to be a 1/32th fraction of its two nearest neighbors. Only integer and bit shift mathematics are used for 32-bin linear interpolation.

The image presentations were blocked by scene, and scene order was counterbalanced with a Latin Square design. Image order within scene was randomized by zoom/crop amount, scan resolution, and interpolation method. The dependent measures were ratio-scaled-image-quality rating and acceptability category.

### Scenes

Four different scenes were used for this experiment: Skipond, Parkbench, Hearth, and Couple (Fig. 1). Among other characteristics, the scenes varied in illumination type and camera-to-subject distance. The Skipond, Parkbench, and Hearth scenes were captured onto 100 speed photographic film and scanned at a resolution of 16 Base (2048 × 3072) with the PCD 2000 scanner. The original images were captured under controlled lighting and camera conditions. MTF targets were measured for all of these scenes.

The Couple scene was captured onto 100 speed photographic film with a Kodak Cameo EX camera and scanned to Photo CD using a Kodak Professional PCD Imaging Workstation (PIW). This scene represents a "base case" consumer type image. Also, the Couple scene was included in the subjective results, but excluded from the objective results and the comparison of objective and subjective results.

In general, zoom and crop coordinates were chosen based on aesthetic appeal through adjusting the location of a fixed-size crop box.

*a) Parkbench*

*b) Hearth*

*c) Skipond*

*d) Couple*

*Figure 1. Study scenes.*

### Image Processing

Initially, the images were decimated to the correct starting scan resolution from a 16 Base (2048 × 3072) scan resolution through successive down by two decimations. A low-pass filter that achieved a pleasing level of sharpness was used to ensure that aliasing artifacts were not evident in the images. All image types were zoomed and cropped at the specified coordinates and amounts and interpolated to the final display or output size. The interpolation methods were as specified above. The images were printed on a high resolution laser printer (508 dpi). The spatial frequency of the printer at a 0.50 response for the green channel was 3.40 cycles/mm in the slow direction (vertical) and 3.50 cycles/mm in the fast direction (horizontal).

### Viewing Environment

The study was conducted in a darkened room and observers adapted to the ambient light level during a practice session. The prints were viewed in a light box under D50 lighting and were viewed at a constant distance of 16 inches. A headrest attached to the light box maintained this distance. The prints were placed in print stands attached to the bottom of the light box.

### Procedure

For the images described above, overall image quality was rated on a ratio scale using fixed modulus magnitude estimation. The reference image modulus was assigned a value of 100 and each scene had its own reference image. The reference image was a 16 Base, 4 × 6", non-zoomed and cropped image. No resampling was required to print the reference images. Observers were especially encouraged to think of the reference image as a representation of the original scene rather than merely an image. They practiced the technique with a set of images processed with all of the image manipulations. Throughout the study, observers were asked to continue to refer to the reference image when providing their ratings.

Finally, observers were asked to categorize the images as "Acceptable" or "Unacceptable." They provided acceptability categories without referring to the reference.

## Results

### Data Analysis

Separate analysis of variance procedures were conducted for 4 × 6" and 8 × 12" print image quality ratings. Post-hoc tests were conducted for significant main effects. Simple effects F-tests and post-hoc tests were conducted to analyze interactions. Duncan's multiple range test was used for all post-hoc tests. The critical p-value was set at 0.05. Results for statistically significant main effects are only reported if they are not part of a statistically significant interaction.

**Image Quality Rating Results.** Overall, the pattern of mean image quality rating results were quite similar for 4 × 6" and 8 × 12" prints; however, the mean image quality ratings were somewhat lower for 8 × 12" than for 4 × 6" print sizes. In general, the acceptability categories exhibited comparable trends to the image quality rating data.

### 4 × 6" Prints

**Interpolation Method.** There was a significant effect of interpolation method on relative image quality ratings [$F(2,34) = 24.91$, $p < 0.0001$]. The cubic interpolation method was rated significantly higher than the linear and the 32-bin linear interpolation types (Fig. 2 and Table 1). However, note that although there were statistically sig-nificant differences, the numerical differences between the means were quite small. If an interpolation method is chosen without regard to processing speed, cubic convolution is the recommended method. Otherwise, it is acceptable to use the 32-bin linear method.

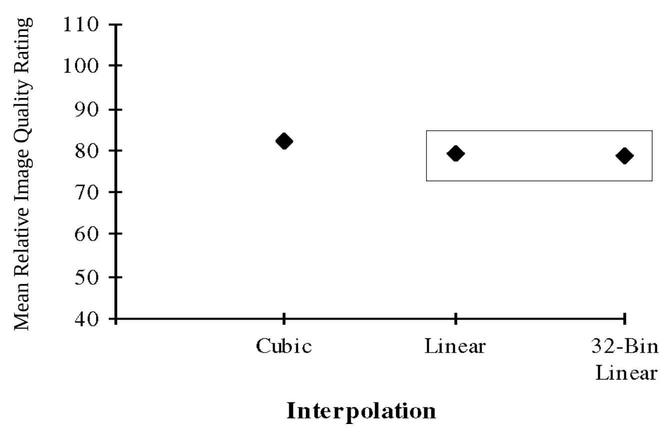


*Figure 2. Mean relative image quality ratings by interpolation. Means enclosed in boxes are not significantly different.*

**Table 1. Percent overall acceptability by interpola-tion for 1080 possible observations per interpolation method.**

| Interpolation Method | | |
|---|---|---|
| Cubic | Linear | 32-Bin Linear |
| 72.5% | 69.4% | 69.4% |

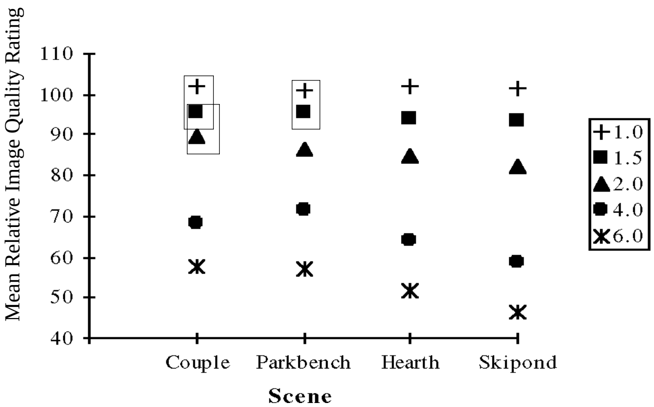


*Figure 3. Mean relative image quality ratings for zoom/crop amount and scene. Means enclosed in boxes are not significantly different. Tests were conducted for a given scene and between zoom/crop amounts.*

**Table 2. Percent overall acceptability by scene and zoom / crop amount for 162 possible observations per zoom / crop amount and scene.**

| | | Zoom / Crop Amount | | | | |
|---|---|---|---|---|---|---|
| | | 1.0 | 1.5 | 2.0 | 4.0 | 6.0 |
| | Couple | 98.7% | 93.2% | 85.2% | 52.5% | 32.7% |
| Scene | Hearth | 100.0% | 92.6% | 80.9% | 51.2% | 30.2% |
| | Parkbench | 98.7% | 93.2% | 81.5% | 63.0% | 38.3% |
| | Skipond | 97.5% | 85.8% | 74.7% | 41.4% | 17.3% |

## Zoom/Crop Amount by Scene

There was a significant interaction of zoom/crop amount and scene for relative image quality ratings [$F(12,204) = 4.03$, $p < 0.0001$]. The order of zoom/crop means was the same for all scenes (Fig. 3 and Table 2). However, the Skipond scene was most sensitive to the effect of zoom/crop amount and the Couple and Parkbench scenes were the least sensitive to the effect of zoom/crop amount. For the Couple and Parkbench scenes, there was no significant difference between the 1.0X and 1.5X zoom/crop amounts. Also, for the Couple scene, there was no significant difference between the 1.5X and 2.0X zoom/crop amounts.

## Scan Resolution by Scene

There was a significant interaction of scan resolution and scene for relative image quality ratings [$F(6,102) = 4.62$, $p < 0.0005$]. For each scene, there were significant differences between scan resolutions (Fig. 4 and Table 3). The 16 Base scan resolution was rated highest and the Base scan resolution was rated lowest.

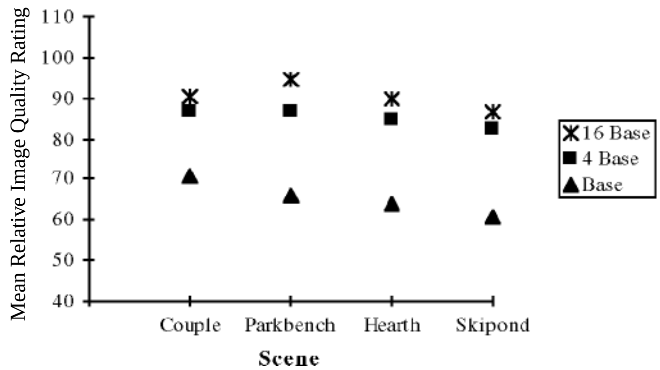


*Figure 4. Mean relative image quality ratings by scene and scan resolution. Tests were conducted for a given scene and between scan resolutions. All tested means were significantly different.*

**Table 3. Percent overall acceptability by scene and scan resolution for 270 possible observations per scene and scan resolution.**

| | | Scan Resolution | | |
|---|---|---|---|---|
| | | 16 Base | 4 Base | Base |
| | Couple | 87.8% | 80.7% | 48.9% |
| Scene | Hearth | 88.5% | 79.6% | 44.8% |
| | Parkbench | 94.4% | 84.1% | 45.6% |
| | Skipond | 80.0% | 72.6% | 37.4% |

## Scan Resolution by Zoom/Crop Amount

There was a significant interaction of scan resolution and zoom / crop amount for relative image quality ratings [$F(4,68) = 2.50$, $p < 0.05$]. As zoom / crop amount increased, the means for each scan resolution decreased and there was an increase in the differences between means by scan resolution at each zoom/crop amount (Fig. 5 and Table 4). There were small differences in ratings between 16 Base and 4 Base images for all crop amounts.

**Table 4. Percent overall acceptability by scan resolution and zoom / crop amount for 216 possible observations per scan resolution and zoom / crop amount.**

| | | Zoom / Crop Amount | | | | |
|---|---|---|---|---|---|---|
| | | 1.0 | 1.5 | 2.0 | 4.0 | 6.0 |
| Scan | 16 Base | 100% | 99.5% | 99.1% | 82.9% | 56.9% |
| Resolution | 4 Base | 100% | 100% | 97.2% | 68.5% | 31.5% |
| | Base | 96.3% | 74.1% | 45.4% | 4.6% | 0.5% |

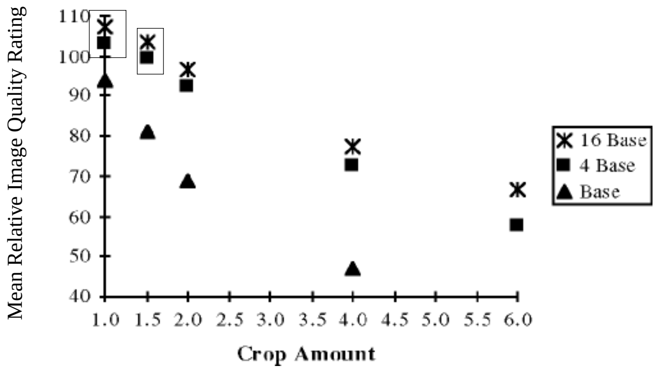


*Figure 5. Mean relative image quality ratings for scan resolution and zoom / crop amount. Means enclosed in boxes are not significantly different. Tests were conducted for a given zoom / crop amount and between scan resolutions.*

### 8 x 12" Images

**Scan Resolution by Scene.** There was a significant interaction of scene and scan resolution for relative image quality ratings [$F(6,102) = 4.03$, $p < 0.002$]. For all scenes, the order of means by scan resolution was the same (Fig. 6 and Table 5). The Parkbench scene was most sensitive to the effect of scan resolution and the Skipond scene was least sensitive to the effect of scan resolution. The 16 Base scan resolution was rated significantly highest and the Base scan resolution was rated significantly lowest.

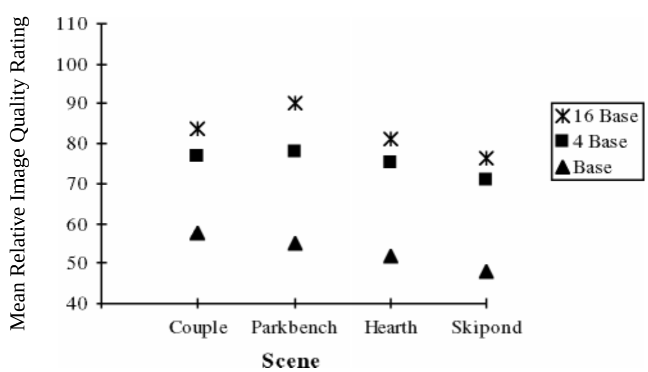


*Figure 6. Mean relative image quality ratings by scene and scan resolution. Tests were conducted for a given scene between scan resolutions. There were significant differences for all means that were tested.*

**Table 5. Percent overall acceptability by scan resolution and scene for 162 possible observations per scene and scan resolution.**

| | | Scan Resolution | | |
|---|---|---|---|---|
| | | 16 Base | 4 Base | Base |
| | Couple | 66.7% | 61.7% | 29.0% |
| Scene | Hearth | 72.8% | 65.4% | 22.8% |
| | Parkbench | 79.0% | 61.7% | 24.7% |
| | Skipond | 65.4% | 59.9% | 18.5% |

### Interpolation Method by Scan Resolution

There was a significant interaction of scan resolution and interpolation method for relative image quality ratings [$F(4,68) = 2.60$, $p < 0.05$]. The sensitivity to the effect of interpolation method increased with a decrease in scan resolution (Fig. 7 and Table 6).

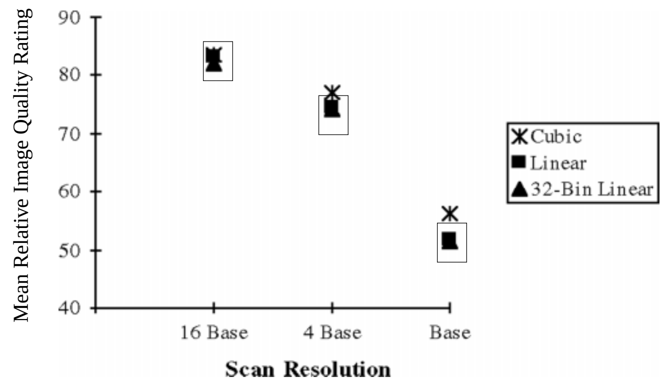


*Figure 7. Mean relative image quality ratings by scan resolution and interpolation method. Means enclosed in boxes are not significantly different. Tests were conducted for a given scan resolution between interpolation methods.*

**Table 6. Percent overall acceptability by scan resolution and interpolation for 216 possible observations per interpolation method and scan resolution.**

| | | Interpolation Method | | |
|---|---|---|---|---|
| | | Cubic | Linear | 32-Bin Linear |
| Scan | 16 Base | 72.3% | 72.3% | 70.4% |
| Resolution | 4 Base | 65.3% | 61.1% | 60.2% |
| | Base | 28.7% | 22.2% | 20.4% |

### Scan Resolution by Zoom / Crop Amount

There was a significant interaction of scan resolution and zoom/crop amount for relative image quality ratings [$F(4,68) = 2.61$, $p < 0.05$]. There were significant differences between scan resolutions. The order of the scan resolution means was the same for all zoom/crop amounts (Fig. 8 and Table 7). The 16 Base scan resolution was rated highest and the Base scan resolution was rated lowest. As the zoom/crop amount increased, the means for scan resolutions decreased.

**Table 7. Percent overall acceptability by scan resolution and zoom/crop amount for 216 possible observations per scan resolution and zoom/crop amount.**

| | | Zoom / Crop Amount | | |
|---|---|---|---|---|
| | | 1.0 | 2.0 | 6.0 |
| Scan | 16 Base | 99.1% | 90.7% | 23.1% |
| Resolution | 4 Base | 99.5% | 82.9% | 4.2% |
| | Base | 61.6% | 9.3% | 0.5% |

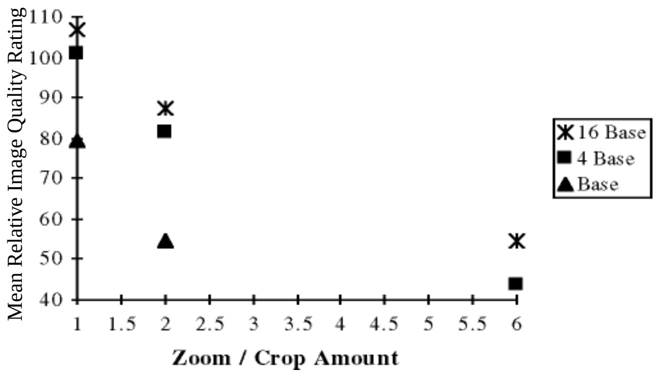


*Figure 8. Mean relative image quality ratings by scan resolution and zoom / crop amount. Tests were conducted for a given zoom / crop amount between scan resolutions. There were significant differences for all means that were tested.*

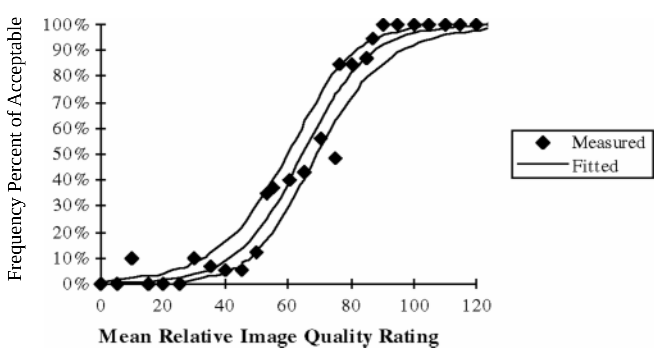


*Figure 9. 4 × 6" acceptability as a function of mean relative image quality rating with 95% fiducial limits.*

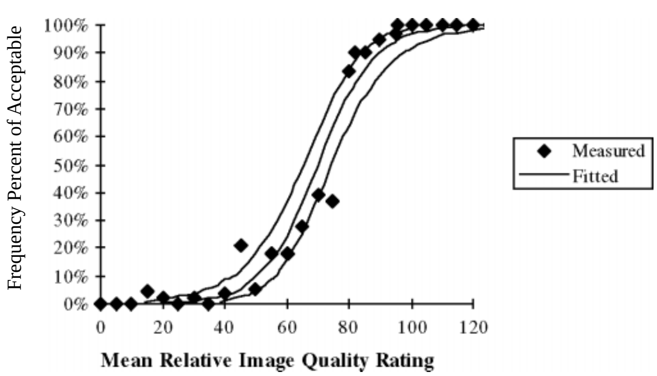


*Figure 10. 8 × 12" acceptability as a function of mean relative image quality rating with 95% fiducial limits.*

## System Analysis

**Acceptability vs Image Quality Rating**

The image quality ratings should be examined in concert with acceptability categories. To this end, the frequency percent for each rating was calculated for 4 × 6" (Fig. 9) and 8 × 12" prints (Fig. 10). Logistic regression was used to fit a curve to the measured data (4 x 6" prints: $X^2_{obs}[41] = 31.1$, $p > 0.9900$, 8 × 12" prints: $X^2_{obs}[41] = 20.71$, $p > 0.9900$). These regression equations then can be used to predict the relationship between mean image quality rating and frequency percent for acceptability. Note that the shapes of the predictive functions for 4 × 6" and 8 × 12" print sizes are quite similar.

**Acutance vs Image Quality Rating**

The acutance values for the Skipond, Parkbench, and Hearth scenes were calculated from printer MTF, viewing distance, magnification amount, interpolation method (only cubic convolution and linear), and the human contrast sensitivity function. These values were cascaded to calculate a one-number value - acutance - that describes the overall sharpness of an image as perceived by a human observer. To further elucidate these relationships, customer perceived quality at a given acutance was calculated and linear regression was used to obtain fitted values. For both 4 × 6" and 8 × 12" prints, as acutance increases, the image quality ratings also increase (Fig. 11).

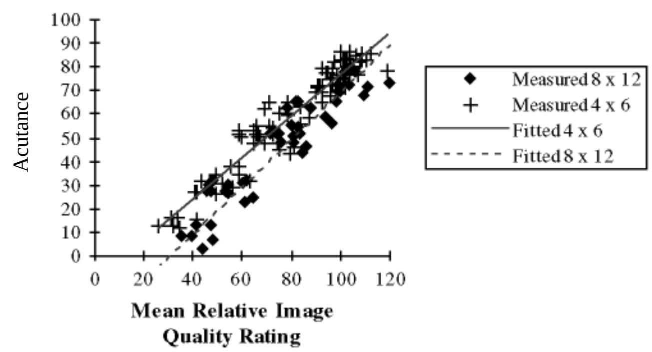


*Figure 11. Acutance as a function of mean relative image quality ratings for 4 × 6" and 8 × 12" prints. For 4 × 6" prints, $R^2 = 0.9182$ and for 8 × 12" prints, $R^2 = 0.9203$.*

## Conclusions

All three metrics can be combined to recommend a minimally acceptable scan resolution at a given zoom/ crop amount. For each acceptability level, a mean quality rating and requisite acutance value can be calcu-lated from the relationships obtained previously. Then, for any system calculated acutance, we can predict the acceptability of a print from that system. This result is quite powerful in that these acceptability levels can hold for any sharpness producing imaging system. Therefore, a scanner resolution for a system can be chosen based on the intended user needs for zoom/crop and acceptability. In addition, when a user is zooming and cropping images with a digital system, they can be warned if they choose a zoom and crop amount that will result in an image with predicted unacceptable quality.

In Tables 8 and 9, for various acceptability levels, the minimally acceptable scan resolution is determined for a given zoom/crop amount. Only the scan resolutions manipulated in the study are shown in the tables below. In some instances, the minimum scan resolution falls between two scan resolutions manipulated in the study. There were cases where a higher scan resolution than used in the study should be recommended. These cases are indicated with a "+" symbol.

**Table 8. Minimally acceptable scan resolutions for 4 x 6" prints.**

| | | Zoom / Crop Amount | | | | |
|---|---|---|---|---|---|---|
| Accept | Quality Rating | 1.0 | 1.5 | 2.0 | 4.0 | 6.0 |
| 100% | 120 | 16Base+ | 16Base+ | 16Base+ | 16Base+ | 16Base+ |
| 90% | 87 | Base | Base to 4 Base | 4Base | 16Base | 16Base+ |
| 50% | 65 | Base - | Base - | Base - | Base to 4Base | 4Base to 16Base |

**Table 9. Minimally acceptable scan resolutions for 8 x 12" prints.**

| | | *Zoom / Crop Amount* | | |
|---|---|---|---|---|
| Accept | Quality Rating | 1.0 | 2.0 | 6.0 |
| 100% | 120 | 16Base+ | 16Base+ | 16Base+ |
| 90% | 90 | Base to 4Base | 16Base+ | 16Base+ |
| 50% | 70 | Base - | Base to 4Base | 16Base+ |

Assuming that most consumers wish to zoom / crop a significant proportion of their pictures by 2.0X and that at least 90% of consumers should rate the image as acceptable, a 4 Base image is required for creating 4 Table 7. Percent overall acceptability by scan resolution and zoom/crop amount for 216 possible observations per scan resolution and zoom/crop amount.

6" prints and an image file in excess of 16 Base is required for creating 8 × 12" enlargements given traditional photo creation methods.

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