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ABSTRACT

A series of tests using OpScan 100DM optical scanner were carried out to determine whether it can mechanically transport paper that does not comply with the manufacturer's specifications for weight and size and see if standard paper stock has sufficient quality, opacity, and brightness to permit it to be used to print forms for the OpScan 100DM. Other objectives were to establish validity and reliability indices and to determine whether standard ink has sufficient reflectivity to be used to print forms for the OpScan 100DM. This report describes the tests and their results. (SK)

SWRL

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TITLE: RESULTS OF INVESTIGATIONS CONCERNING THE CAPABILITIES OF THE OPSCAN 100DM OPTICAL SCANNER

AUTHORS: Gordon L. Gibbs and Judith Hooper

ABSTRACT

A series of tests using the OpScan 100DM optical scanner were carried out to achieve the following objectives:

1. To determine whether the OpScan 100DM optical scanner can mechanically transport paper that does not comply with the manufacturer's specifications for weight and size.
2. To determine whether standard paper stock possesses sufficient quality, opacity, and brightness to permit it to be used to print forms that are scannable by the OpScan 100DM.
3. To establish validity and reliability indices for the OpScan 100DM.
4. To determine whether standard inks possess sufficient reflectivity to permit them to be used to print forms that are scannable by the OpScan 100DM.

The purpose of this document is to describe these tests and their results.

I. INTRODUCTION

A. Optical Scanning Techniques

Mark Detection

All optical scanning is accomplished through the ability of a scanner to sense varying degrees of reflected light. Whenever there is sufficient contrast between the amount of light reflected from a mark and the amount of light reflected from the surrounding background, an optical scanner can detect the presence of the mark.[1]

Forms Production

Paper. Paper requirements vary enough that a paper that is right for one scanner may be wrong for another. The most important characteristics of paper used with optical scanning equipment are:

1. Reflectance - paper used with optical scanning equipment must be highly reflective to provide good contrast with the marks to be read.

2. Opacity - a minimum opacity is required to provide adequate reflectance.

3. Quality - the paper must be free from dirt, blemishes, and water marks.

Ink. Two basic types of ink are used in the production of scannable forms. Ink used to print marks that can be detected by the scanner is called "scan" ink, and must be non-reflective enough to provide the necessary contrast in the amount of reflected light. Ink used to print material (e.g., response positions) that is invisible to the scanner is called "non-scan" ink, and must be highly reflective so it reflects almost the same amount of light as the paper on which it is printed.

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[1] Moore Business Forms, Inc. The world of optical character recognition. Niagra Falls, New York, Moore Business Forms, Inc., 1971.

Printing. The OpScan 100DM internally controls the on/off timing of the reading cells to the marking positions which are referenced from the leading and aligning edges of the form, eliminating the need for timing marks. However, this means that the marking positions must be printed with extreme accuracy which imposes strict tolerances during the printing process.

B. Implications for SWRL

The availability and cost of the special paper and ink, as well as the rigid tolerances that must be maintained during the printing process, have been major obstacles to the production of low cost forms that can be produced by SWRL and optically scanned by the OpScan 100DM optical scanner. The use of a standard paper stock, standard inks, and less restrictive printing tolerances would result in significant cost reductions. However, because SWRL does not possess the means to determine if standard paper and ink meet the specifications set forth by the Optical Scanning Corporation for the OpScan 100DM, and because the effect that less restrictive printing tolerances would have on the scanner's reliability was not known, it was necessary to assess the scanner's ability to mechanically transport and optically scan forms that could be produced by SWRL's Production Services staff and printing equipment, using standard paper and ink.

A series of investigations using the OpScan 100DM were carried out. The objectives of these investigations were to:

1. Determine whether the OpScan 100DM optical scanner can mechanically transport paper that does not comply with the manufacturer's specifications for weight and size.

2. Determine whether standard paper stock possesses sufficient quality, opacity, and brightness to permit it to be used to print forms that are scannable by the OpScan 100DM.
3. Establish validity and reliability indices for the OpScan 100DM.
4. Determine whether standard inks possess sufficient reflectivity to permit them to be used to print forms that are scannable by the OpScan 100DM.

The purpose of this Technical Note is to describe the procedures used to carry out these investigations, and to report their results.

II. INVESTIGATIONS CONCERNING PAPER

A. Manufacturer's Specifications

The specifications for paper, as set forth by Optical Scanning Corporation, are:[2]

> The paper is 8½" x 11" (+ or - .015") 60 lbs., offset, with grain short, and minimum caliper of .005 inches, with Vellum finish. The paper must be 100% woodpulp, free from water-marks and blemishes. The opacity should be 85% or better as read on a Bausch and Lomb Opacimeter. The brightness should be 79% (+ or - 5%) as read on a General Electric Meter.

The first series of investigations were designed to determine whether a standard paper stock possesses the specified characteristics.

B. Weight and Dimensions

Of primary interest was the ability of the OpScan 100DM to batch feed and transport paper that was lighter[3] in weight than the specified 60 pounds without damaging the paper or causing a scanner malfunction. Beginning with a weight of 60 pounds, 100, 8½ x 11 inch sheets of paper were fed into the scanner. The weight of the paper was systematically decreased until the paper ceased to be properly fed into and transported through the scanner's mechanism. The lightest weight paper that passed this test was 45 pound stock.

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[2] Optical Scanning Corporation. Forms design manual: 100DM. Newtown, Pennsylvania, Optical Scanning Corporation, 1971, p. 21.

[3] Heavier paper was not considered since its use could not be expected to result in any cost reduction.

Since none of the paper was precision cut, it was assumed that the dimensions - length, width, and caliper - of the various sheets were representative of standard 8½ x 11 inch stock, and did not necessarily conform to the tolerances set forth by Optical Scanning Corporation.

Based upon the results of this investigation, it was concluded that the OpScan 100DM could successfully batch feed and transport standard (not precision cut) 8½ x 11 inch sheets, ranging in weight from 45 to 60 pounds. However, because the actual scan forms will be subjected to a variety of conditions that may degrade their physical appearance, transportability, and scannability, the use of 60 pound stock is recommended since it would be less subject to wrinkle, tear, etc. For this reason, all further tests were conducted on 60 pound paper stock.

C. Optical Characteristics

The fact that 60 pound paper was successfully batch fed and transported by the OpScan 100DM provided no evidence regarding the paper's optical characteristics; i.e., its finish, quality (cleanliness), opacity, brightness, and reflectivity. It was therefore necessary to determine whether the optical characteristics of a standard 60 pound stock meet the specifications set forth by Optical Scanning Corporation.

Because SWRL does not possess the equipment required to measure these characteristics directly, it was necessary to adopt an heuristic approach in each case.

Finish

Paper with a non-Vellum finish tends to gradually coat the lead of a pencil with a thin film as more and more marks are made on the paper.

The accumulation of this film causes the marks to become lighter and lighter until eventually they can become so light that the scanner is unable to consistently detect them. Paper with a somewhat rough surface is desirable so that it will withstand erasures. For these reasons, and because the cost of paper with Vellum finish is not appreciably different from the cost of paper with non-Vellum finishes, it was decided to retain Vellum finish as an absolute specification.

Because of its availability and relatively low cost, it was decided to use 60 pound offset, white Mustang paper with Vellum finish for all subsequent investigations.

Quality

To determine whether the scanner would detect water-marks or blemishes in this particular paper, a large number of blank sheets were fed into the scanner. After these blank sheets had been scanned, the contents of the magnetic tape, on which the OpScan 100DM recorded the results of the scanning process, were listed using SWRL's line printer. If anything other than a blank had been detected in any marking position, the conclusion must be that the scanner had detected something (i.e., a water-mark or a blemish) "in" the paper. An examination of the tape listing revealed that the scanner had not detected any "marks" on any of the sheets. It was concluded that 60 pound offset, white Mustang paper with Vellum finish does not contain any water-marks or blemishes that can be detected by the OpScan 100DM.

Opacity, Brightness, and Reflectivity

Each of these optical characteristics of paper is related to the scanner's ability to detect a mark that has been made on the paper.

Because SWRL does not possess the instruments required to measure these characteristics directly, the adequacy of the opacity, brightness, and reflectivity of 60 pound Mustang with Vellum finish must be inferred from the measures of the scanner's validity and reliability.

III. VALIDITY AND RELIABILITY

A. Validity

Definition of Validity

The validity with which the OpScan 100DM reads an 8½ x 11 inch sheet refers to the amount of agreement between what the scanner read and what was actually on the paper. Operationally, validity was defined as a decimal number less than or equal to 1.00, obtained from the following equation:

$$V = 1.00 - E_T/N \qquad (1)$$

where V = index of validity

E_T = total number of errors

N = number of marks to be read

The value of E_T was obtained by tallying the discrepancies between what the scanner read and what was actually on the paper. Discrepancies (errors) could occur in any one of two ways:

Type I - the scanner failed to detect a mark where one actually occurred.

Type II - the scanner detected a mark where one did not occur.

To more clearly understand each type of error, consider the following examples.

Figure 1 shows a grid consisting of three marking positions in which a mark has been placed in the second position. If the scanner detects no mark in any of the three positions, a Type I error has occurred. If no mark had been made, but the scanner detected one, a Type II error has occurred.

Figure 1. Three marking position grid with a mark in the second position.

From the foregoing discussion, it is obvious that the term E_T in Equation 1 represents the sum of Type I and Type II errors. Algebracially

$$E_T = E_1 + E_2 \qquad (2)$$

where E_1 = number of Type I errors

E_2 = number of Type II errors

Equation 1 may then be written as

$$V = 1.00 - (E_1/N + E_2/N) \qquad (3)$$

It is obvious from either Equation 1 or Equation 3 that a validity index of 1 represents the ideal case in which no errors occur.

Determination of Validity Index

Procedures. To determine the validity of the OpScan 100DM when reading sheets of 60 pound Mustang, three marking patterns were used. Each pattern consisted of 31 rows, 12 grids per row, three marking positions per grid. The patterns were differentiated on the basis of the location of the mark within the grid. The first pattern consisted of marks placed in the first marking position in each grid; marks placed in the second marking position in each grid made up the second pattern; and the third pattern consisted of marks placed in the third marking position in each grid. The N for each pattern was 372 marks per sheet.

Each pattern was used to mark a sheet of 60 pound Mustang, as well as standard forms provided by Optical Scanning Corporation.[4] These sheets were then fed into the scanner along with a Q-Control Form that programmed the scanner to "look for" the darkest mark in each of the 372 grids on a sheet.

Following the scanning process, the contents of the magnetic tape were listed, and one "pass" was thus completed. Using the same sheets on each pass, three passes were made.

Findings. The results for the OpScan forms supported the hypothesis that the validity index would assume a value of 1.

Totaled over all marking patterns and all passes, the validity index (V) was 0.993. Within marking patterns, the value of V assumed a low of 0.952 and a high of 1.00.

Table 1. Number of errors and the validity index (V), obtained for the 60 pound Mustang.

PASS NO.	MARKING PATTERN	N	NUMBER OF ERRORS TYPE I	NUMBER OF ERRORS TYPE II	V
	1	372	0	0	1.000
1	2	372	5	0	0.987
	3	372	0	0	1.000
	1	372	0	0	1.000
2	2	372	1	0	0.998
	3	372	0	0	1.000
	1	372	1	0	0.998
3	2	372	18	0	0.952
	3	372	0	0	1.000
TOTAL		3348	25	0	0.993

[4] These forms met all specifications set forth by the manufacturer, and were used to provide base line data against which the data for the Mustang paper could be compared. The validity index for these forms was expected to be 1.00.

Conclusions. The fact that the same value of V was not obtained on successive passes using the same marking pattern means that the scanner had made "different" errors on each pass of the 60 pound Mustang paper. For this reason, the value of V cannot be properly interpreted, nor can any inferences be made regarding the adequacy of the optical characteristics of the paper without first investigating the scanner's reliability.

B. Reliability

Definition of Reliability

The reliability with which the OpScan 100DM reads an 8½ x 11 inch sheet refers to the amount of agreement between what the scanner reads on any two passes of the same sheet of paper. Operationally, reliability is defined as a decimal number less than or equal to 1.00, obtained from the following equation:

$$R = \sum_{i=1}^{N} \frac{f(i)}{N} + \sum_{i=1}^{N} \frac{h(i)}{N} \qquad (4)$$

where R = index of reliability

i = i-th response grid; i = 1, 2, . . ., N

N = number of response grids

f(i) = 1 if the scanner registered the same character in the i-th response grid on two passes of the same sheet

f(i) = 0 otherwise

h(i) = 0 if f(i) = 1

h(i) = 1 if f(i) = 0 and the scanner did not register a blank in the i-th response grid on either pass

A value of R equal to 1 represents the ideal case in which the scanner registered the same character in each pair of corresponding grids on two passes of the same sheet of paper.

Determination of Reliability Index

Procedures. Because no errors had been made with the forms provided by Optical Scanning Corporation, it was obvious that the scanner read these forms with perfect reliability (R = 1). Therefore, it was only necessary to compute a value for R when the 60 pound Mustang paper was used.

By comparing the number and type of errors made between each possible combination of three passes, taken two at a time, for the same sheet, hence for the same marking pattern, three values for R were obtained for each pattern. These values were then averaged to obtain a mean value for R, denoted as $\overline{R}$, for each marking pattern. A grand mean for the index was obtained by averaging the three values of $\overline{R}$ and the grand mean was considered to be the best estimate of the scanner's reliability when reading 60 pound Mustang paper.

Findings. The results of the computations are shown in Table 2. The grand mean for reliability was 0.987. Within comparisons and marking patterns, the value of R ranged from a low of 0.954 to a high of 1.000.

Table 2. Values of R obtained by comparing the number and type of errors made between each possible combination of three passes, taken two at a time, using three marking patterns on 60 pound Mustang paper.

MARKING PATTERN	N	PASS 1 v PASS 2 R	PASS 1 v PASS 3 R	PASS 2 v PASS 3 R	$\bar{R}$
1	372	1.000	0.997	0.997	0.998
2	372	0.989	0.954	0.954	0.965
3	372	1.000	1.000	1.000	1.000
GRAND MEAN					0.987

Conclusions. Having obtained measures of the OpScan 100DM's validity and reliability, the combined implications can be discussed.

To provide a single measure of the scanner's capability an algebraic product was formed. It was obtained by multiplying the reliability grand mean (.987) by the total validity (.993). The resultant product (.980) was considered to be the best estimate of the scanner's capability when reading 60 pound Mustang paper.

Based upon these results, and those of previously described tests, it was concluded that 60 pound offset, white Mustang paper with Vellum finish possesses adequate opacity, brightness, and reflectivity; is free from water-marks and blemishes that can be detected by the scanner; and can be batch fed and transported without being damaged or causing a scanner malfunction.

C. Cost Factors

Purchased Forms

Based upon prices quoted by Optical Scanning Corporation, Besel[5] found that the cost per test per pupil for printing a single sheet, two page test varied inversely with the number of pupils involved. When 100,000 pupils were considered, the cost per test per pupil was 1.4 cents. An increase in the number of pupils would result in no appreciable cost reduction. When 5000 pupils were considered, the cost per test per pupil became 8.1 cents, and further reductions in the number of pupils considered would result in additional increases in cost.

SWRL Produced Forms

Computations showed that the cost per test per pupil was 1.2 cents when 100,000 pupils were considered, and 1.3 cents when 5,000 pupils were considered.

These figures indicate that scannable forms can be produced by SWRL, in both large and small quantities, at a cost significantly less than that quoted by Optical Scanning Corporation.

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[5] Besel, Ronald. Scannable Test Forms for IMS - Version 3 Tryout. SWRL, Final TN draft, June 24, 1971.

IV. INVESTIGATIONS CONCERNING INK

A. Manufacturer's Specifications

Having established the fact that 60 pound offset, white Mustang with Vellum finish can be used as the paper stock for scannable forms, the next step was to determine the kind of ink and/or the production process that could be used by SWRL to print such forms.

The specifications regarding the ink used to print forms, as set forth by Optical Scanning Corporation, are:[6]

> All ink used to print the forms require a reflectance level of 48 millivolts as read on Kidder Mark Read Tester (MR8)... Response blocks and any material in these blocks should be screened 30% at 133 lines per inch.

B. Xerography

It was decided to determine whether the OpScan 100DM would detect images produced by a Xerox machine. Using a Xerox model 2400 copier, several copies of the Weekly Log[7] were made on 60 pound Mustang. Along with an appropriate Q-Control Form, these Xerox copies were fed into the scanner, and the contents of the tape were listed and examined.

The extremely large number of Type II errors (detection of a mark where none was supposed to occur) indicated that the scanner had detected the Xerox images. In addition, the number of Type I errors (failure to detect a mark where one appeared) suggested that the registration achieved by the Xerox model 2400 was imprecise and the marking positions and the scan head were not synchronized.

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[6] Optical Scanning Corporation. Op. cit., p. 21.

[7] A scannable form used during the 1968-69 tryout of FYCSP.

Based on these findings, it was concluded that forms produced by current xerography processes cannot be correctly read by the OpScan 100DM.

C. Standard Inks

Unscreened

A prototype criterion exercise response sheet was developed and given to Production Services for art layout and reproduction. Using blue ink, copies were printed on 60 pound Mustang. Unmarked sheets were fed into the scanner and the tape was listed. The number of Type II errors that appeared on the listing indicated that the scanner had detected the ink.

Screened

The same format was used to print additional response sheets, using red, green, and blue ink. However, on this occasion the line delimiters of the marking positions were screened to the manufacturer's specifications (30 percent at 133 lines per inch). These sheets were tested in the same manner as described in the preceding paragraph. The results indicated that the scanner did not detect the delimiters of the marking positions.

The results of all above tests indicated that a standard blue, green, or red ink must be screened to the manufacturer's specifications. However, because SWRL's Production Services had been unable to accomplish this screening, but had to have it done by the Government Printing Office, it was concluded that the forms could not be produced by SWRL using standard ink.

D. Specialized Inks

The previous tests had demonstrated only that screening was required when the reflectivity criterion had not been met. The need for screening when the criterion of reflectivity is met was still in question. Conversations with a representative of Gans Ink Company suggested that reflectivity was both a necessary and sufficient criterion. It was therefore decided to test an ink whose reflectance level was known to be greater than 48 millivolts.

Gans Ink Company provided Production Services with the serial number of a commercially available ink, commonly known as "drop-out blue," whose reflectance level was known to be greater than 48 millivolts. Using this ink (unscreened) additional copies of the prototype response sheet were printed and tested. The results of this test indicated that the scanner did not detect the drop-out blue ink. It was concluded that scannable forms could be produced by SWRL's Production Services, using drop-out blue ink to print any material that was to appear within a marking position.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. Summary

Tests were conducted on the OpScan 100DM optical scanner to accomplish the following objectives:

1. To determine whether the scanner can mechanically transport paper that does not comply with the manufacturer's specifications for weight and size.
2. To determine whether standard paper stock possesses sufficient quality, opacity, and brightness to permit it to be used to print forms that are scannable by the OpScan 100DM.
3. To establish validity and reliability indices for the OpScan 100DM.
4. To determine whether standard inks possess sufficient reflectivity to permit them to be used to print forms that are scannable by the OpScan 100DM.

To accomplish the first objective, sheets of standard 8½ x 11 inch paper were fed into the scanner and their passage through the paper transport mechanism was observed. Beginning with a weight of 60 pounds, the weight was reduced until the paper was no longer properly transported. The lightest weight paper to pass this test was 45 pound.

The quality (cleanliness) of the paper was tested by passing through the scanner sheets of paper that were known to be free from visually observable marks. Any mark registered by the scanner would then have to be the direct result of a water-mark or blemish in the paper. All paper tested was found to be free from such water-marks and blemishes.

Because opacity and brightness could not be measured directly, they had to be inferred from the results of tests of the scanner's validity and reliability. The best estimate of the scanner's validity was considered to be the value V obtained from the following equation:

$$V = 1.00 - (E_{1/N} + E_{2/N})$$

while the best estimate of the scanner's reliability was considered to be the value R obtained from the following equation:

$$R = \sum_{i=1}^{N} \frac{f(i)}{N} + \sum_{i=1}^{N} h(i)$$

The obtained values, V = .993 and R = .987, were then multiplied to provide a single value, .980, which was considered to be the best estimate of the scanner's capability.

Finally, the scanner's ability to detect any or all of a variety of inks was tested by scanning prototype response sheets that had been printed with each of the inks, both screened and unscreened, in question. It was found that standard blue, red, and green inks all must be screened to the manufacturer's specifications to prevent them from being detected, while "drop-out blue" cannot be detected, even if it is not screened.

B. Conclusions

The results of the tests support the following conclusions:

1. The OpScan 100DM can successfully batch feed and transport standard cut, 8½ x 11 inch sheets, as light as 45 pounds.
2. Paper stock with Vellum finish is preferable to paper with a non-Vellum finish.
3. The OpScan 100DM cannot detect water-marks or blemishes in 60 pound offset, white Mustang paper with Vellum finish.

4. The capability of the OpScan 100DM when reading 60 pound offset, white Mustang paper with Vellum finish is sufficiently high (i.e., .98) to allow its use as the stock on which scannable forms are printed.
5. The reflectance level of standard blue, red, and green inks, when screened 30 percent at 133 lines per inch, and of unscreened drop-out blue, is sufficiently high to permit their use in the printing of scannable forms.
6. The cost of producing scannable forms "in-house" is significantly less than that quoted by Optical Scanning Corporation.

C. Recommendations

Based upon the findings and conclusions, the following recommendations are made:

1. All scannable forms are to be printed on standard cut, 8½ x 11 inch sheets of 60 pound offset, white Mustang paper with Vellum finish.
2. All printed material that appears in a marking position on any scannable form be printed using the unscreened, drop-out blue ink. All other printed material should be printed using a standard, unscreened, ink.
3. All scannable forms be produced by SWRL's Production Services.