

# Analysis of Damage to Direct Mail in the Postal Stream

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## Abstract

This study is a follow-up study from work done in 2008 by the Printing Industries of America (PIA) on the damage sustained by advertising pieces sent through the United States Postal Service (USPS). The results of the 2008 study are presented in a white paper, *Digital Printing and Survivability in the U.S. Postal System*.

This study examined the damage done to color cards sent from 11 different U.S. post offices to the Sewickley, PA headquarters of PIA. All of the cards were produced on the same digital press and the same coated-two-sides card stock. Half of the card fronts were UV-coated. There were 100 UV-coated and 100 uncoated sent from each of the 11 post offices. Fifty random coated and fifty uncoated samples from each post office were selected for analysis.

The analysis answered four research questions. It was found that the coated samples had lower defect scores than the uncoated ones. It was also found that the variability of defect scores for the coated samples was lower than for the uncoated samples.

The backs of the coated cards had lower defect scores than the backs of the uncoated cards. This was surprising because none of the card backs were UV-coated.

The post offices of origin were widely different in their defect scores. This was disconcerting because it indicated that the USPS did not provide uniform quality service throughout its system.

The defect categories varied considerably in their contributions to the overall defect scores. This finding was nuanced because the effects were not the same on the coated and uncoated cards. Overall, the most significant source of damage to the cards was damage to the *edges*, followed by a *miscellaneous* category, then *rips and tears*, then *scratches*, and finally, *scuffs*.

### **Background**

The use of electrophotographic digital color printing for short-run or personalized marketing pieces is increasing rapidly in the United States. In this market, electrophotography has been competing against sheetfed lithography. Historically, lithography has had a significant quality advantage over electrophotography, but electrophotography has had strong advantages for short runs. These include no requirement for platemaking, plate processing, plate mounting, or press makeready. Thus, it is a much more immediate and environmentally friendly process producing comparatively little waste. Electrophotography is much less expensive for producing a few copies. The size of the pressrun where lithography becomes more cost-effective is a matter of some dispute. A pressrun of 1,000 copies is a quantity where many customers will turn to sheetfed lithography instead of electrophotography.

The average size of pressruns in the U.S. has been decreasing for over two decades. At the same time, the quality of electrophotographic printing has improved dramatically, reaching a point where many customers compare it favorably with lithography. Simultaneously, marketers have been using more targeted—and even personalized—advertising pieces to more effectively reach their customers. Although much of the targeted marketing has been taking place online, there is still a strong print component that either complements the online messages or reaches customers who are not found online. Furthermore, a printed advertisement has the advantages of permanence and portability, which make it an effective way to convey advertising messages.

The most common way to distribute hard-copy direct-marketing pieces is through the postal system. The Electronic Document Systems Foundation (EDSF) reported that in 2008, 148.6 billion pieces of mail were sent to U.S. households, 63% of which was advertising mail. This total included 8.3 billion pieces of stand-alone advertising and a similar amount of secondary advertising pieces that were bundled in with other products (billing statements, for instance).

EDSF cites a report by McCann-Erickson indicating that in 2008, American businesses spent \$271 billion on advertising, 22% of which was spent on direct mail, making it the second leading media choice behind television. The Direct Marketing Association (DMA) reports that, in 2011, direct marketing revenues were \$163 billion, accounting for 52% of all advertising spending in the U.S. Yory Wurmser, DMA's director of marketing and media insights, sees direct marketing as “one of the current engines of economic growth for the U.S.” It is clear that direct marketing has been

steadily growing and has become a favored means by which companies reach out to their customers.

It is common to produce targeted marketing pieces on cardstock and send them to recipients without covering or enclosing them in envelopes. This approach is preferred because it is less expensive, less wasteful, and the recipients cannot easily ignore the messages. Graphic providers who use this delivery approach have found that some of the printed pieces are damaged in the postal stream. The damage ranges from minor to severe.

**Figure 1** illustrates the situation. Stanton, in his capacity as an educator, receives regular mailings from the ChoosePrint.org organization extolling the virtues of direct-mail print advertising. The pieces are full-color images on 6x11-in. card



*Figure 1. Direct-mail advertising samples (top—undamaged; bottom—damage circled in red).*

stock. Two cards that arrived several months apart are shown in Figure 1. The card depicted at the top arrived in excellent condition, while the lower card had sustained some damage en route. The damaged card was less effective in conveying its message.

### **2008 PIA Study**

In 2008, on behalf of their member companies and on the recommendation of the Digital Printing Council (DPC), Printing Industries of America (PIA) studied the occurrence of postal stream damage on digitally printed cards mailed uncovered (no envelope) through the United States Postal Service. The results of the study were published by PIA in a white paper, *Digital Printing and Survivability in the U.S. Postal System*.

The 2008 study compared samples printed by five different electrophotographic presses and a control sample printed by lithography. The protocol for the study was to have all of the prints made on the same substrate. None of the prints were to be coated because the DPC reported that 62% of survey respondents did not apply coating to direct-mail cards. There was not to be a preprinted bar code; instead, first-class stamps were to be applied, thus assuring that the printed pieces would be processed by a maximum number of machines by the postal service.

It proved to be impractical for all of the digital presses to use the same substrate. In fact, each of the five participating digital presses and the lithographic press used different 10-pt., coated-one-side card stocks for the study.

Sample cards from each press were subjected to Sutherland Rub Testing. The results showed a wide range of scratch resistance: from 200 rubs for the Océ digital sample to 25 rubs for the Xerox sample. The lithographic print was mid-range, at 100 rubs.

One hundred cards from each of the six printing conditions were carefully wrapped and sent to four different cities where they were unpackaged, inspected, and entered into the mail stream. During transit through the postal system, the cards were processed by two types of machines. The Post Office reports that all of their distribution centers use the same types of mail-handling machines that are centrally sourced from Washington DC. Therefore, the cards sent from different post offices were assumed to have been processed by the same types of machines.

Since the cards did not have preprinted bar codes, they were first processed by machines called Advanced Facing Cancellation System (AFCS) machines. These machines orient the cards, cancel the stamps, capture the addresses and zip codes, and print fluorescent inkjet barcodes onto the cards.

The second piece of equipment that processed the cards was the Delivery Bar Code Sorter (DBCS). The cards were sorted multiple times (up to 4) by DBCS machines, depending on the transit route of the post cards. The PIA research team attributed most of the damage sustained by the cards to the DBCS machines.

Overall, the digitally printed cards performed better than the lithographic prints. Thirteen of 2400 cards were lost in the mail. There were clear differences between the four post offices in terms of damage to cards. Statistical tests of significance were not performed in the 2008 study.

### **Procedure for the 2011 Study**

The current study of postal damage is the second phase of the work reported in 2008. This study took place in the latter part of 2011 and the beginning of 2012. It was designed with fewer variables so that a more accurate characterization of post offices could be obtained. All of the cards were printed on the same substrate with the same digital press and the same toners. Furthermore, a 10-pt., coated-2-side stock was selected for greater back-to-front uniformity of printing characteristics. No lithographic samples were used. The samples were preprinted with delivery barcodes so that they only needed to be processed by DBCS machines, although this would occur multiple times depending on the post office of origin.

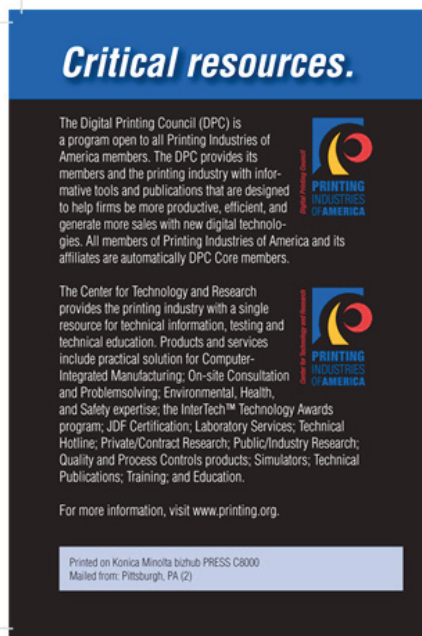
The guiding philosophy for this study was to mimic an optimum mailing strategy, albeit with a challenging image. The results were intended to inform digital print providers with a realistic idea of the type and amount of damage to anticipate for unprotected cards being mailed through the USPS.

The variables for this study included the following:

- The post offices of origin were increased from four to eleven locations.
- Clear UV coating was applied to the fronts of half of the samples to test the effectiveness of this treatment for reducing damage sustained in the postal stream.

The test piece for this study was a direct-mail, full-color card containing heavy color coverage on one side and lighter coverage on the back, where half of the area was left for the addressing information. The back of each card was also coded to indicate the post office of origin and whether the card front was UV coated. All the cards were addressed to Printing Industries of America in Sewickley, PA. The front and back of the card design are shown in **Figure 2**.

The card depicted in Figure 2 did not yet have the printed delivery bar code added to it, although all of the cards that were mailed received barcodes.



  
 PRINTING INDUSTRIES OF AMERICA  
 200 Deer Run Road  
 Sewickley, PA 15143-2600

Nonprofit Org  
 U.S. Postage  
 PAID  
 Pittsburgh, PA  
 Permit No. 361

Printing Industries of America  
 Attention: Dusty Giliman  
 200 Deer Run Road  
 Sewickley, PA 15143-2600

*Figure 2. The card design used in this research (front and back).*

The cards were produced at Printing Industries of America in Sewickley, PA using a Konica-Minolta Bizhub C8000 electrophotographic press with standard toners on 10-pt. card stock that was coated on both sides. The study required 2,200 cards printed on two sides. The front sides of half of the cards were coated offline with Techwet UV coating. None of the back sides of the cards were coated.

Samples of the coated and uncoated cards were subjected to rub resistance testing according to ASTM D-5264 at the PIA materials testing lab. The Sutherland rub test apparatus is shown in **Figure 3**. The rub tests were performed three times on each card tested using four-pound weights.



*Figure 3. Sutherland Rub Tester used in this study.*

The results showed that the UV-coated samples failed after 50 rubs on average, while the noncoated samples failed after 25 rubs. Thus, the UV-coated samples were significantly more resistant to scuffing and other rub-related maladies than were the noncoated samples.

The printed samples were inspected and divided into 11 groups—each group consisting of 100 coated and 100 uncoated cards. Ten sets of these were carefully shrink-wrapped, boxed, and sent to participating affiliates who unpackaged the cards, inspected them, and mailed them back to the PIA headquarters in Sewickley, PA. The eleventh set of 200 cards was mailed from the local Sewickley Post Office. The affiliates were instructed to send the cards at the mixed AADC presort rate for standard mail, in spite of the fact that the cards would qualify for a lower rate because they were all going to the same address. This strategy ensured that the processing of the cards would be analogous to the processing that commercial direct-mail advertising would receive. A copy of the letter of instructions to the affiliates that was included with the shipped cards is shown in **Appendix A**.

The 11 post offices were located in Amherst, NY; Orlando, FL; Chicago, IL; Los Angeles, CA; Milwaukee, WI; Dallas, TX; Nashville, TN; Phoenix, AZ; Portland, OR; St. Paul, MN; and Sewickley, PA.

### **Defect Analysis**

The data analyzed in this study was based on the defect scores assigned by Lindsay Ferrari, research technician at Printing Industries of America. The defect scores, in turn, were based on the observed damage sustained by the test cards that had been prepared for this study and mailed from various locations.

After the cards were delivered by the post office to the PIA Headquarters, they were sorted into 22 groups according to their post office of origin and whether they were coated or uncoated. They were then counted to determine if any cards had been lost in shipment.

The count found that 4 of the 200 cards mailed from Florida were not delivered, and 1 card from Minnesota was lost. All cards from each of the other 9 post offices were delivered. The total loss rate was 5 cards from 2,200—a 0.2% loss. This finding was a slight improvement from the 2008 study, in which 13 of 2,400 cards, or 0.5%, were lost.

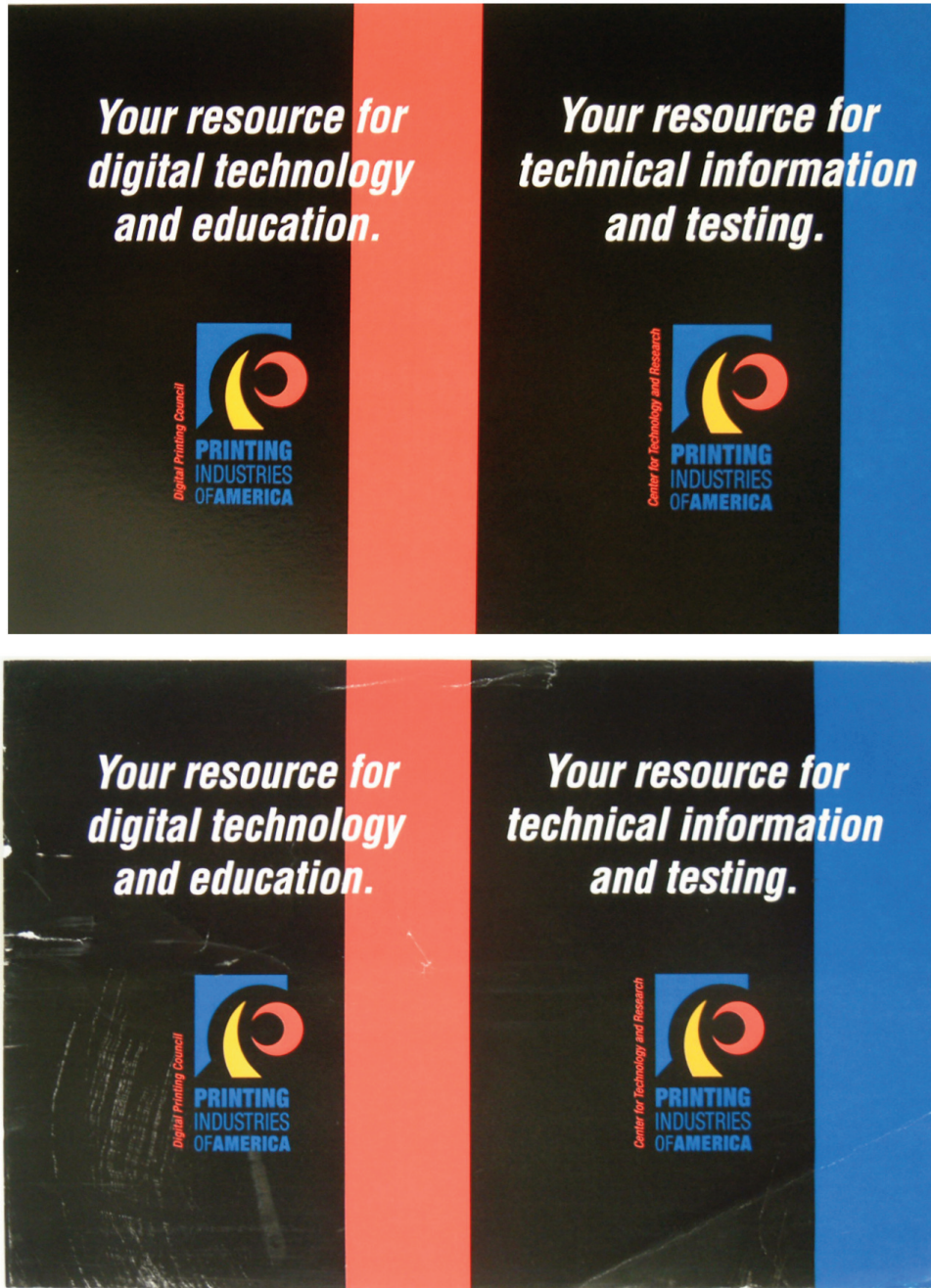
Of the cards delivered, 50 were randomly selected from each of the twenty-two groups to be subjected to analysis. Overall, the conditions of the cards varied from undamaged to severely damaged. **Figure 4** shows examples of these two extremes.

Examination of multiple cards led to the categorization of defect types. In addition, given types of damage tended to be clustered in specific areas. The defect categories, therefore, reflect both a type of damage and its location. They are listed below.

Furthermore, the research team recognized that the defect categories were not equally detrimental to the value of the cards as marketing pieces. For example, a tear in the card was considered to be far more detrimental than a dent along the card edge. Therefore, weighting factors were applied to the defect categories, so that the total defect scores would be more representative of the loss of value due to the damage sustained in postal transit. Throughout this study, the defect scores of cards refer to the weighted scores.

Defects were divided into 11 discrete groups for the front side of the cards. They are presented here together with their weighting factors:

1. Scuffs on the red bar (weighting 2)
2. Damage to the left PIA logo (weighting 2)



*Figure 4. Examples of cards in good and bad condition.*

3. Damage at the left edge of the card (weighting 0.33)
4. Damage to the text on the left side of the card (weighting 1)
5. Scratches along the bottom portion of the card (weighting 1.5)

6. Rips or surface tears that remove fibers from the card (weighting 3)
7. Damage to the right edge of the card (weighting 1)
8. Damage to the right PIA logo (weighting 1)
9. Damage to the text on the right side of the card (weighting 1)
10. A machine mark denting the left edge of the card (weighting 1)
11. Other damage (weighting 1)

Similarly, six categories of defects were identified for the back side:

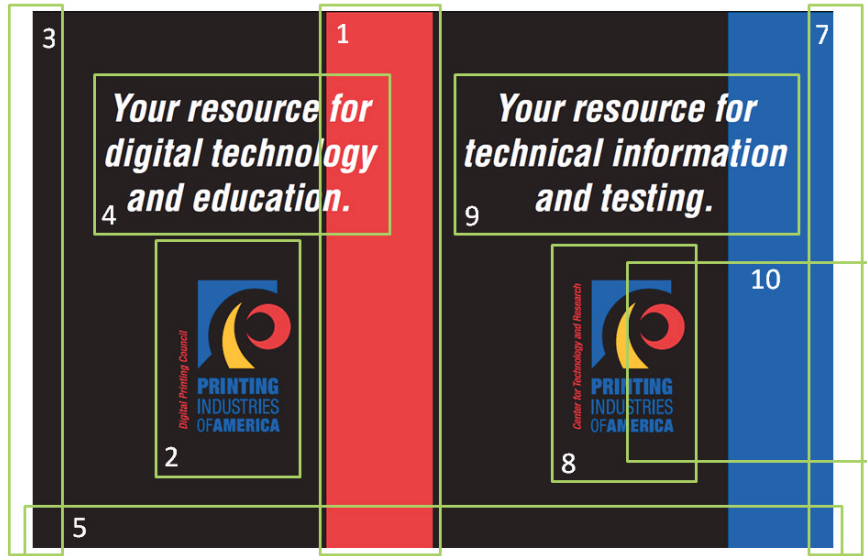
1. Horizontal mark across the card (weighting 2)
2. Damage to the left edge of the card (weighting 1)
3. Red ink transfer (weighting 1)
4. Damage to the right edge (weighting 1)
5. Rips or surface tears that remove fibers from the card (weighting 3)
6. Other damage (weighting 1)

The locations for various defect categories on the front and the back of the cards are shown in **Figure 5**.

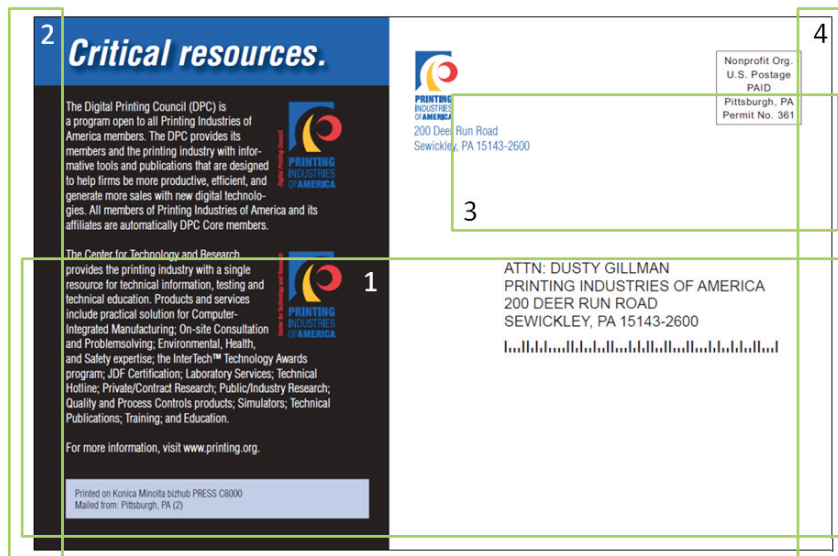
Ferrari examined each card and entered defect scores based on the categories as described above. The scores were given values of 1, 2, or 3 based on the severity of the defect, with 1 being the most minor and 3 the most severe. Furthermore, the number of occurrences of each defect on a given card was noted.

For example, when rating card A for the occurrence of scratches along the bottom portion of its front, it might have 3 minor occurrences (scored as 1s), 1 moderate occurrence (scored as a 2), and zero severe occurrences. Card B might have zero minor occurrences, zero moderate occurrences, and two severe occurrences (scored as 3s).

When calculating total defect scores for these two cards, a weighting factor of 1.5 would be applied based on the category of the defect (i.e., scratches along the bottom of the card). Card A would have a total defect score for this category of 7.5 (based on  $(3+2)*1.5$ ). Card B would have a total defect score for this category of 9.0 (based on  $6 \times 1.5$ ).



- 6) "Rips and tears" occurred on all four edges of the cards.
- 11) Defects identified as "others" occurred in random places

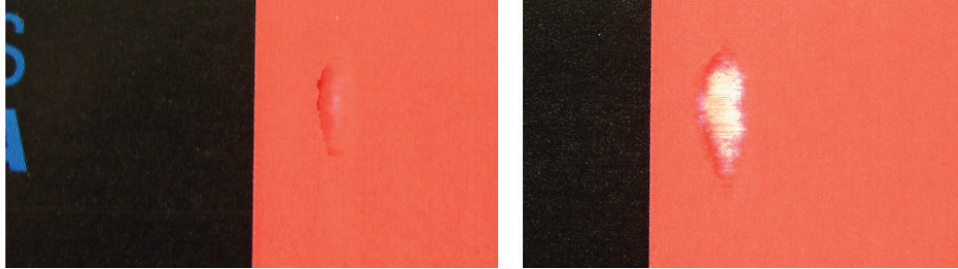


- 5) "Rips and tears" occurred on all four edges of the cards.
- 6) Defects identified as "others" occurred in random places

**Figure 5.** The locations of defects on the front and back of the cards.

In completing the defect analysis for this study, Ferrari made a total of 12,100 evaluations from the fronts of the cards (11 post offices, 2 coating states, 50 samples, 11 defect categories). She made an additional 6,600 evaluations from the backs of the cards.

The scores for severity of defects were judged in the context of many examples of similar defects. **Figure 6** shows examples of a minor (1) and severe (3) occurrence of a scuff in the red section of the card. **Appendix B** contains selected photographs and photomicrographs of typical damage found to the cards in this study.



*Figure 6. Examples of minor and severe red scuffing.*

The defect data were organized into four Excel workbooks (coated fronts; coated backs, uncoated fronts, uncoated backs). The terms “coated backs” and “uncoated backs” are used throughout this study to refer to the backs of the coated and uncoated samples. (In fact, none of the samples had UV coating applied to the backs of the cards.) The research team wanted to determine if the backs of the coated cards would suffer different levels or categories of defects than the backs of the uncoated cards. Therefore, the terminology was adapted to distinguish these two populations.

Forty-four different experimental conditions were identified in this study based on:

- 2 treatments (coated and uncoated)
- 2 sides (front and back)
- 11 points of origin (post offices)

There were 50 samples in each of these categories. A sample data file for a single experimental condition (Wisconsin post office, front of card, UV-coated) is shown in **Appendix C**.

These 44 conditions were examined in terms of the total defect scores for each of the conditions. Additionally, analysis was done based on the different categories of defects.

### **Analysis of Data**

The summary statistics for the total defect scores (across all 11 categories) on the fronts of both the coated and uncoated cards for each post office are shown in Table 1. The statistics shown in **Table 1** relate to the weighted defect scores. The rows in Table 1 are as follows: the average defect scores; the highest defect scores; the lowest

defect scores; the range of defect scores; the standard deviation of defect scores; and the weighted total of all defects for 50 samples. The values in each cell in Table 1 represent 50 samples.

The differences in average values of a given post office between the coated and uncoated cards show that some post offices (notably Arizona) caused much more damage to uncoated cards than to coated cards.

<b>Coated</b>	<b>AZ</b>	<b>CA</b>	<b>FL</b>	<b>IL</b>	<b>MN</b>	<b>NY</b>	<b>OR</b>	<b>PA</b>	<b>TN</b>	<b>TX</b>	<b>WI</b>
average	10.7	14.5	10.8	9.9	10.8	9.9	10.0	0.1	17.2	10.6	18.1
max	19.5	55.5	19.0	22.0	20.7	18.1	14.8	3.0	66.3	32.7	25.6
min	3.0	5.0	5.0	3.0	3.3	4.0	5.5	0.0	8.0	2.7	8.5
range	16.5	50.5	14.0	19.0	17.3	14.2	9.3	3.0	58.4	30.0	17.2
std dev	3.04	6.61	2.25	5.74	2.73	3.92	2.61	0.48	7.79	7.38	3.47
total	537	724	538	497	540	496	500	6	860	529	906

<b>Uncoated</b>	<b>AZ</b>	<b>CA</b>	<b>FL</b>	<b>IL</b>	<b>MN</b>	<b>NY</b>	<b>OR</b>	<b>PA</b>	<b>TN</b>	<b>TX</b>	<b>WI</b>
average	29.7	11.6	17.5	5.7	10.3	16.1	12.5	0.2	25.7	9.4	19.6
max	44.3	19.6	26.7	12.0	17.0	30.3	72.5	2.0	34.6	14.5	47.0
min	23.3	5.5	13.0	0.3	4.6	8.1	5.6	0.0	14.6	6.7	8.6
range	21.0	14.2	13.7	11.7	12.3	22.1	66.8	2.0	20.0	7.8	38.3
std dev	4.13	3.00	3.10	2.37	2.84	3.89	9.39	0.40	4.45	1.79	5.40
total	1483	581	876	284	516	807	623	8	1286	471	982

*Table 1. Summary statistics for front sides of 50 samples across 11 defect categories.*

The high maximum values and high range values for some post offices indicate that some cards were badly damaged during their processing. California and Tennessee are notable in the coated section of the table, while Oregon, Wisconsin, and Arizona stand out in the uncoated section.

**Table 2** contains the same data for the backs of the cards. The backs were analyzed separately because they had only 6 defect categories (vs. 11 for the fronts), and the total values were not comparable.

<b>Coated</b>	<b>AZ</b>	<b>CA</b>	<b>FL</b>	<b>IL</b>	<b>MN</b>	<b>NY</b>	<b>OR</b>	<b>PA</b>	<b>TN</b>	<b>TX</b>	<b>WI</b>
average	9.2	7.4	10.3	2.3	6.6	11.7	6.6	0.1	13.2	3.2	30.0
max	16.0	52.0	21.0	10.0	22.0	25.0	11.0	1.0	38.0	16.0	52.0
min	4.0	2.0	1.0	0.0	0.0	1.0	2.0	0.0	0.0	0.0	13.0
range	12.0	50.0	20.0	10.0	22.0	24.0	9.0	1.0	38.0	16.0	39.0
std dev	2.94	6.99	4.31	2.07	4.41	4.97	2.52	0.24	5.39	4.57	8.80
total	460	372	513	116	329	583	330	3	662	159	1500

<b>Uncoated</b>	<b>AZ</b>	<b>CA</b>	<b>FL</b>	<b>IL</b>	<b>MN</b>	<b>NY</b>	<b>OR</b>	<b>PA</b>	<b>TN</b>	<b>TX</b>	<b>WI</b>
average	16.2	11.8	14.1	4.3	8.9	12.8	12.4	0.2	15.0	7.2	16.9
max	27.0	23.0	20.0	12.0	20.0	23.0	41.0	2.0	23.0	17.0	52.0
min	11.0	7.0	8.0	1.0	4.0	7.0	6.0	0.0	8.0	0.0	7.0
range	16.0	16.0	12.0	11.0	16.0	16.0	35.0	2.0	15.0	17.0	45.0
std dev	3.87	3.03	2.92	2.24	3.31	3.12	5.44	0.56	3.69	2.98	7.34
total	812	588	707	216	446	641	620	12	750	361	843

*Table 2. Summary statistics for back sides of 50 samples across 6 defect categories.*

Bear in mind that while the backs are labeled as “coated” and “uncoated,” this refers to the “back of the cards with coated fronts” and the “back of the cards with uncoated fronts”; there was no UV coating applied to the backs of any cards in this study. Differences between the values in the coated and uncoated results for the backs of the cards are either attributable to random variation or a change in damage based on coating being applied to the other sides of the cards. This question will be addressed further in the Analysis of Variance section that follows.

Two results stand out in Table 2. It was previously noted that uncoated card fronts sustained substantially more damage than coated card fronts from the Arizona post office. Table 2 shows that at 10 of 11 post offices, the backs of uncoated cards sustained more damage than the backs of coated cards. Wisconsin is the only post office where the backs of the coated cards sustained more damage than the backs of uncoated cards, even though the fronts of the coated cards had slightly lower defect scores than the backs. Furthermore, the average defect scores for the backs of the coated cards from Wisconsin was more than two times higher than the average defect score from any other post office. It seems likely that the DBCS machine in this post office was in need of repair or maintenance.

Nearly all of the cards in this study sustained some level of damage in shipment through the Post Office with the notable exception of the cards mailed from the local Sewickley, PA post office. Of the 50 coated samples from Sewickley, 46 of the fronts and 47 of the backs had no defects. For the uncoated samples, 42 of the fronts and 41 of the backs had no defects. It was assumed that the cards mailed from Sewickley had suffered less damage because they had been subjected to fewer processing operations in the postal stream. By contrast, *all* of the cards from each of the other post offices had some defects on the fronts, and the great majority had defects on the backs as well. **Appendix D** shows the number of samples from each post office that had defects in each of the defect categories identified in this study. The tables in Appendix D show the widespread incidence of defects, but do not capture the frequency and severity of a given defect on an individual card.

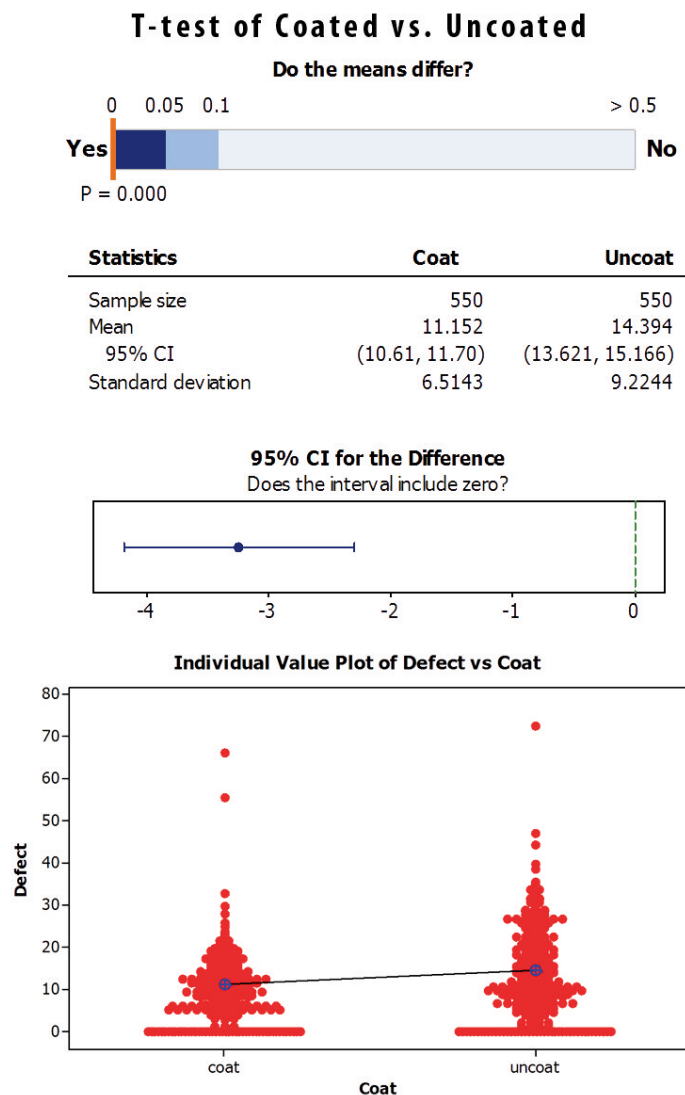
### **Research Questions**

The analysis of data involved multiple t-tests and ANOVAs depending on the characteristic of the factors being tested. T-tests were needed when there were fewer than three levels of the factor being tested. Some of the research questions that the team articulated were:

1. Was there a difference in defect scores between the coated and the uncoated cards?
2. Was there a difference in defect scores on the backs of the cards associated with whether the fronts were coated or not coated?

3. Was the post office of origin a significant factor?
4. Were some defect categories more significant than others in accounting for the total defect scores?

**Question 1** was whether UV-coating on the cards had an influence on the defect scores. A two-sample t-test was used to compare means because there were only two levels of the coating factor: coated and uncoated. To answer question 1, the analysis was only run for the front sides of the cards because none of the card backs had received any coating. The summary of the analysis for the fronts of the cards is shown in **Figure 7**.

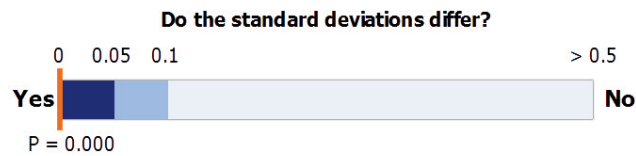


*Figure 7. Two sample t-tests for coated vs. uncoated fronts of cards.*

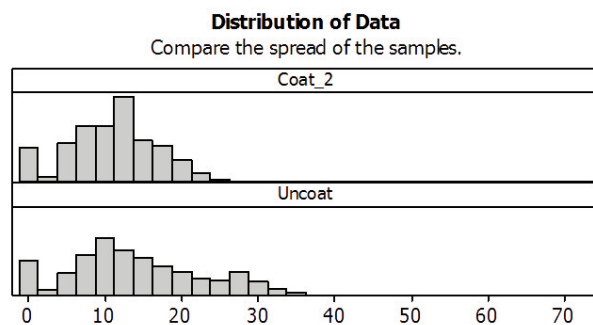
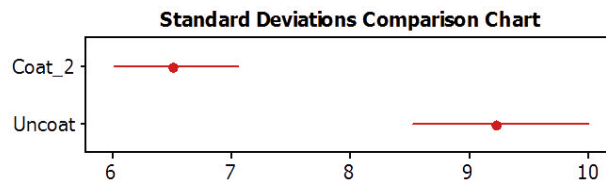
The t-test in Figure 7 shows a clear difference ( $P=0.000$ ) between the defect scores of the coated and the uncoated samples. The average defect score for coated fronts was 11.15 versus 14.39 for uncoated cards. This difference is not large in absolute terms, but from the confidence interval in Figure 7, it was clear that it was a real effect of adding coating to the cards.

What might be of even greater value to persons using direct-mail marketing is the reduced standard deviation of defect scores associated with UV-coatings. This is seen in the statistics in Figure 7 and also in the individual value plots. The standard deviation of the UV-coated cards is only about 70% of the deviation of the uncoated cards. To confirm that the difference in standard deviations was significant, the Levene/Brown-Forsythe Test was run on the data. Those results are shown in Figure 8.

### Std. Dev. of Coated vs. Uncoated



Statistics	Coat_2	Uncoat
Sample size	550	550
Mean	11.152	14.394
Standard deviation	6.5143	9.2244
95% CI	(5.563, 7.655)	(8.459, 10.10)

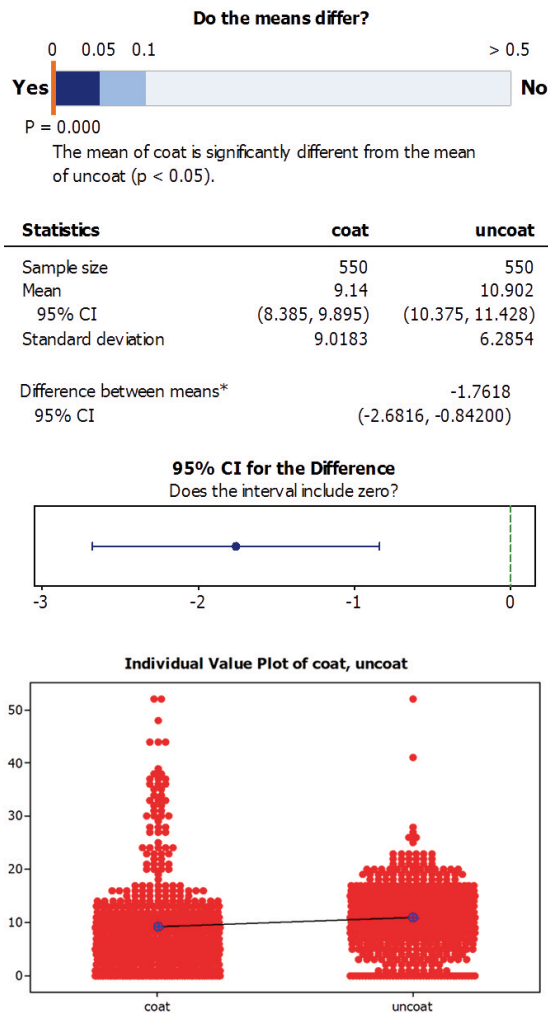


*Figure 8. Two-sample standard deviation test for coated vs. uncoated fronts of cards.*

Figure 8 shows a significant difference in the standard deviations of the coated and uncoated cards. The 95% confidence intervals show the ranges that the standard deviations are likely to fall within for these two populations. The distribution of data shown in Figure 8 gives a clear picture of the more dispersed and higher ranging defect scores found for the uncoated samples in this study when compared against the coated samples.

**Question 2** was whether UV-coating on the front of the cards influenced on the defect scores on the backs. Again, a two-sample t-test was run for front coating influence on the card back defect scores. The results of this test are shown in **Figure 9**.

### T-test Coated vs. Uncoated Backs



*Figure 9. Two sample t-tests for coated vs. uncoated backs of cards.*

Surprisingly, there was a significant difference in the defect levels on the backs of the cards depending on whether or not the fronts had been coated. The backs of the coated cards sustained slightly less damage than the backs of the uncoated cards. Even though the difference is small (9.14 for coated and 10.90 for uncoated), the large sample size of this study provides over 99.5% confidence that it is a real difference.

The most striking thing about the data presented in Figure 9 compared to the same data from the fronts of the cards (Figure 7), was that the standard deviation of defect scores for the uncoated backs was lower than for coated backs, even though the mean defect score for the uncoated backs was higher. On the fronts of the cards, by contrast, both average defect scores and the standard deviations of the coated samples were lower than the corresponding values for the uncoated cards.

The individual value plots from Figure 9 show the situation clearly. The coated distribution shows more samples with very low defect scores, and, also, more samples with high defect scores than are seen in the distribution of uncoated cards.

There is an underlying assumption of normality of data with the two-sample t-test if the sample sizes are small (less than 15). With the sample sizes of 550 in this study, the t-test is valid even with non-normal data. Still, the individual value plots in Figure 9 begged the question of whether the samples in this study were normally distributed. The Anderson-Darling test of normality was conducted for the coated and the uncoated backs of the cards. The probability plots for this analysis are shown in **Appendix E**. In both cases the P-values were less than 0.005, indicating a high probability that the populations were *not* normally distributed.

The explanation for the non-normality of the defect values is seen in the individual value plots in Figure 9. The distributions have limiters on the lower side at zero defects where there are many data points. There is no limiting value on the high side of the distributions and there are enough outlying data points above the mean to preclude close fits with normal distributions.

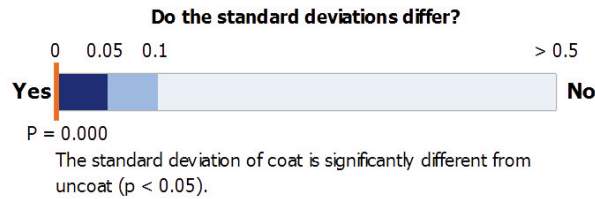
The difference in standard deviations for the card backs was more substantial than the difference in mean values. To confirm that the difference in standard deviations was significant, the Levene/Brown-Forsythe Test was run on the data. The results are shown in **Figure 10**.

Again, there is nearly 100% confidence that the standard deviations are different and that the backs of the uncoated cards had less variability in defect scores, even though the average defect score was higher than for the backs of the coated cards.

Looking at the statistical summary data shown in Table 2, it is clear that the different post offices varied with respect to the relative standard deviations that they achieved on the backs of cards based on whether the fronts were coated or not.

Four of the post offices had lower standard deviations on the backs of coated cards, while the rest had higher standard deviations for the backs of the coated cards. The influences of post offices on defect scores will be examined next.

### Std. Dev. Coated/Uncoated Backs



Statistics	coat	uncoat
Sample size	550	550
Mean	9.14	10.902
Standard deviation	9.0183	6.2854
95% CI	(8.112, 10.06)	(5.714, 6.939)

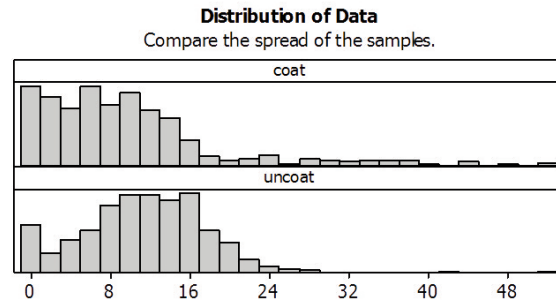
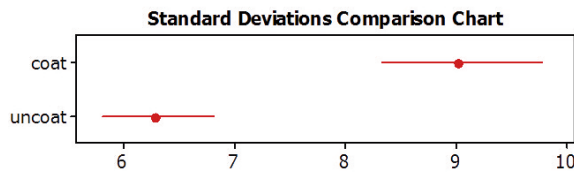


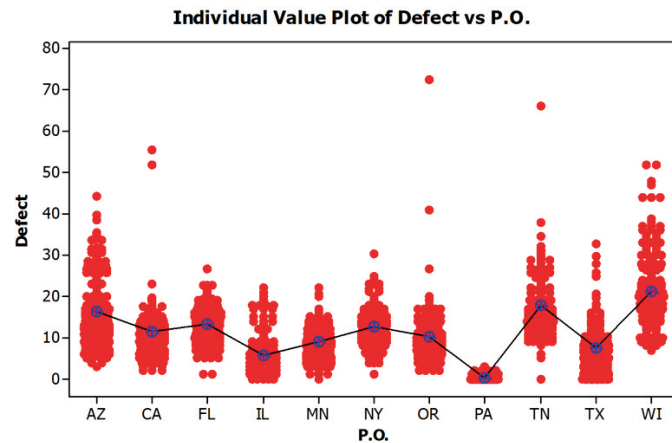
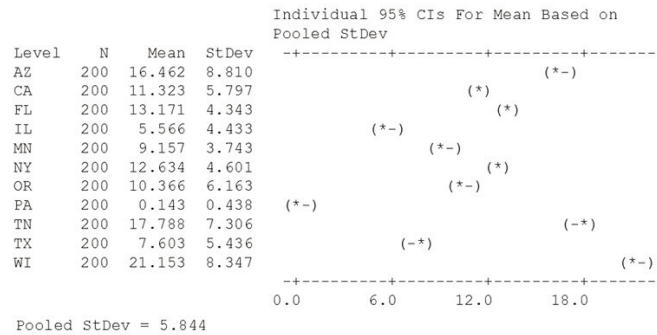
Figure 10. Two-sample standard deviation test for coated vs. uncoated backs of cards.

**Question 3** was whether the post offices of origin influenced the defect scores on cards. This question was answered for the total defect scores (front plus back; coated plus uncoated). It was then examined separately for coated fronts, uncoated fronts, coated backs, and uncoated backs. The analysis of variance (ANOVA) technique was used to answer these questions since there were 11 levels of the post office factor. The ANOVA results for the total defect scores (front plus back plus coated plus uncoated) versus the post offices of origin and are shown in **Figure 11**.

## ANOVA Defect Scores vs. Post Offices Coated & Uncoated Front & Back

Source	DF	SS	MS	F	P
P.O.	10	69497.8	6949.8	203.49	0.000
Error	2189	74760.9	34.2		
Total	2199	144258.7			

S = 5.844 R-Sq = 48.18% R-Sq(adj) = 47.94%



**Figure 11.** ANOVA table, confidence intervals, and value plots for defect scores vs. post offices (all samples).

The ANOVA in Figure 11 shows a clear significance for the factor of post office of origin with respect to the defect scores on cards. The P-value of 0.00 gives a high degree of confidence in this finding. Figure 11 also shows that the large sample size (200 for each post office) yields high precision for the 95% confidence intervals around the estimated mean defect values for each post office. The R-squared value (48.18%) indicates that nearly half of the variation in defect scores is explained by the post offices of origin.

The individual value plots show tightly clustered defect scores for most post offices and a few scores reflecting cards with high levels of damage. Normality of the residuals is not essential to the validity of this finding, but the Anderson-Darling test was administered and a histogram of the residuals was plotted. They

are shown in **Appendix F**. The results indicate that the distribution of residuals is not a normal distribution. Examination of the histogram sheds light on the non-normality of the data. The distribution has a lower limit of zero and no upper limit. There are enough cards in the study with unusually high levels of damage to preclude normal distribution. This observation implies that all the defects found on the cards were not the result of normal variability in the process; instead, the damage on some cards indicates a machine malfunction or some other unusual event.

Since the post offices were found to be a significant factor in defect scores, the Tukey multiple comparison test was run to determine which post offices were significantly different from others with respect to the defect levels found with each post office. The results of this analysis are found in **Figure 12**.

P.O.	N	Mean	Grouping
WI	200	21.153	A
TN	200	17.788	B
AZ	200	16.462	B
FL	200	13.171	C
NY	200	12.634	C
CA	200	11.323	C D
OR	200	10.366	D E
MN	200	9.157	E F
TX	200	7.603	F
IL	200	5.566	G
PA	200	0.143	H

Means that do not share a letter are significantly different.

**Figure 12.** Tukey test of significance: defect scores vs. post offices (all samples).

Figure 12 shows the lowest defect scores at the bottom of the list and the highest defect scores at the top. The results are interpreted as follows:

- PA post office had significantly lower defect scores than any other post office.
- IL post office had higher defects than PA, but lower than the rest of the post offices.
- TX was third with defect scores that are significantly lower than all the remaining post offices except for MN.
- MN was not significantly different than TX or OR, but was lower than the remaining post offices.
- OR was not different than MN or CA, but was lower than the remaining 5 post offices.
- CA was not different than OR, NY, or FL but lower than AZ, TN, WI.

- NY and FL were not different from each other or CA, but were lower than AZ, TN, and WI.
- AZ and TN were not different from each other, but were lower than WI.
- WI had significantly higher levels of defects than any other post office.

Thus far, the significance of post offices of the total defect scores has been examined for the combined front and back defect scores of all the cards—both coated and uncoated. Because the addition of coating had significant effects on the defect scores on both the fronts and backs of the cards, the analysis was repeated for four subpopulations:

- Coated fronts
- Uncoated fronts
- Backs of coated cards
- Backs of uncoated cards

The ANOVA tables, estimated means with 95% confidence intervals and individual value plots for these four conditions are shown in **Appendix G**.

The results of all four ANOVAs were to reject the null hypotheses with p-values of 0.000, indicating that in each of the subpopulations the post offices of origin were significant with respect to defect scores. The R-squared values were as follows: coated front 47.83%, uncoated front 78.49%, back of coated 71.66%, and back of uncoated 62.80%. Thus, the post offices of origin accounted for between 48% and 78% of the variability in defect scores in all instances.

Coated front			Uncoated front			Back of coated			Back of uncoated		
PO	Mean	Group	PO	Mean	Group	PO	Mean	Group	PO	Mean	Group
WI	18.12	A	AZ	29.67	A	WI	30.00	A	WI	16.86	A
TN	17.20	AB	TN	25.72	B	TN	13.24	B	AZ	16.24	AB
CA	14.47	B	WI	19.63	C	NY	11.66	BC	TN	15.00	ABC
MN	10.81	C	FL	17.52	CD	FL	10.26	BCD	FL	14.14	BCD
FL	10.76	C	NY	16.13	D	AZ	9.20	CDE	NY	12.82	CD
AZ	10.74	C	OR	12.47	E	CA	7.44	DE	OR	12.40	D
TX	10.59	C	CA	11.62	EF	OR	6.60	E	CA	11.76	D
OR	10.00	C	MN	10.32	EF	MN	6.58	E	MN	8.92	E
IL	9.45	C	TX	9.42	F	TX	3.18	F	TX	7.22	E
NY	9.92	C	IL	5.68	G	IL	2.32	FG	IL	4.32	F
PA	0.12	D	PA	0.15	H	PA	0.06	G	PA	0.24	G

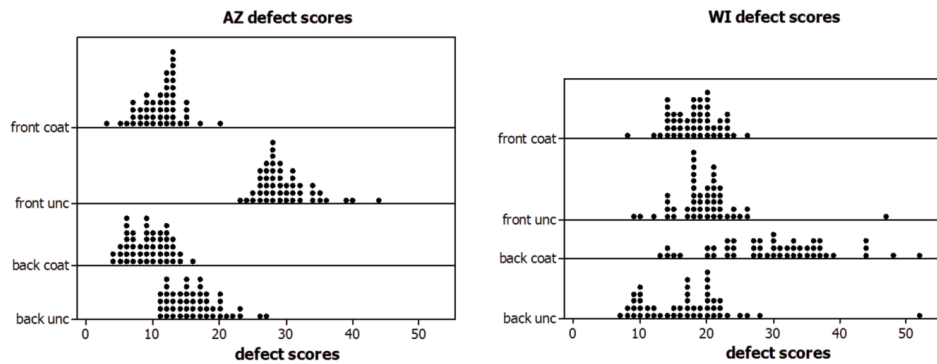
**Table 3.** Tukey tests of significance: defect scores vs. post offices (four conditions). Means that do not share a letter are significantly different (95% confidence).

Each of the four conditions was subjected to Tukey paired-comparison analyses to determine the order of the means and which ones were significantly different from the others in each of the subpopulations. The ranks, means, and grouping varied for the four conditions. The results of the Tukey analyses were combined into a single table (**Table 3**) to facilitate comparisons of the results.

Several observations can be drawn from examination of Table 3 in comparison to Figure 12, the Tukey results for the combined defect scores:

- The rank orders of the post offices in terms of defect scores were similar, but not identical for any two of the conditions.
- The coated fronts of the cards had much greater consistency in defect scores than any of the other conditions, including the overall ranking, as evidenced by the smaller number of significantly different groups for coated fronts (4 as opposed to 7 or 8).
- The ranges of defect scores between the best-performing post offices and the worst are striking.
- The WI post office did not perform well overall, but the defects on the backs of the coated cards are more than twice as high as the second worst post office (30.00 vs. 13.24).

To better assess the differences in defects that each post office experienced on the fronts and backs of coated and uncoated cards, individual value plots were generated for each post office and each of the four conditions: coated front, uncoated front, back of coated, and back of uncoated. The results for all 11 post offices are shown in **Appendix H**. **Figure 13** shows the value plots for the WI and AZ post offices, which scored at or near the bottom of the group in every category.



*Figure 13. Individual defect score value plots for AZ and WI post offices under four conditions.*

Both of the diagrams in Figure 13 show serious problems with card damage occurring to the cards that originated at these two post offices. The AZ defect scores clearly show that the uncoated card fronts were consistently damaged more than the coated card fronts. Examining the distributions from the other post offices shown in **Appendix H** makes it clear that the AZ damage levels to uncoated cards were atypical.

One-way ANOVAs and Tukey analyses were run for each post office to test the differences in defect levels between the four categories of coated fronts, uncoated fronts, backs of coated, and backs of uncoated. The results are shown in **Appendix I**.

Only the PA post office showed no significant differences between any of the categories. This was because the defect levels were so low from the PA post office that even the defect levels from the fronts and the backs of the cards were similar. The findings from the other post offices were varied. For 9 of 10 post offices (excluding PA where no significant differences were found) the backs of the coated cards had the lowest defect levels of any of the four categories. The highest defect levels were on the uncoated fronts for 5 post offices and on the coated fronts for 4 post offices.

Only the cards from the WI post office had the highest defect levels on the backs of the coated cards. These defect levels were significantly higher than the other three conditions (coated fronts, uncoated fronts, and backs of uncoated), which showed no significant differences among them. Furthermore, Table 2 showed that the standard deviation for the backs of the coated cards from WI was 8.8, which was higher than the standard deviations of the other three conditions. This can be seen in Figure 13 by the widely spread data points for the WI coated back cards.

The ANOVA and Tukey analysis for AZ (Appendix I) showed the defect scores for the uncoated fronts to be significantly higher than any of the other three categories. This relationship is apparent from the data plots shown in Figure 13. The defect scores of the backs of the uncoated cards are significantly higher than those of the backs or fronts of coated cards. No significant difference was found between the later two categories.

**Question 4** was whether some defect categories were more significant than others in accounting for the total defect scores. Because the defect categories were different on the two sides of the cards, this question was addressed separately for each side.

The relationship of the front defect categories to the defect scores were examined for the all of the cards first, then separately for the coated cards and the uncoated cards. The same analysis was then repeated for the backs of the cards. Each of these was addressed with a one-factor ANOVA followed by Tukey analysis. The ANOVAs, Tukey analyses, and individual value plots are shown in **Appendix J** for the card fronts and **Appendix K** for their backs.

Not surprisingly, the null hypotheses were rejected in all cases with greater than 99% confidence. The defect categories clearly were significant with respect to the defect scores. The large sample sizes—550 for coated, 550 for uncoated, and 1,100 for all cards—for each defect category led to relatively tight 95% confidence intervals around the estimates of means, as seen in Appendices J and K. This caused the Tukey analyses to yield nuanced pictures of significant differences between the defect categories. **Table 4** shows a summary of the Tukey results for the category effects on the fronts of the cards.

rank	all samples			coated fronts			uncoated fronts		
	category	sign	mean	category	sign	mean	category	sign	mean
1	rt edge	A	3.11	lt text	A	2.31	rt edge	A	5.11
2	lt text	B	1.85	bottom	B	1.81	other	B	2.16
3	lt edge	B	1.80	lt edge	B	1.48	lt edge	B	2.13
4	other	B	1.64	other	C	1.12	lt text	C	1.39
5	bottom	C	1.02	rt edge	C	1.11	lt logo	CD	1.15
6	lt logo	CD	0.99	rip/tear	C	1.05	mark	DE	0.82
7	rip/tear	DE	0.73	lt logo	CD	0.84	red bar	EF	0.73
8	mark	DE	0.73	mark	DE	0.64	rip/tear	FG	0.40
9	red bar	E	0.59	red bar	E	0.46	bottom	G	0.23
10	rt logo	F	0.26	rt logo	EF	0.34	rt logo	G	0.19
11	rt text	F	0.05	rt text	F	0.00	rt text	G	0.10

**Table 4.** Tukey tests of significance: defect scores vs. defect categories for card fronts. Means that do not share a letter are significantly different (95% confidence).

Several observations about the damage to card fronts can be made from Table 4:

- The defect categories associated with the most damage were different for the coated and the uncoated cards.
- The mean defect scores for five of the categories were higher for the uncoated cards not sure I'm interpreting this correctly, than for the coated ones, but not uniformly. For example, the right edge damage to uncoated cards was nearly five times higher than it was with coated cards.
- Conversely, the bottom scratches and left text damage to coated cards were more severe than they were for uncoated cards.

In this analysis, the defect scores for all samples (the second column) represent the averages of the scores for the coated and uncoated samples. A company sending a mix of coated and uncoated advertising pieces through the mail from a variety of post offices of origin expects defect rates per card to be the mean values shown under *all samples*.

The Tukey results for the backs of the cards are shown in **Table 5**. This study has consistently found significant differences in defect levels between the backs of uncoated and the backs of coated cards, even though none of the backs themselves were coated. This analysis extends this finding to the types of damage as well as the overall defect scores.

rank	all samples			backs of coated			backs of uncoated		
	category	sign	mean	category	sign	mean	category	sign	mean
1	other	A	2.69	rip/tear	A	3.52	other	A	3.13
2	rip/tear	B	2.04	other	B	2.26	rt edge	B	2.66
3	rt edge	B	1.95	rt edge	C	1.23	hor sc	B	2.36
4	hor sc	C	1.57	lt edge	C	1.13	lt edge	C	1.93
5	lt edge	C	1.53	hor sc	C	0.79	rip/tear	D	0.55
6	red trans	D	0.23	red trans	D	0.20	red trans	D	0.27

**Table 5.** Tukey tests of significance: defect scores vs. defect categories for card backs. Means that do not share a letter are significantly different (95% confidence).

As with the card fronts, the card backs showed differences in the ranking of the damage categories for backs of the coated and the uncoated cards. Rips and tears were the largest contributors to defect scores for the backs of the coated cards, but they were only small contributors to the defect scores on the backs of the uncoated cards. The difference in magnitude is striking: The average coated card had a rip/tear defect value of 3.52, compared to a value of 0.55 for the average uncoated card. Conversely, the backs of the uncoated cards were much more likely to suffer from horizontal scratches than were the backs of the coated cards.

Again, marketers using the postal system to send both coated and uncoated cards from multiple points of origin can consider the results for all samples as good predictors of the types and levels of damage to expect on the backs of the cards.

### Grouping Defect Categories

In order to combine the category findings for the card backs and fronts and to provide a more simplified picture of the types of damage sustained by the cards in this study, the various defect categories from both the fronts and the backs of the cards were placed into five simplified groups. These were scratch, scuff, rip/tear, edge, and other. The more specific categories used throughout this study were placed into these five simplified categories as follows:

Eleven categories of defects for the front sides of the cards

- Scuffs on the red bar (scuff)
- Damage to the left PIA logo (scuff)
- Damage at the left edge of the card (edge)
- Damage to the text on the left side of the card (scuff)
- Scratches along the bottom portion of the card (scratch)
- Rips or surface tears that remove fibers from the card (rips/tears)
- Damage to the right edge of the card (edge)
- Damage to the right PIA logo (scuff)
- Damage to the text on the right side of the card (scuff)
- A machine mark denting the left edge of the card (edge)
- Other damage (other)

Six categories of defects for the back sides of the cards.

- Horizontal mark across the card (scratch)
- Damage to the left edge of the card (edge)
- Red ink transfer (scuff)
- Damage to the right edge (edge)
- Rips or surface tears that remove fibers from the card (rips/tears)
- Other damage (other)

An ANOVA with Tukey analysis was run on the simplified categories for all cards (fronts, backs, coated, and uncoated). The weighting factors from the study stayed with the sources of damage in the simplified categories. Therefore, the scratch category, for example, contained some defect scores that had been weighted at 2 and other defect scores that had been weighted at 1.5. This was done because the weighted scores more accurately described the perceived damage to a card than did the unweighted defect scores.

The results of this analysis are shown in **Appendix L**. The categories were found to be significant with respect to defect scores. The Tukey analysis divided the five simplified categories into four significantly different groups. The summary of this analysis is shown in **Table 6**.

all cards			
rank	category	sign	mean
1	edge	A	2.16
2	other	B	1.82
3	rip/tear	C	1.38
4	scratch	C	1.30
5	scuff	D	0.66

**Table 6.** Tukey tests of significance: defect scores vs. simplified defect categories for all cards. Means that do not share a letter are significantly different (95% confidence).

As Table 6 indicates, the greatest amount of damage overall was to the card edges; they accounted for defect scores of 2.16 for each card in the study. The second most significant group was the miscellaneous (other) category that consisted of defects that did not fit into the other groups. Defects in this category were significantly less than the edge defects, but they were significantly higher than the other three categories. The rip/tear and scratch categories were not significantly different from each other. The rips/tears group had a high defect value because it had a weighting value of 3. There were actually more scratches on the cards than tears, but each tear represented a more serious defect than each scratch. Scuffing had the lowest average defect score— significantly less than any of the other four simplified categories.

### Summary

Cards shipped through the USPS incur a certain amount of damage. Shipping distance appears to matter, because the cards in this study that were shipped locally suffered significantly less damage than cards shipped over greater distances. However, it was not simply the case that the further shipping distances equated to more card damage. The post offices of origin differed significantly from one another in terms of the amount of damage that was done to the cards, and the post offices that had the highest defect rates were not the most distant post offices.

It is not fair to conclude that the post office of origin is responsible for all of the damage done to the cards that originated there. It is assumed that there are intermediate sorting facilities where the cards were subjected to further damage by passing through additional bar code sorting machines.

The specific routes that cards take from one destination to another, and the number of machine-reading operations they are subjected to, are unknown to the authors of this study and to postal customers at large. It is assumed that if the sets of cards

were mailed from the same points of origin, but to a different destination, the ranking of the post offices in terms of defect scores would be different. It is also assumed that the overall defect levels would be similar.

Only a small percentage of the cards were not delivered—0.2% in this study and 0.5% in the 2008 study – so the postal service has high reliability for delivering the mail. However, there is routinely some damage done to the pieces that are delivered. In this study the average card had defect scores of 12.77 for the front and 10.02 for the back. These defects typically do not impair the functionality of the cards in that the type is legible and the communication intent is clear, but they can diminish the value of the cards as marketing/branding pieces.

Marketers using direct mail as a conduit to drive sales face a dilemma. They can protect their pieces by putting them in envelopes or bundling them with other products. However, they incur additional costs to do this, and, at the same time, reduce the visibility of their marketing efforts.

This study shows that applying UV coating to the pieces will reduce the overall damage done to the cards (11.15 for coated vs. 14.39 for uncoated). Furthermore, it reduces the variability of defects for a group of cards. In the case of this study, 550 coated cards had defect scores with a standard deviation of 6.51, while the same number of uncoated cards had a standard deviation of 9.22.

Surprisingly, UV-coating the fronts of the cards significantly reduces the defect scores on the backs as well, even though the backs were not UV-coated. The reduction was modest, with average defect scores for the backs of the coated cards of 9.14 vs. 10.90 for the uncoated ones. With the large sample size in this study, this difference was found to be significant at over 99% confidence. Inexplicably, the standard deviation for the defect scores on the backs of the coated cards (9.02) was higher than for the uncoated cards (6.29). Looking at the individual value plots for the backs of the cards showed several coated cards with very high defect scores while the uncoated group had only a few outliers with very high scores.

The graphic design of the cards used in this study was created to show damage. The design was based on large blocks of uniform colors that bled off the edges and had heavy color coverage over their entire surface. The cards were highly susceptible to edge damage, scratches, and scuffs.

Some advantage can be gained by designing advertising pieces that are more tolerant of defects. This study found that the most prevalent type of damage done to cards was damage to the card edges. Scratches and scuffs were also notable sources of damage. Designs that do not bleed off the card edges will make damage to the edges less noticeable. Complex color pictures will mask scratches and scuffs much more effectively than uniform color blocks.

However, the purpose of advertising pieces does not lend itself to artificially imposed design constraints. Advertisers work to generate the most compelling designs possible to showcase their products. Ultimately, it falls on the USPS to deliver the materials they are given with a minimum of damage. This study indicates that the USPS is not uniform in the amount of damage done to pieces in the mail stream. Ideally, the USPS should be able to reduce the overall level of damage caused to the materials they handle, but surely they could reduce the variability of that damage.

The resurgence of the use of direct mail might falter if advertisers lose confidence in the USPS to deliver their advertising pieces in undamaged condition.

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Marin, Joseph, *Digital Printing and Survivability in the U.S. Postal System*, Printing Industries of America white paper, 2008, 42 pp.

### **Acknowledgment**

The authors wish to acknowledge Joseph Marin of Printing Industries of America for his help in designing the cards and coordinating with the PIA affiliates to accomplish mailing of the cards.

## Appendix A

Copy of the letter of instruction provided to the participating PIA affiliates who mailed the printed samples back to PIA Headquarters.



August 5, 2011

Re: *2<sup>nd</sup> Mailing*, Printing Industries of America Mailing Research Study

Hi Rick,

Enclosed are the pre-packaged postcards and check to cover costs (based on the last study) as discussed via our email request for the *second round* of the Mailing Research Study. They already contain the appropriate Standard Mail indicia and are ready to be mailed. Here is the short list of what I need you to do:

1. If you normally use a mailing service provider to handle your mailings, ask the provider to handle this mailing, as well. We will reimburse your costs for mail preparation, handling, and postage.
2. Prepare the mailing and take it to the local Business Mail Entry Unit at the post office that issued the permit for the indicia.
3. Mail the 200 pieces at the **mixed AADC presort rate for Standard Mail** (27.3¢ per piece). Mailing at the mixed AADC rate is intentional, since we want the pieces to go through as much processing as possible. We understand that the pieces could qualify for a lower rate, however please make sure to enter them at the mixed AADC rate.
4. Please send a note to [jmarin@printing.org](mailto:jmarin@printing.org) on the day that the postcards are placed in the mail.
5. Please contact us before deviating from these instructions.

Once the postcards are received, we will evaluate them and complete the report. Thanks so much for the help, your continued support is greatly appreciated!

Sincerely,

A handwritten signature in black ink that reads 'Mark Bohan'.

Mark Bohan  
Vice President, Technology and Research  
[mbohan@printing.org](mailto:mbohan@printing.org)

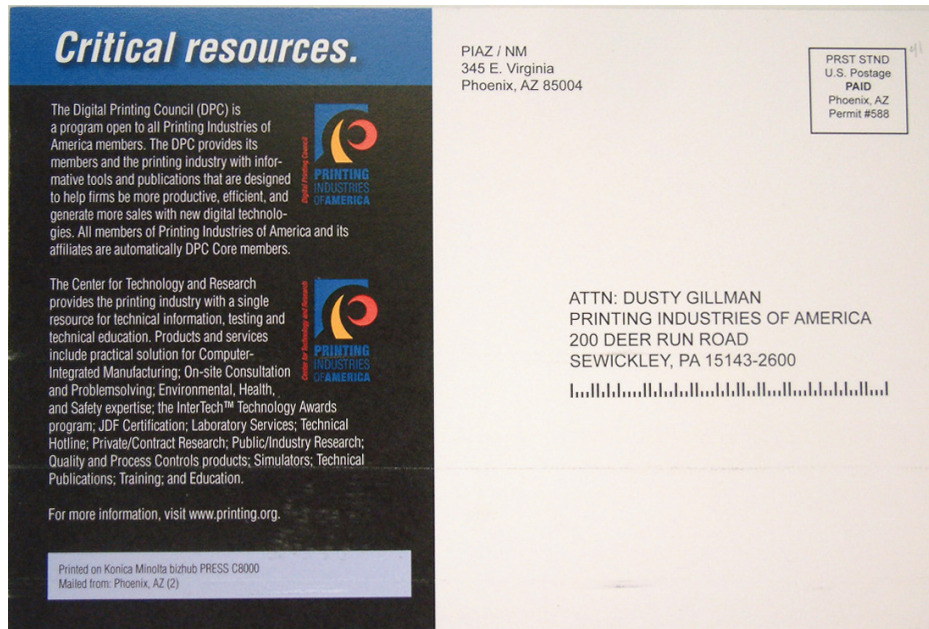
A handwritten signature in black ink that reads 'Joe Marin'.

Joe Marin  
Senior Analyst, Digital Technologies  
[jmarin@printing.org](mailto:jmarin@printing.org)

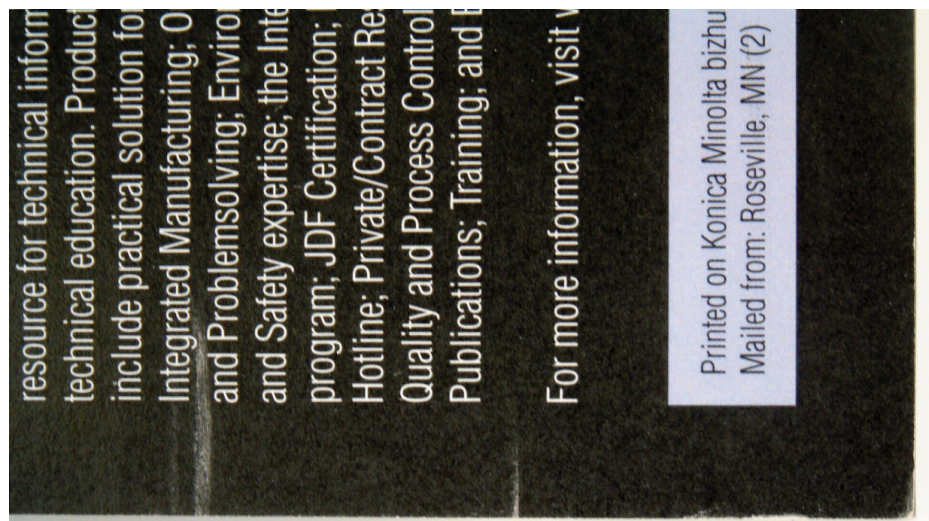
200 Deer Run Road | Sewickley, PA 15143-2600 | phone: 412.741.6860 | fax: 412.741.2311 | [www.printing.org](http://www.printing.org)

## Appendix B

Samples of postal damage found on the cards in this study.



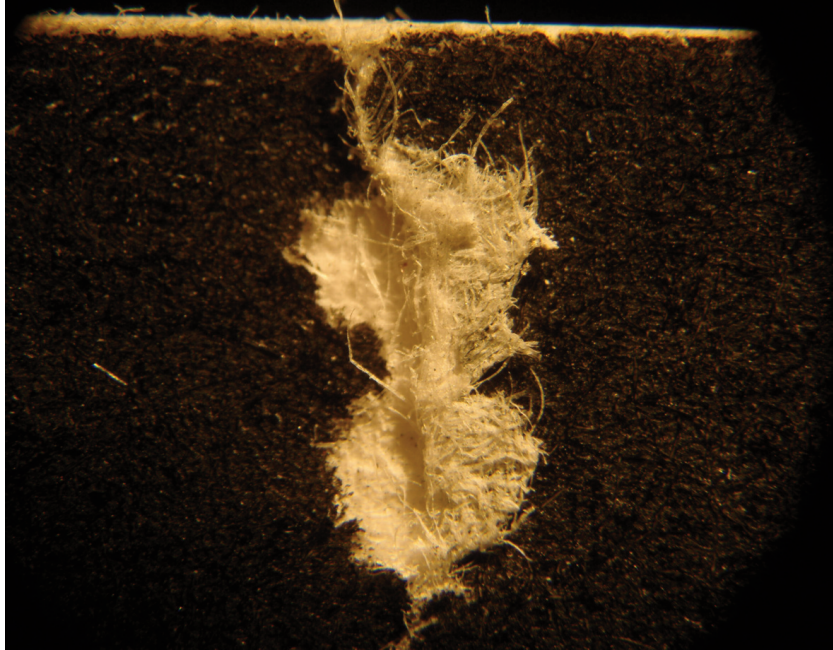
Scuff, black transfer, and scratches on back of card.



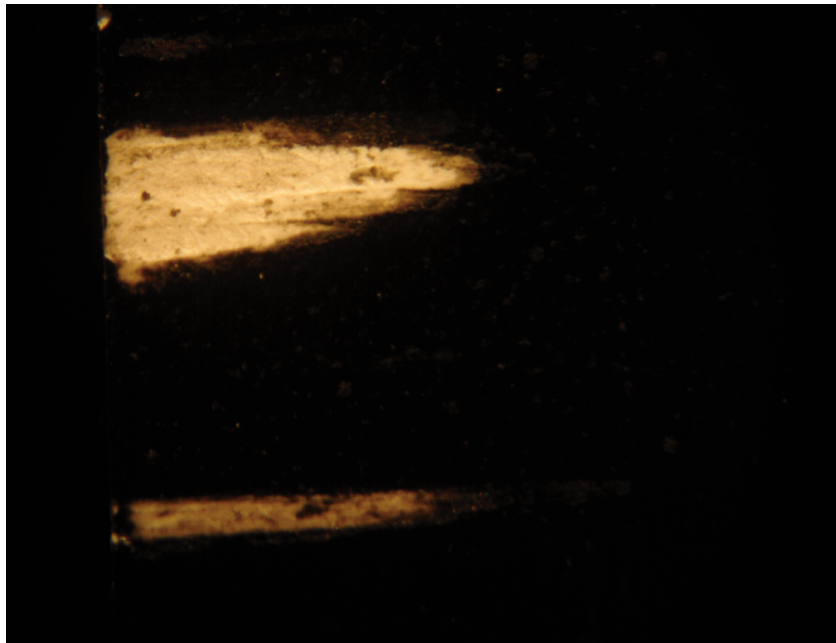
Edge marks and scratches in black section on back of card.

## Appendix B (continued)

Samples of postal damage found on the cards in this study.



Tear on edge of card including removal of fibers from paper.



Edge scratches including removal of fibers from paper.



## Appendix D

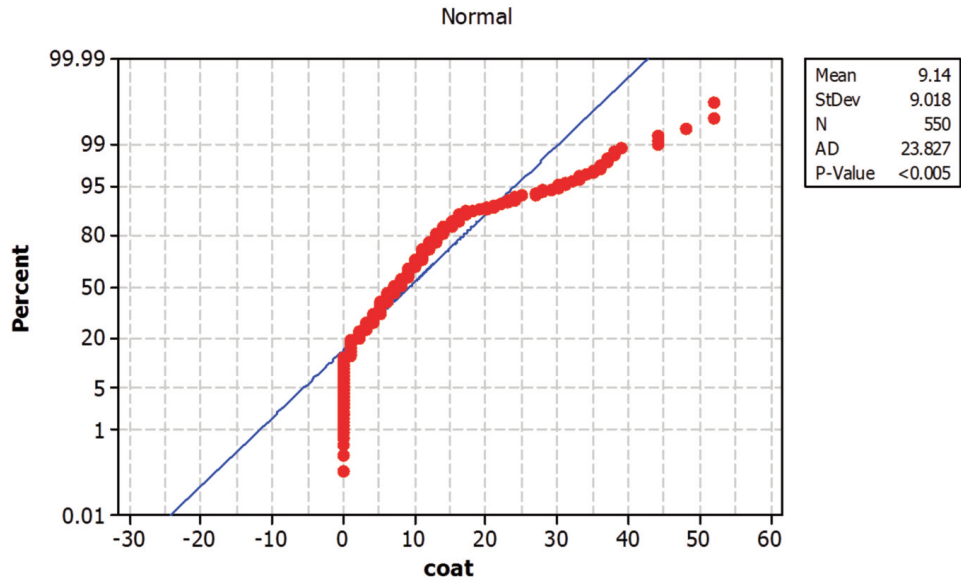
Numbers of samples out of 50 total samples from each Post Office with various defects.

Coated front										
P.O.	red bar	lt. logo	lt. edge	lt. text	bottom	tear	rt. edge	rt. logo	rt. text	other
AZ	0	1	0	50	40	14	17	0	0	40
CA	0	4	47	47	45	4	46	0	0	50
FL	2	44	46	50	12	1	31	0	0	15
IL	0	0	1	0	0	3	29	50	0	48
MN	0	0	50	46	49	0	0	0	0	6
NY	0	10	50	50	24	0	20	0	0	17
OR	0	36	50	22	45	1	44	0	0	21
PA	0	0	0	0	0	1	0	0	0	3
TN	41	49	50	49	28	2	0	0	0	20
TX	14	37	49	1	14	11	25	0	0	27
WI	0	3	50	48	49	46	50	0	0	39
Uncoated front										
P.O.	red bar	lt. logo	lt. edge	lt. text	bottom	tear	rt. edge	rt. logo	rt. text	other
AZ	0	50	50	50	9	0	50	0	0	50
CA	0	0	50	42	19	0	50	0	0	41
FL	0	49	50	50	9	0	50	0	0	25
IL	0	0	33	0	0	0	5	44	43	48
MN	0	5	50	14	0	0	49	1	1	33
NY	0	2	50	49	7	0	50	0	0	16
OR	0	3	50	48	8	1	48	0	0	28
PA	0	1	3	1	0	0	0	0	0	3
TN	45	31	50	34	8	1	50	0	0	34
TX	0	37	50	0	13	0	50	0	0	45
WI	1	0	50	32	1	35	49	0	0	46
Coated back										
P.O.	across	lt. edge	red mark	rt. edge	rip/tear	other				
AZ	0	38	2	39	26	50				
CA	0	29	4	50	11	49				
FL	34	34	0	47	10	48				
IL	0	41	0	4	4	24				
MN	0	18	0	34	26	43				
NY	8	26	0	48	33	49				
OR	1	30	0	50	22	45				
PA	0	1	0	0	0	2				
TN	49	25	43	48	16	27				
TX	0	25	0	11	7	24				
WI	26	41	0	26	50	50				
Uncoated back										
P.O.	across	lt. edge	red mark	rt. edge	rip/tear	other				
AZ	49	28	4	50	0	45				
CA	15	45	2	50	0	48				
FL	32	44	0	50	1	48				
IL	0	31	0	14	0	48				
MN	22	39	1	45	2	44				
NY	40	42	2	50	1	47				
OR	10	47	1	50	1	49				
PA	0	2	0	0	0	7				
TN	50	47	41	43	0	43				
TX	38	25	0	40	0	39				
WI	48	36	0	50	35	44				

## Appendix E

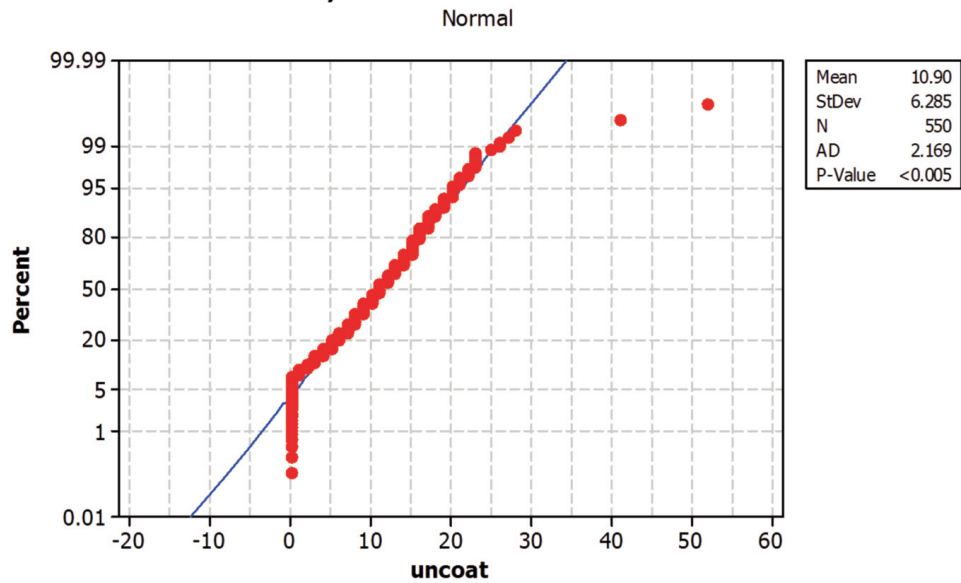
Research Question 2: Anderson-Darling normality test of samples.

### Probability Plot of Coated Backs



P-value less than 0.005 indicates data is not normally distributed.

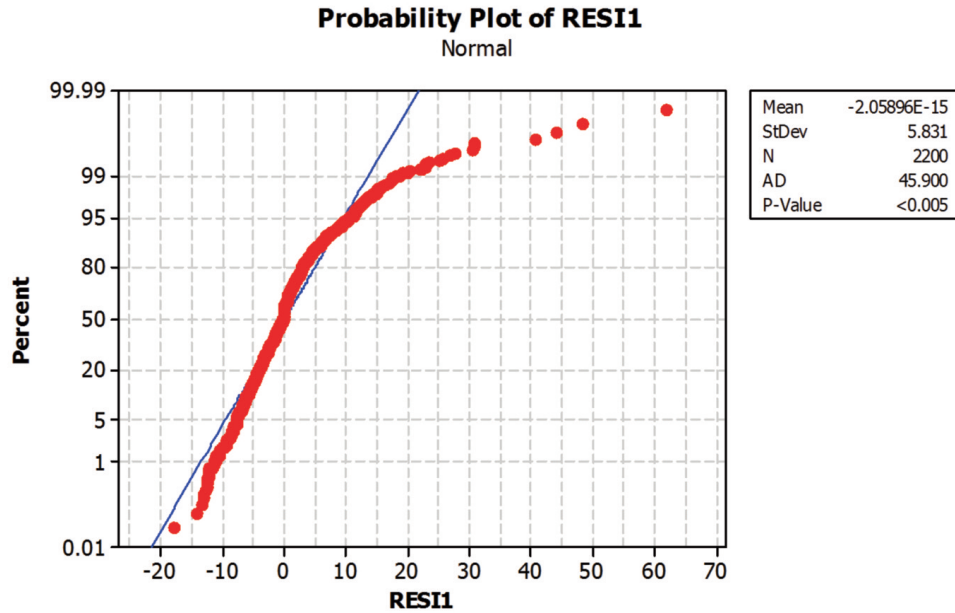
### Probability Plot of Uncoated Backs



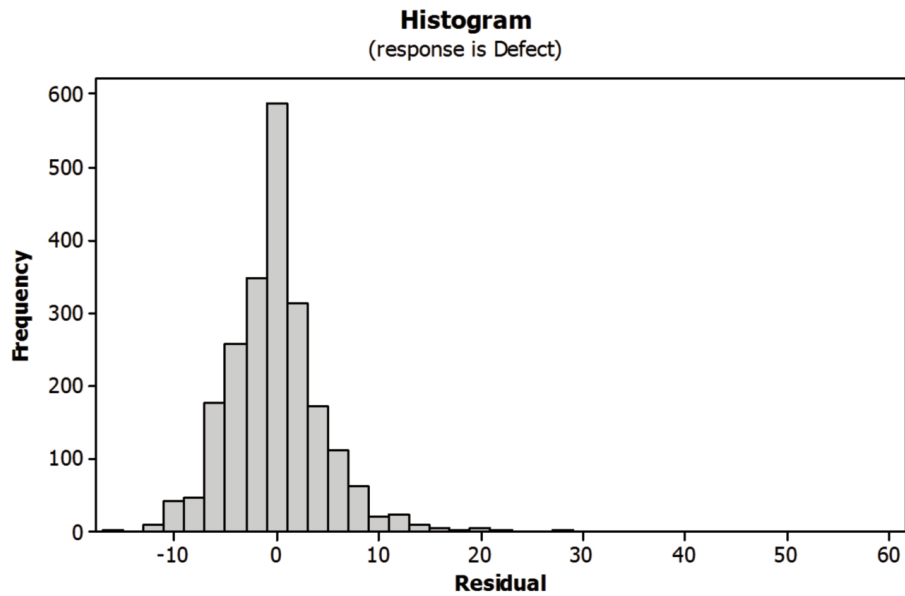
P-value less than 0.005 indicates data is not normally distributed.

## Appendix F

Research Question 3: Anderson-Darling normality test and histogram of residuals for ANOVA of defect scores vs. post offices (all samples, both sides).



P-value less than 0.005 indicates data is not normally distributed.



## Appendix G

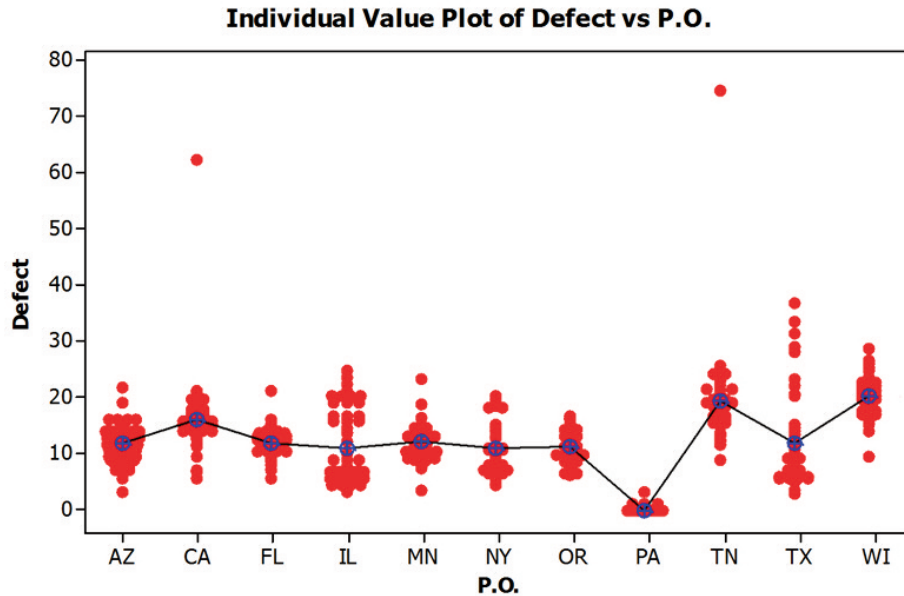
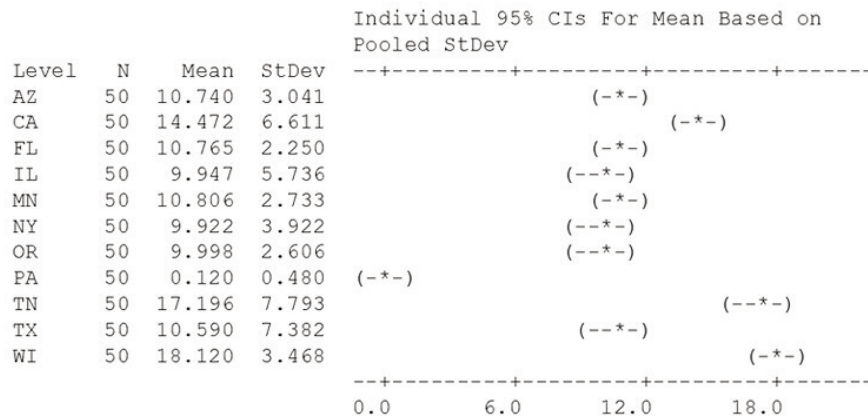
Analysis of Research Question 3: coated fronts of the cards.

### ANOVA Defect Scores vs. Post Offices

Coated Samples Front of Cards

Source	DF	SS	MS	F	P
P.O.	10	11143.0	1114.3	49.42	0.000
Error	539	12154.1	22.5		
Total	549	23297.1			

S = 4.749    R-Sq = 47.83%    R-Sq(adj) = 46.86%



## Appendix G (continued)

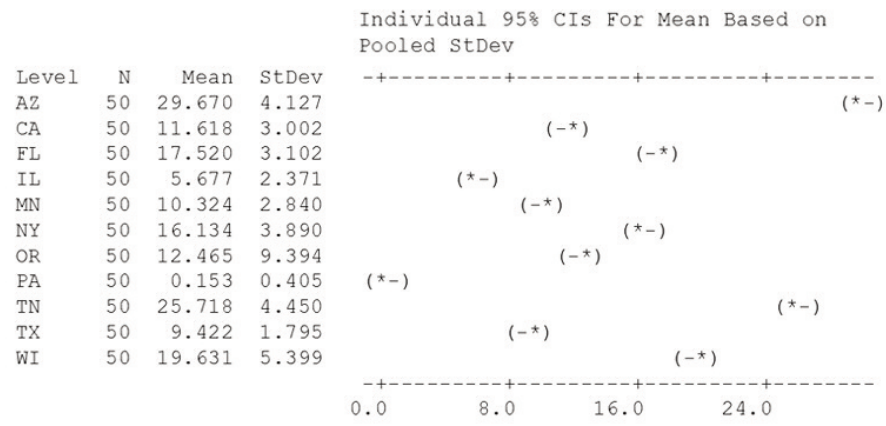
Analysis of Research Question 3: uncoated fronts of the cards.

### ANOVA Defect Scores vs. Post Offices

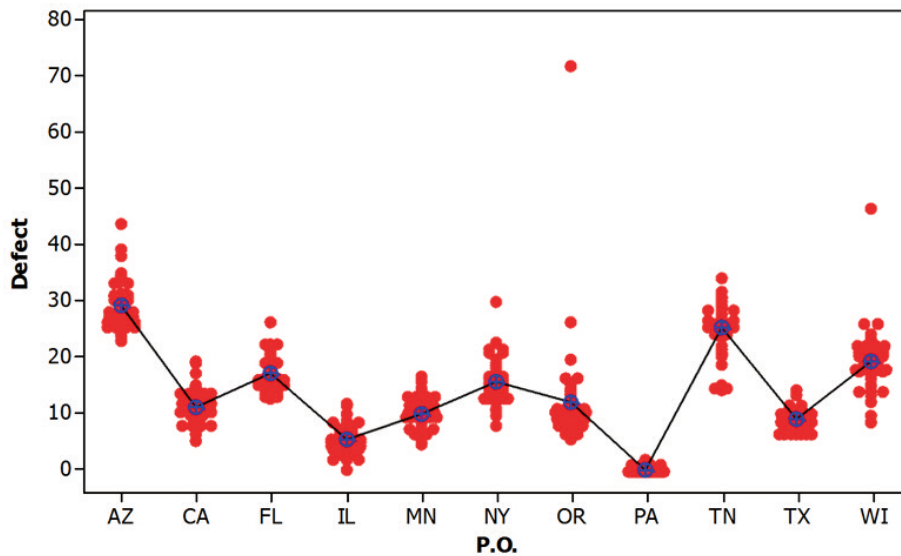
Uncoated Samples Back of Cards

Source	DF	SS	MS	F	P
P.O._1	10	36665.9	3666.6	196.68	0.000
Error	539	10048.3	18.6		
Total	549	46714.2			

S = 4.318    R-Sq = 78.49%    R-Sq(adj) = 78.09%



**Individual Value Plot of Defect vs P.O.**



## Appendix G (continued)

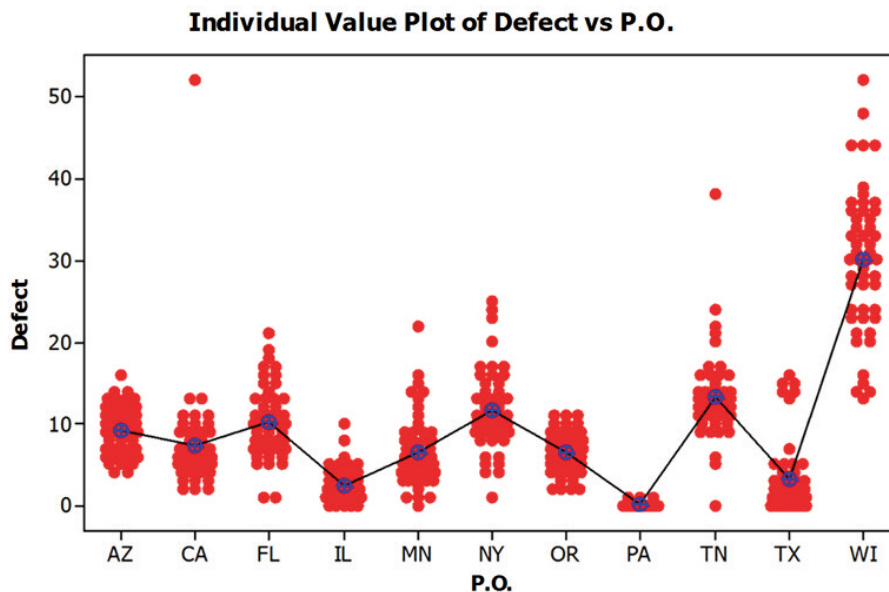
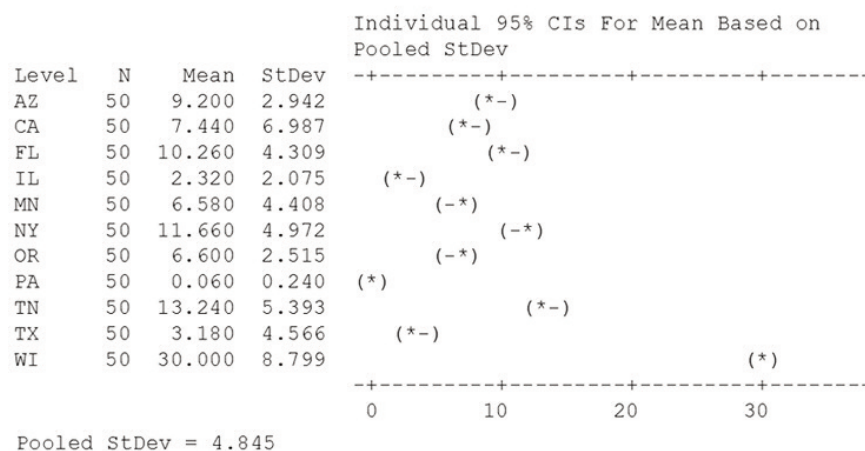
Analysis of Research Question 3: backs of coated cards.

### ANOVA Defect Scores vs. Post Offices

Coated Samples / Back of Cards

Source	DF	SS	MS	F	P
P.O._2	10	31996.7	3199.7	136.30	0.000
Error	539	12653.5	23.5		
Total	549	44650.2			

S = 4.845    R-Sq = 71.66%    R-Sq(adj) = 71.13%



## Appendix G (continued)

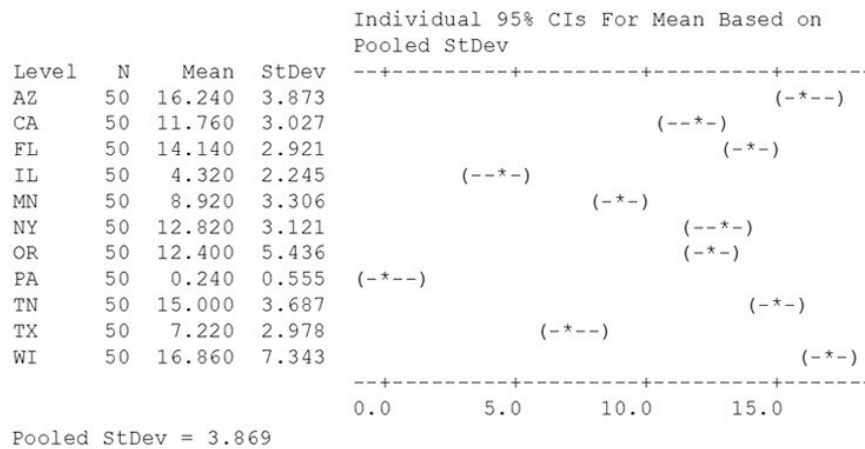
Analysis of Research Question 3: backs of uncoated cards.

### ANOVA Defect Scores vs. Post Offices

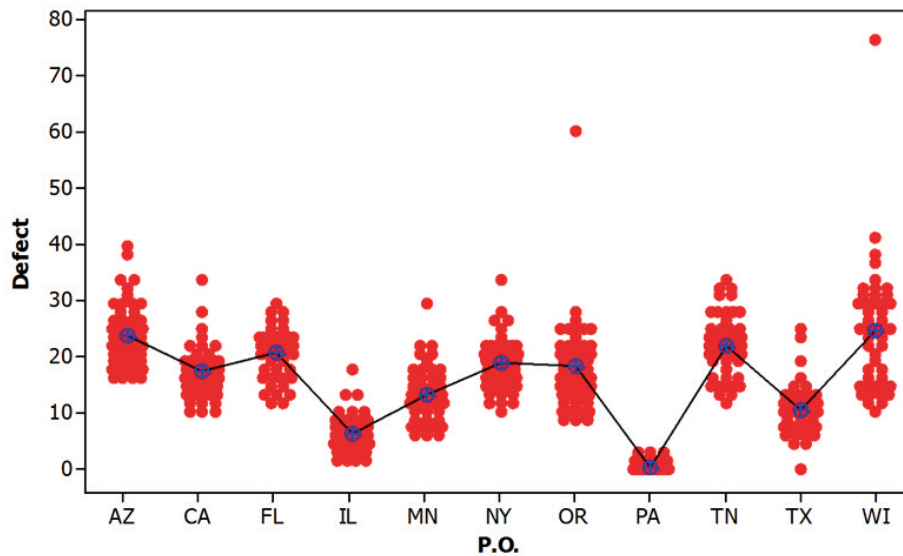
Uncoated Samples Back of Cards

Source	DF	SS	MS	F	P
P.O._3	10	13620.8	1362.1	91.00	0.000
Error	539	8067.9	15.0		
Total	549	21688.7			

S = 3.869    R-Sq = 62.80%    R-Sq(adj) = 62.11%

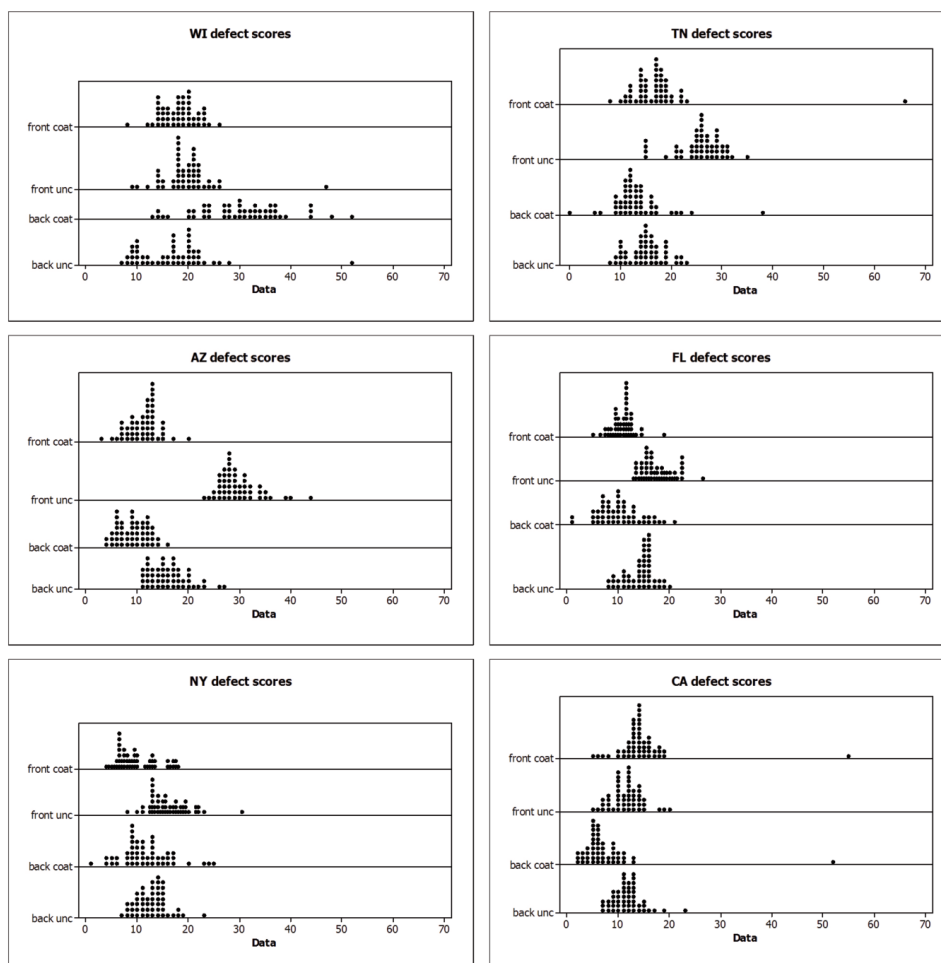


**Individual Value Plot of Defect vs P.O.**



## Appendix H

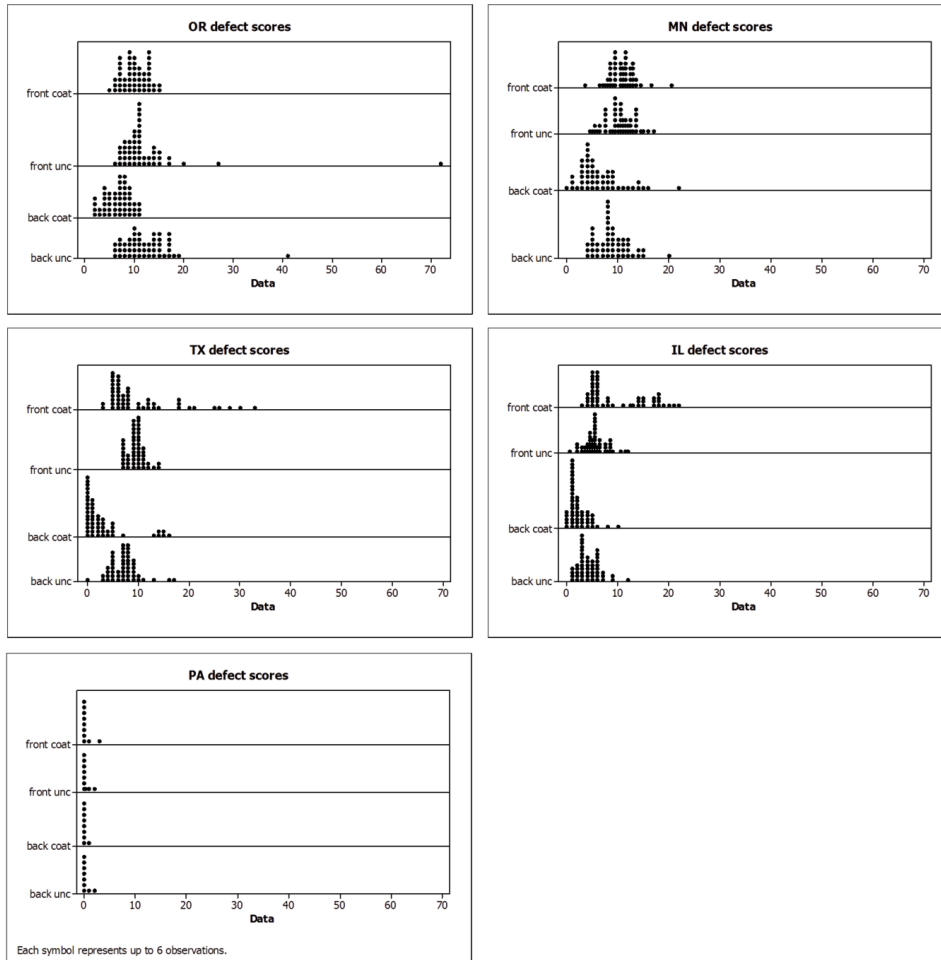
Analysis of Research Question 3: individual post office value plots.



Post offices are listed in the order of most damage to cards to least damage to cards when all conditions (coated fronts, uncoated fronts, back of coated, and back of uncoated) were considered together.

## Appendix H (continued)

Analysis of Research Question 3: individual post office value plots.



Post offices are listed in the order of most damage to cards to least damage to cards when all conditions (coated fronts, uncoated fronts, back of coated, and back of uncoated) were considered together.

## Appendix I

Analysis of Research Question 3: ANOVAs of post offices vs. coating/card sides.

### ANOVA - AZ

Source	DF	SS	MS	F	P
cond	3	12998.7	4332.9	347.07	0.000
Error	196	2446.9	12.5		
Total	199	15445.5			

S = 3.533 R-Sq = 84.16% R-Sq(adj) = 83.92%

Grouping Information Using Tukey Method

cond	N	Mean	Grouping
unc frt	50	29.670	A
unc bck	50	16.240	B
ct frt	50	10.740	C
ct bck	50	9.200	C

### ANOVA - FL

Source	DF	SS	MS	F	P
cond	3	1705.7	568.6	54.43	0.000
Error	196	2047.3	10.4		
Total	199	3753.0			

S = 3.232 R-Sq = 45.45% R-Sq(adj) = 44.61%

Grouping Information Using Tukey Method

cond	N	Mean	Grouping
unc frt	50	17.520	A
unc bck	50	14.140	B
ct frt	50	10.765	C
ct bck	50	10.260	C

### ANOVA - MN

Source	DF	SS	MS	F	P
cond	3	538.9	179.6	15.65	0.000
Error	196	2249.1	11.5		
Total	199	2787.9			

S = 3.387 R-Sq = 19.33% R-Sq(adj) = 18.09%

Grouping Information Using Tukey Method

cond	N	Mean	Grouping
ct frt	50	10.806	A
unc frt	50	10.324	A B
unc bck	50	8.920	B
ct bck	50	6.580	C

### ANOVA - CA

Source	DF	SS	MS	F	P
cond	3	1263.7	421.2	15.22	0.000
Error	196	5424.8	27.7		
Total	199	6688.5			

S = 5.261 R-Sq = 18.89% R-Sq(adj) = 17.65%

Grouping Information Using Tukey Method

cond	N	Mean	Grouping
ct frt	50	14.472	A
unc bck	50	11.760	A B
unc frt	50	11.618	B
ct bck	50	7.440	C

### ANOVA - IL

Source	DF	SS	MS	F	P
cond	3	1564.5	521.5	43.58	0.000
Error	196	2345.4	12.0		
Total	199	3910.0			

S = 3.459 R-Sq = 40.01% R-Sq(adj) = 39.10%

Grouping Information Using Tukey Method

cond	N	Mean	Grouping
ct frt	50	9.947	A
unc frt	50	5.677	B
unc bck	50	4.320	B
ct bck	50	2.320	C

### ANOVA - NY

Source	DF	SS	MS	F	P
cond	3	1029.2	343.1	21.12	0.000
Error	196	3183.9	16.2		
Total	199	4213.1			

S = 4.030 R-Sq = 24.43% R-Sq(adj) = 23.27%

Grouping Information Using Tukey Method

cond	N	Mean	Grouping
unc frt	50	16.134	A
unc bck	50	12.820	B
ct bck	50	11.660	B C
ct frt	50	9.922	C

ANOVAs and Tukey tests of significance for each post office versus the four conditions of coated fronts, uncoated fronts, backs of coated, and backs of uncoated. In the Tukey groupings conditions that do not share a letter are significantly different.

## Appendix I (continued)

Analysis of Research Question 3: ANOVAs of post offices vs. coating/card sides.

### ANOVA - OR

Source	DF	SS	MS	F	P
cond	3	1143.1	381.0	11.64	0.000
Error	196	6414.7	32.7		
Total	199	7557.8			

S = 5.721 R-Sq = 15.12% R-Sq(adj) = 13.83%

Grouping Information Using Tukey Method

cond	N	Mean	Grouping
unc frt	50	12.465	A
unc bck	50	12.400	A
ct frt	50	9.998	A
ct bck	50	6.600	B

### ANOVA - TN

Source	DF	SS	MS	F	P
cond	3	4584.6	1528.2	49.61	0.000
Error	196	6037.1	30.8		
Total	199	10621.8			

S = 5.550 R-Sq = 43.16% R-Sq(adj) = 42.29%

Grouping Information Using Tukey Method

cond	N	Mean	Grouping
unc frt	50	25.718	A
ct frt	50	17.196	B
unc bck	50	15.000	B C
ct bck	50	13.240	C

### ANOVA - WI

Source	DF	SS	MS	F	P
cond	3	5410.8	1803.6	41.82	0.000
Error	196	8453.5	43.1		
Total	199	13864.3			

S = 6.567 R-Sq = 39.03% R-Sq(adj) = 38.09%

Grouping Information Using Tukey Method

cond	N	Mean	Grouping
ct bck	50	30.000	A
unc frt	50	19.631	B
ct frt	50	18.120	B
unc bck	50	16.860	B

### ANOVA - PA

Source	DF	SS	MS	F	P
cond	3	0.846	0.282	1.48	0.220
Error	196	37.247	0.190		
Total	199	38.094			

S = 0.4359 R-Sq = 2.22% R-Sq(adj) = 0.73%

Grouping Information Using Tukey Method

cond	N	Mean	Grouping
unc bck	50	0.2400	A
unc frt	50	0.1530	A
ct frt	50	0.1200	A
ct bck	50	0.0600	A

### ANOVA - TX

Source	DF	SS	MS	F	P
cond	3	1596.9	532.3	24.35	0.000
Error	196	4283.9	21.9		
Total	199	5880.9			

S = 4.675 R-Sq = 27.15% R-Sq(adj) = 26.04%

Grouping Information Using Tukey Method

cond	N	Mean	Grouping
ct frt	50	10.590	A
unc frt	50	9.422	A B
unc bck	50	7.220	B
ct bck	50	3.180	C

ANOVAs and Tukey tests of significance for each post office versus the four conditions of coated fronts, uncoated fronts, backs of coated, and backs of uncoated. In the Tukey groupings conditions that do not share a letter are significantly different.

## Appendix J

Analysis of Research Question 4: ANOVA categories vs. defects—all card fronts.

### One-way ANOVA: defects versus cats – all card fronts

Source	DF	SS	MS	F	P
category	10	8467.58	846.76	193.83	0.000
Error	12089	52812.18	4.37		
Total	12099	61279.76			

S = 2.090    R-Sq = 13.82%    R-Sq(adj) = 13.75%

Pooled StDev = 2.090

Individual 95% CIs For Mean Based on Pooled StDev

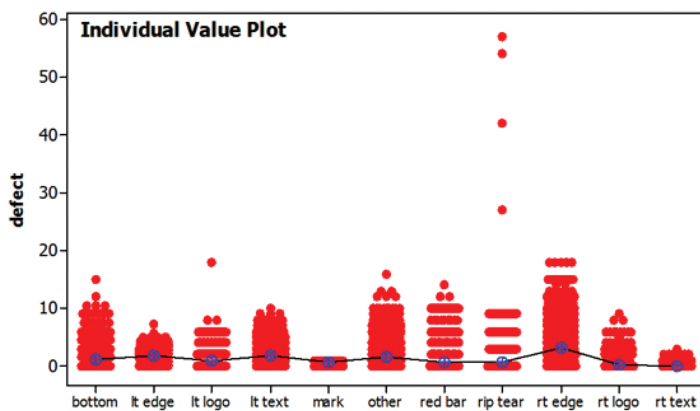
Level	N	Mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev	
bottom	1100	1.020	1.905	(*)	
lt edge	1100	1.803	1.221	(*)	
lt logo	1100	0.991	1.718	(*)	
lt text	1100	1.850	1.969	(-*)	
mark	1100	0.727	0.446	(*-)	
other	1100	1.639	2.249	(*-)	
red bar	1100	0.593	2.063	(*)	
rip tear	1100	0.728	3.323	(*-)	
rt edge	1100	3.108	3.814	(*)	
rt logo	1100	0.264	0.968	(-*)	
rt text	1100	0.048	0.253	(*-)	

Tukey 95% Simultaneous Confidence Intervals

All Pairwise Comparisons among Levels of category

category	N	Mean	Grouping	Individual confidence level = 99.87%
rt edge	1100	3.108	A	
lt text	1100	1.850	B	
lt edge	1100	1.803	B	
other	1100	1.639	B	
bottom	1100	1.020	C	
lt logo	1100	0.991	C D	
rip tear	1100	0.728	D E	
mark	1100	0.727	D E	
red bar	1100	0.593	E	
rt logo	1100	0.264	F	
rt text	1100	0.048	F	

Means that do not share a letter are significantly different.



## Appendix J (continued)

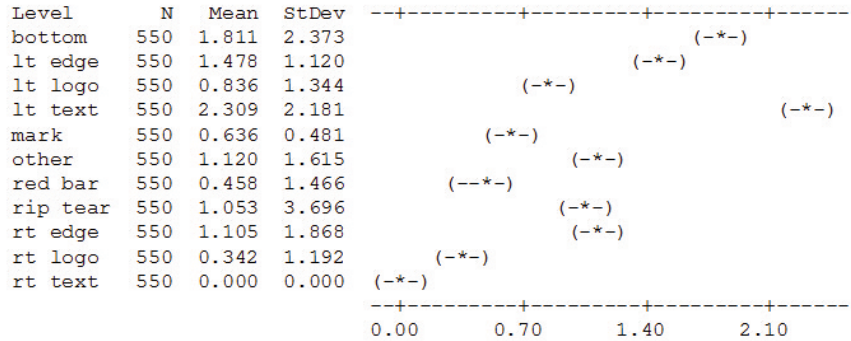
Analysis of Research Question 4: ANOVA categories vs. defects—coated fronts.

### One-way ANOVA: defect versus category – coated fronts

Source	DF	SS	MS	F	P
category	10	2481.41	248.14	73.75	0.000
Error	6039	20319.08	3.36		
Total	6049	22800.49			

S = 1.834    R-Sq = 10.88%    R-Sq(adj) = 10.74%

Pooled StDev = 1.834    Individual 95% CIs For Mean Based on Pooled StDev

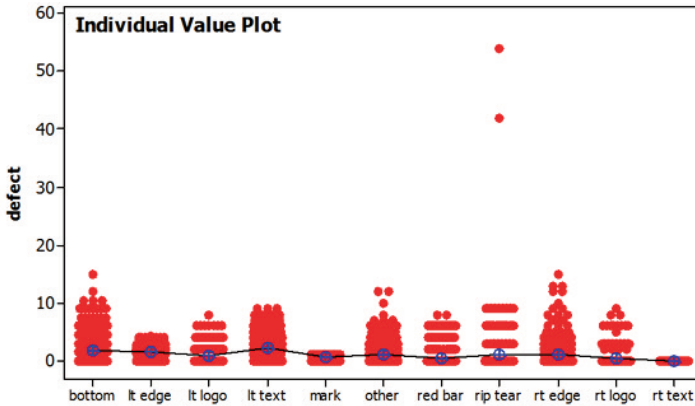


#### Tukey 95% Simultaneous Confidence Intervals

All Pairwise Comparisons among Levels of category

category	N	Mean	Grouping	Individual confidence level = 99.87%
lt text	550	2.309	A	
bottom	550	1.811	B	
lt edge	550	1.478	B	
other	550	1.120	C	
rt edge	550	1.105	C	
rip tear	550	1.053	C	
lt logo	550	0.836	C D	
mark	550	0.636	D E	
red bar	550	0.458	E	
rt logo	550	0.342	E F	
rt text	550	0.000	F	

Means that do not share a letter are significantly different.



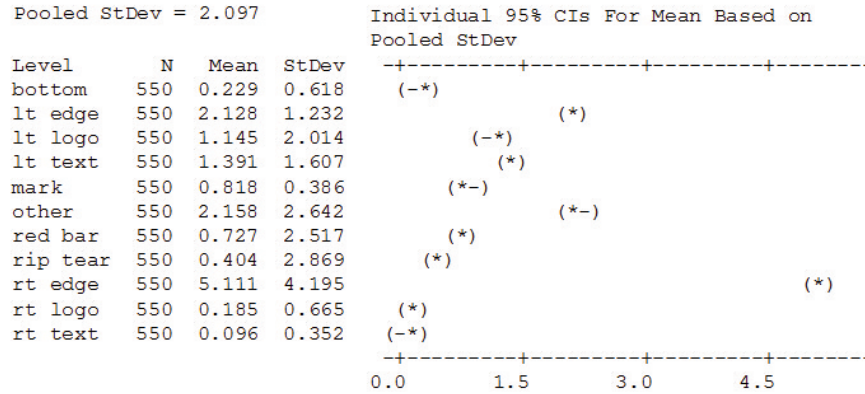
## Appendix J (continued)

Analysis of Research Question 4: ANOVA categories vs. defects—uncoated fronts.

### One-way ANOVA: defect versus category – uncoated fronts

Source	DF	SS	MS	F	P
category	10	11648.01	1164.80	264.76	0.000
Error	6039	26568.01	4.40		
Total	6049	38216.03			

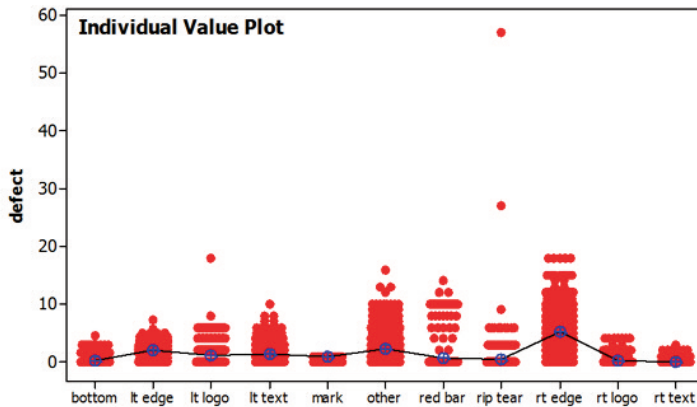
S = 2.097    R-Sq = 30.48%    R-Sq(adj) = 30.36%



Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of category

category	N	Mean	Grouping	Individual confidence level = 99.87%
rt edge	550	5.111	A	
other	550	2.158	B	
lt edge	550	2.128	B	
lt text	550	1.391	C	
lt logo	550	1.145	C D	
mark	550	0.818	D E	
red bar	550	0.727	E F	
rip tear	550	0.404	F G	
bottom	550	0.229	G	
rt logo	550	0.185	G	
rt text	550	0.096	G	

Means that do not share a letter are significantly different.



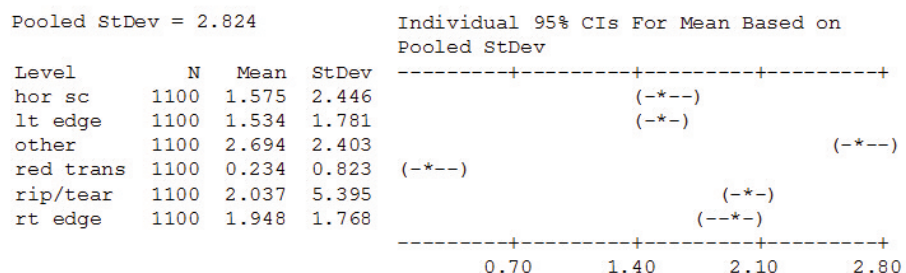
## Appendix K

Analysis of Research Question 4: ANOVA categories vs. defects—all card backs.

### One-way ANOVA: defects versus categories – all card backs

Source	DF	SS	MS	F	P
cat	5	3686.05	737.21	92.47	0.000
Error	6594	52572.87	7.97		
Total	6599	56258.92			

S = 2.824    R-Sq = 6.55%    R-Sq(adj) = 6.48%



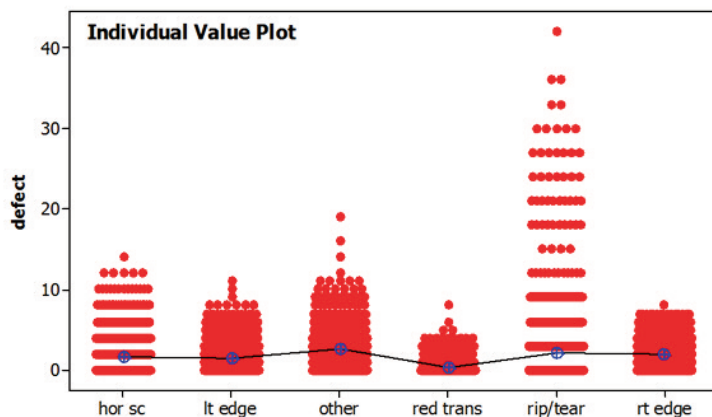
Grouping Information Using Tukey Method

cat	N	Mean	Grouping
other	1100	2.694	A
rip/tear	1100	2.037	B
rt edge	1100	1.948	B
hor sc	1100	1.575	C
lt edge	1100	1.534	C
red trans	1100	0.234	D

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of cat

Individual confidence level = 99.56%



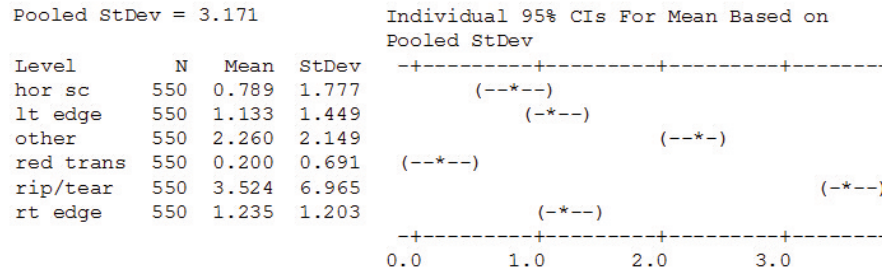
## Appendix K (continued)

Analysis of Research Question 4: ANOVA categories vs. defects—backs of coated.

### One-way ANOVA: defect versus categories – backs of coated

Source	DF	SS	MS	F	P
cat	5	3888.6	777.7	77.37	0.000
Error	3294	33112.6	10.1		
Total	3299	37001.2			

S = 3.171    R-Sq = 10.51%    R-Sq(adj) = 10.37%



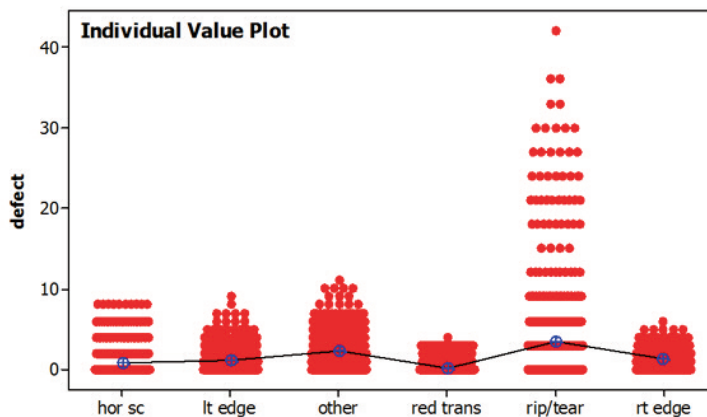
Grouping Information Using Tukey Method

cat	N	Mean	Grouping
rip/tear	550	3.524	A
other	550	2.260	B
rt edge	550	1.235	C
lt edge	550	1.133	C
hor sc	550	0.789	C
red trans	550	0.200	D

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of cat

Individual confidence level = 99.56%



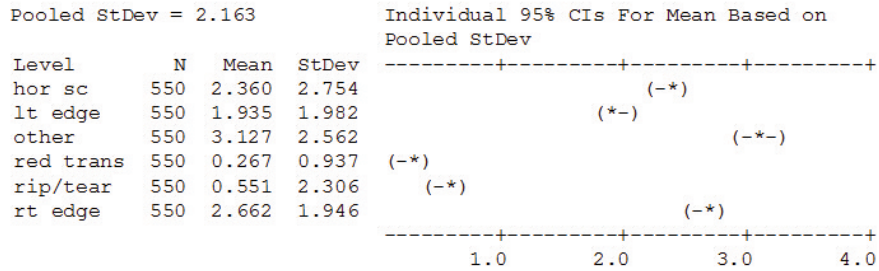
## Appendix K (continued)

Analysis of Research Question 4: ANOVA categories vs. defects—backs of uncoated.

### One-way ANOVA: defect versus categories – backs of uncoated

Source	DF	SS	MS	F	P
cat	5	3709.11	741.82	158.61	0.000
Error	3294	15406.34	4.68		
Total	3299	19115.45			

S = 2.163    R-Sq = 19.40%    R-Sq(adj) = 19.28%



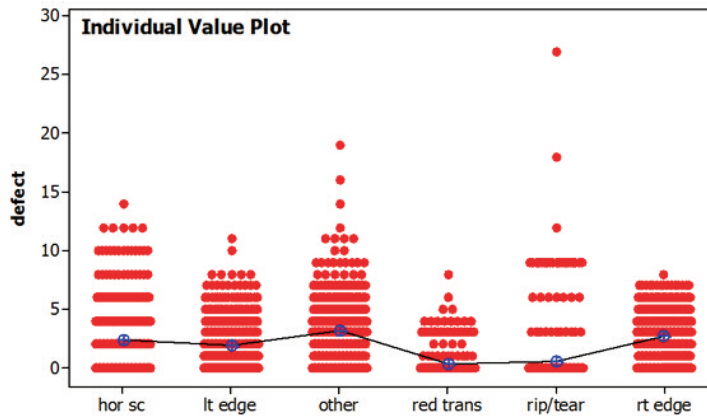
Grouping Information Using Tukey Method

cat	N	Mean	Grouping
other	550	3.127	A
rt edge	550	2.662	B
hor sc	550	2.360	B
lt edge	550	1.935	C
rip/tear	550	0.551	D
red trans	550	0.267	D

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of cat

Individual confidence level = 99.56%



## Appendix L

Analysis of Research Question 4: ANOVA simplified categories vs. defects—all cards.

### One-way ANOVA: defect versus simplified categories – all cards

Source	DF	SS	MS	F	P
category	4	5822.4	1455.6	241.20	0.000
Error	18695	112823.3	6.0		
Total	18699	118645.7			

S = 2.457    R-Sq = 4.91%    R-Sq(adj) = 4.89%

Level	N	Mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
edge	5500	1.824	2.257	(*-)
other	2200	2.166	2.386	(--*)
rip/tear	2200	1.383	4.527	(--*)
scratch	2200	1.297	2.210	(--*)
scuff	6600	0.663	1.581	(*)

Grouping Information Using Tukey Method

category	N	Mean	Grouping
other	2200	2.166	A
edge	5500	1.824	B
rip/tear	2200	1.383	C
scratch	2200	1.297	C
scuff	6600	0.663	D

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals  
All Pairwise Comparisons among Levels of category

Individual confidence level = 99.36%

