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Introduction

Direct Part Marking (DPM) is a technology whereby an item is physically altered to produce two different surface conditions. The area of the alteration is called "the mark". The area that includes the mark and background as a whole, when containing a pattern defined by a bar code symbology specification, is called "a symbol".

When light reflects off a symbol, it scatters differently depending on whether it impinges on the background of the part or on the physical alteration.
In most bar code scanning environments, light is reflected off a smooth surface that has been colored to produce two different diffuse reflected states. The DPM environment generally does not fit this model because the two different reflected states depend on at least one of the states having material oriented to the lighting such that the angle of incidence is equal to the angle of reflection. Sometimes the material so oriented produces a specular (mirror like) reflectance that results in a signal orders of magnitude greater than the signal from diffuse reflectance.

In addition, from the scanner point-of-view, some DPM marking technologies and some direct printing methods are not capable of generating smooth lines.
Acknowledging that current specifications for matrix symbologies and two-dimensional print quality are not exactly suited for DPM symbol evaluation, an ad-hoc committee under the supervision of the AIM TSC has developed this guideline to act as a bridge between the existing specifications and the DPM environment in order to provide a standardized image based measurement method for DPM that is predictive of scanner performance.

1 Scope

This document is applicable to the symbol quality assessment of direct marked parts, where the marking process involves a physical alteration of the surface of the item marked and the reading device is a two-dimensional imager.

This document describes modifications which are to be considered in conjunction with the symbol quality methodology defined in ISO/IEC 15415 and a symbology specification. It defines alternative illumination conditions, some new terms and parameters, modifications to the measurement and grading of certain parameters and the reporting of the grading results.

2 Normative references

ISO/IEC 16022 - Symbology specification - Data Matrix

ISO/IEC 18004 - Symbology specification - QR Code

AIM ITS 97-002 - Symbology specification - Aztec Code

ISO/IEC 15415 - Symbol quality - Two-dimensional symbols

SAE AS 9132 - Data Matrix (2D) coding quality requirements for parts marking

3 ISO/IEC 19762 – AIDC – Harmonised vocabulary term(s) and definition(s)

The terms and definitions given in ISO 17962, ISO ISO/IEC 15416 and ISO ISO/IEC 15415 apply, together with the following:

3.1 MLcal
Mean of the light lobe from a histogram of the calibrated standard.

3.2 MLtarget
Mean of the light lobe from the final grid-point histogram of the symbol under test.

3.3 Reference Symbol
High-contrast printed calibration card (such as the EAN/UPC card).

3.4 Rcal
Reported reflectance value, Rmax, from a calibration standard.

3.5 Rtarget
Measured percent reflectance of the light elements of the symbol under test relative to the calibrated standard.

3.6 SRcal
System Response parameters (such as exposure and/or gain) used to create an image of the calibration standard.

3.7 SRtarget
System Response parameters (such as exposure and/or gain) used to create an image of the symbol under test.

3.8 Stick
Line segment comprised of image pixels that is used to connect areas of the same color that are near to each other.

3.9 T1
Threshold created using a histogram of the defined gray-scale pixel values in a circular area 20 times the aperture size in diameter, centered on the image center using the algorithm defined in Annex A.

3.10 T2
Threshold created using the histogram of the reference gray-scale image pixel values at each intersection point of the grid using the method defined in Annex A.

4 Symbols (and abbreviated terms)

CM Cell Modulation
CC Cell Contrast
FPD Fixed pattern damage

5 Overview of methodology

5.1 Process differences from 15415
All parameters in the symbology and print quality specifications apply except for:
- A different method for setting the image contrast.
- A different method for creating the binary image.
- A new method for choosing the aperture size.
- An image pre-process methodology for joining disconnected modules in a symbol.
- A different process for determining the Modulation parameter renamed Cell Modulation.

- A different process for determining the Symbol Contrast parameter which has been renamed Cell Contrast.
- A difference process for computing Fixed Pattern Damage
- A new parameter called Minimum Reflectance.

This guideline explains how to both specify and report quality grades in a manner complementary to, yet distinct from, the method in ISO/IEC 15415.

5.2 Lighting

This guideline recommends three specific lighting environments consisting of two forms of diffuse lighting (non-directional):

- diffuse on-axis illumination uses a diffuse light source illuminating the symbol approximately perpendicularly to its surface (nominally parallel to the optical axis of the camera).
- diffuse off-axis illumination uses light from an array of LEDs reflected from the inside of a diffusely reflecting surface of a hemisphere, with the symbol at its centre, to provide even incident illumination from all directions.

- Directional illumination is oriented at a low angle (approximately 30 degrees) to the mark surface.

6 Obtaining the image

6.1 Lighting

Two lighting environments each with two options are defined in this document. This does not limit the prerogative of an Application Specification to choose different lighting environments. The defined lighting environments are denoted in the reported grade using the format defined in IEC/ISO 15415 using the angle specifier with a combination of numbers and letters as defined below.

6.1.1 Diffuse perpendicular (on-axis/bright field) (90)

A flat diffusing material is oriented such that the plane of the material is parallel to the plane of the symbol area. The symbol is uniformly illuminated with diffuse light incident at 90 degrees to the plane of the symbol. The angle specifier shall be 90 to denote this lighting environment.

6.1.2 Diffuse off-axis (D)

A diffusely reflecting dome is illuminated from below so that the reflected light falls non-directionally on the part and does not cast defined shadows. This is commonly used for reading curved parts. The angle specifier shall be D.

6.1.3 Low angle, two direction (30T)

Light is aimed at the part at an angle of 30 +/- 3 degrees from two sides. The light may be incident from any of the two possible orientations with respect to the symbol (see 6.2.2 below). The lighting shall illuminate the entire symbol area with uniform energy. The angle specifier shall be 30T.

6.1.4 Low angle, four direction (30Q)

Light is aimed at the part at an angle of 30 +/- 3 degrees from four sides such that the lines describing the center of the beams from opposing pairs of lights are co-planar and the planes at right angles to each other. The lighting shall illuminate the entire symbol area with uniform energy. The angle specifier shall be 30Q.

6.2 Orienting the camera

6.2.1 Camera position

The camera is positioned such that its optical axis is perpendicular to the plane of the symbol area.

6.2.2 Camera alignment

The image sensor is oriented such that one edge of the sensor is parallel with one of the low angle lighting planes.

6.3 Orienting the symbol

The part is placed with the symbol in the center of the field of view such that, in its nominal orientation, the lines in the symbol are parallel with at least one plane of the low angle lighting within +/- 5 degrees.

Note: A summary of the arrangement of the camera, low angle lights and symbol is as follows: the symbol is placed such that its grid is in the same orientation as the pixels of the camera and all its lines are either parallel or perpendicular to a low angle lighting plane.

6.4 Reflectance calibration

Using a high-contrast printed calibration card (such as the EAN/UPC card), take an image of the symbol card and perform a histogram of the image pixels in the symbol area including quiet zones. Set the system response so that the mean of the light elements is centered at 78 +/- 10% of the maximum gray scale (equal to 200 +/- 20 for an 8-bit gray-level sensor) and the black level (no light) is nominally equal to zero. Record the System Response as the Reference System Response and record MLcal.

6.5 Initial image reflectance level of the symbol under test

6.5.1 Initialize aperture size

Set the aperture to 0.8 of the minimum X-dimension of the application.

6.5.2 Create initial histogram of symbol under test

Create a histogram of the defined gray-scale pixel values in a circular area 20 times the aperture size in diameter, centered on the image center, and find the Threshold, T1, using the algorithm defined in Annex A.

6.5.3 Compute mean

Compute the mean of the light lobe.

6.5.4 Optimize image

Adjust the system response by taking new images and repeating steps 6.5.1 and 6.5.2 until the mean of the light elements is centered at 78 +/- 10% of the maximum gray scale (equal to 200 +/- 20 for an 8-bit gray-level sensor).

7 Obtaining the test image

The referenced matrix symbologies all require the locating of continuous modules in their reference decode algorithms. Some marking technologies are not capable of producing symbols with smooth, continuous lines when viewed by an imager. For example, dot peened symbols often produce unconnected dots. This section includes a method of pre-processing the image that will connect disconnected modules so that the standard reference decode algorithms can operate successfully.

Once the grid of the symbol is determined, the location information is transferred to the evaluation of the reference grayscale image and subsequent processing occurs using the reference grayscale image.

7.1 Binarize image

Compute a reference grayscale image using the current aperture size. Using T1, binarize the entire image.

7.2 Apply Reference Decode Algorithm

Attempt to find and process the symbol using the symbology Reference Decode Algorithm and the current aperture size. If the attempt fails, go to 7.3. If successful go to 7.4.

7.3 Connect areas of the same color

This process is called the "stick function" and operates on the binarized image. The output is used for the initial decode using the reference decode algorithm. The steps below seek to connect areas in the image that are separated by less than one module, while not connecting areas which are separated by a distance of more than a module, for example alternating "clock teeth" modules.

7.3.1 Initializing stick size and module color

Since a module size is not known during the execution of this algorithm, succeedingly larger distance guesses are used within a range from the size of the smallest and the largest X-dimension allowed by the application specification.

In addition, knowledge of the color of “on” versus “off” modules is also required by the algorithm. Generally the “on” color is dark for bright field illumination and light for dark field illumination. (For instance, the "on" color is the color of the “L” pattern of a Data Matrix symbol.) If a verifier does not “know” the color of "on", the algorithm may need to be repeated for each case.

Note: Implementers are free to optimize this algorithm (such as by attempting a better first guess of the correct stick size by analyzing the image) in order to reduce execution time, as long as the equivalent result is obtained.

7.3.2 Connect like colors

1. Prepare by:
   a) Setting every pixel in the output image to the background (off) color.
   b) Selecting an initial stick size equal to the minimum X of the application.
2. Starting on the row of the image one half-stick length down from the top, and the column one half-stick length in from the left:
   a) If the color of the pixel is the “on” color, set the pixel in the same position in the output image to the “on” color, and continue at step 2e.
   b) Find the two pixels which are one-half stick distance to the left and one-half the stick distance to the right and the two pixels that are one-half stick distance above and below.
   c) If both of the horizontal or vertical pixels found in step 2b are the “on” color, then go to step 2d else continue to step 2e.

d) For each pixel on the line or lines between the two "on" pixels found in step 2b (a line equal in length to the stick), set the correspondingly positioned pixels in the output image to the “on” color.
e) Move to the next pixel and go to step 2a. (If the position of the current pixel is one half-stick length in from the right, the next pixel is at the start at the column one half-stick length in from the left of the next row. If the position of the current pixel is on the row one half stick length up from the bottom, and one half stick length in from the right, exit since the image is completely processed.)

7.3.3 Apply the Reference Decode Algorithm

Attempt to find the symbol in the output image from 7.3.2 using the symbology Reference Decode Algorithm. If successful, go to 7.4.

7.3.4 Repeat if necessary

If the decode attempt fails, choose a new stick size that is at least one pixel more in length and a new aperture size equal to 0.8 stick size and go to 7.1.

7.3.5 Continue until end

Continue until the symbol is successfully decoded or the stick size exceeds the maximum X-dimension allowed by the application (if known) or one-tenth of the maximum image dimension in pixels (if the maximum X-dimension is not known). If the lines are not found, the symbol grade is Zero.

Note: This algorithm assumes that the symbol is oriented orthogonal to the image sensor, so that modules that must be connected are aligned vertically and horizontally in the image. If this were not true, the stick would need to be rotated through all angles, in addition to the vertical and horizontal directions.

7.4 Final image adjustment

This procedure uses only the nominal centers of modules to create a highly bi-modal histogram of the symbol reflectance states.

7.4.1 Determine grid-point reflectance with two apertures

Re-compute the reference gray-scale image using two new aperture sizes equal to 0.5 and 0.8 of the measured average grid spacing. Perform the following calculations and grading for both apertures.

7.4.2 Create a grid-point histogram

Create a histogram of the reference gray-scale image pixel values at each intersection point of the grid determined from the decode and find T2 using the algorithm defined in Annex A.

7.4.3 Measure MeanLight

Measure the MeanLight of the grid-center point histogram. If it is equals 78 +/- 10% of the dynamic range of the camera (equal to 200 +/- 20 for an 8-bit gray-level sensor) then retain the values for MeanDark (MD) and MeanLight.

If not, adjust the system response and go to 7.4.1

7.4.4 Record parameters

Set MLtarget equal to MeanLight. Record the system response as SRtarget. Record the new T2.

7.4.5 Create binarized images for the Symbology Reference Decode

If the decode was achieved using the Stick Function then set the stick size to the average grid spacing and apply the stick algorithm using T2 on the new reference gray-scale image to create the final binarized image. Otherwise, binarize using T2.

7.4.6 Decode

Decode the final binary image using the symbology Reference Decode Algorithm.

8 Determine contrast parameters

8.1 Calculate CC

Calculate CC using the following equation, referencing the algorithm found in Annex A:

CC = (MLtarget – MD) / MLtarget

8.2 Calculate CM

Calculate CM using the following equation:

If (R < T2) then CM = (T2 - R) / (T2 - MD) Else CM = (R - T2) / (MLtarget - T2)

Where R is the measured reflectance of the cell.

8.3 Calculate Rtarget

Rtarget = Rcal x (SRcal/SRtarget) x (MLtarget/MLcal)

9 Grading

9.1 Cell Contrast (CC)

Table 1 — Grading of Cell Contrast

CC	Grade
≥ 30%	4
≥ 25%	3
≥ 20%	2
≥ 15%	1
< 15%	0

Note: With an 8-bit gray-scale sensor, 15% is equal to a difference of 30 gray scale values.

9.2 Minimum Reflectance

Table 1 — Grading of Minimum Reflectance

Rtarget	Grade
≥ 5%	4
< 5%	0

Note: this limits the ratio of SRtarget/SRcal to approximately 16.

9.3 Cell Modulation (CM)

Replace Modulation in 15415 with CM, using the new calculation for threshold and formula for CM and reduce the number of notional UEC levels to 4, 3, and 0 (A, B, and F), where the grade level of 3 now spans 1 to 3. The grade for Cell Modulation uses the same grading scale as Modulation in ISO/IEC 15415.

9.4 Fixed pattern damage

Calculate fixed pattern damage as described in ISO/IEC 15415 and the symbology specifications except:

- Use the threshold, T2, for the modulation overlay and
- When determining the average grade of the segments, use the average of the notional damage grade at the D grade level.
- Rename average grade as "distributed damage grade".

9.5 Final grade

Select the aperture size that generated the better of the two grades in the parameters above and use the associated image and parameters for the remainder of the grading calculations from 15415. If the two grades are identical, use the image and parameters associated with the aperture size of 0.8 X.

10. Communicating the grade

This section discusses the method of signaling grading requirements to the maker of the mark and for reporting the resulting grade to the customer. Depending on the requirements of the application specification, one or more grades for each part may be required. See Annex B.

The application shall specify a range of X-dimensions taking into consideration that large X-dimensions will facilitate greater surface texture. For example, for an application that has a range of X of 10 to 20 mils, the grade requirement is reported as /10-20/ in place of the aperture size.

Grades reported according to this guideline shall be prefaced with "DPM".

With the preface of "DPM", the grade, aperture size and light color are reported in the same way as defined in ISO/IEC 15415, however lighting angle and orientation are communicated as follows.

10.1 Low angle lighting

Depending on the surface texture and other parameters, either of the two orientations may give a different grade than the others.

Low-angle lighting orientation is described with the angle as "30T" (representing the grade obtained with illumination from two sides in the same plane) or "30Q" (representing the grade obtained with illumination from four sides).

Note: where it is not possible to have lighting from two sides, 30T can be measured using light from one side. When this lighting configuration is used, the measurement report should indicate that lighting from one side was used.

10.2 High-angle lighting

Non-directional diffuse off-axis lighting is referenced as "D" and diffuse on-axis (near-perpendicular) lighting as "90".

10.3 Lighting orientation grade

Lighting orientation is reported as the single orientation that was used to determine the grade. If the requirement is for more than one lighting setup, then the grade should be reported for each setup.

10.4 Lighting angle grade

Lighting angle is specified using the separator "|" to designate "or" and the separator "&" to designate "and". For example,
"30Q" or "90" = (30Q|90)
"30Q" and "90" = (30Q&90)
Lighting angle is reported as the single angle that was used to determine the grade. If the requirement is for more that one angle, then at least the lowest grade shall be reported or optionally one grade reported for each angle.

Annex A (Normative)

Threshold determination method

Start by creating a histogram of the defined gray-scale values in the defined region and proceeds as follows:

1. Initialize the variable minVariance to a very large number and initialize Tmin and Tmax to zero.
2. For every gray-scale value, "t", starting from the lowest gray-scale value to the highest gray-scale value (0 to 255 for an 8-bit image sensor),

a. Compute the mean and variance of pixels below t and call it MeanDark and VarianceDark
b. Compute the mean and variance of pixels above or equal to t and call it MeanLight and VarianceLight
c. Compute Variance = VarianceLight & VarianceDark.
d. If Variance < minVariance, save Variance in minVariance and save t in Tmin
e. If Variance = minVariance save t in Tmax.

Note: The step e is used to break ties. Tmin is the smallest gray-level where the variance is the minimum and Tmax is the largest gray-level where the variance is the same minimum.

3. Optimal threshold T = (Tmin + Tmax) / 2.

Annex B (Informative)

Meaning of the grade

B.1 Scanning environment examples

B.1.1 Category 0 part description

The most stringent marking environment requires that a mark be easy to read in "normal" (diffuse reflection off printed labels) scanning environments where scanners are not expected to be able to read most DPM parts. This requirement is not prefaced with "DPM" and follows procedures laid out in 15415 and the symbology specification. This type of requirement is referred to as "Category 0" and is the default if the requirement is not prefaced with "DPM".

B.1.2 Category 1 part description

Parts that are easy to read using a specialized DPM type scanner in a field type environment such as a supply depot or an airfield which also may include printed labels. This type of requirement is referred to "Category 1". Category 1 parts may require some user orientation of the DPM scanner.

B.1.3 Category 2 part description

Parts that require specialized lighting to be read such as those with curved surfaces, very low contrast or highly textured surfaces. Such parts should not be expected to read in field type situations, but are intended to be read in specialized environments such as a sophisticated repair location. This type of requirement is referred to as "Category 2".

B.1.4 Category 3 part description

Parts which cannot pass this specification and that have marking methods and substrates that cannot be modified to pass include some parts with difficult surface conditions for use in extreme environments and/or parts with difficult lighting access to the symbol. These parts may require not only specialized lighting but also proprietary reading devices. These parts cannot be expected to be read in open system environments.

Category 3 parts should be evaluated using proprietary algorithms to determine Decode, Unused Error Correction, Grid Non-uniformity and Axial Non-uniformity and/or by using visual based methods using AS9132.

B.2 Grade communication examples

Following are reasonable examples of grading communication both from an application specification to the maker of the mark and for reporting the resulting grade to the customer.

B.2.1 Grade requirement examples

B.2.1.1 Category 0 part requirement

2.0/05/640

This requirement is typical in a printed label environment where DPM parts are not encountered. Lighting here is 45Q and there is no DPM processing.

B.2.1.2 Category 1 part requirement

DPM2.0/10-20/640/(30Q|90|30T)

This requirement is intended for mixed environments where both printed labels and DPM parts are encountered and where the DPM parts are relatively easy to read with a DPM scanner and a moderately trained operator.

B.2.1.3 Category 2 part requirement

DPM1.0/10-20/640/(30Q|90|30T|D)

This requirement is intended for DPM environments where parts are both difficult to mark and/or where the parts are intended to be read using specialized lighting, fixed mount operation and/or extensive user training.

Note: the "10-20" corresponds to the X-dimension range of the application, not the aperture size.

B.2.2 Grade reporting examples

B.2.2.1 Category 0 part reporting

2.0/05/640

B.2.2.2 Category 1 part reporting

One of either
DPM2.0/08/640/30Q
Or
DPM2.0/16/640/90
Or
DPM2.0/05/640/30T
Is acceptable even if the other grades are less than 2.0.

B.2.2.3 Category 2 part reporting

One of either
DPM1.0/08/640/30T
Or
DPM1.0/16/640/90
Or
DPM1.0/05/640/D
Is acceptable even if one or more of the other grades is less than 1.0.

Note: the single value, i.e. "16", refers to the size of the aperture used to obtain the grade for the symbol, not the X-dimension of the symbol.

B.3.2 Application grade reporting

The application standard is the place where the technology meets the marking vendor. In the case of DPM, marking vendors are more interested in making a good part then they are in knowing whether it will read at some later date. Consequently a simple communication method is recommended in application standards using a Green/Yellow/Red format for use by the marking vendor. Following are recommended outputs for the examples in B.2 above.

B.3.2.1 Category 0 part reporting

Green	3 or better
Yellow	2 or better but less than 3
Red	less than 2

B.3.2.2 Category 1 part reporting

Green	3 or better
Yellow	2 or better but less than 3
Red	less than 2

B.3.2.1 Category 2 part reporting

Green	2 or better
Yellow	1 or better but less than 2
Red	less than 1

Annex C (Informative)

Cross Reference to IEC/ISO 15415

IEC/ISO 15415	This document	Description of change
7.2.4 Binarized image	6 and 7	Threshold uses Annex A
7.3.1 General requirements	6 and 7	100% Reflectance defined for specular reflection
7.3.4 Optical geometry	6 (6.1, 6.1.1-6.1.4)	Dome and two sided illumination environments added
7.4 Number of scans	6.2 (6.2.1-6.3)	Orientations fixed between image sensor and symbol, T defined as either of two orientations to symbol.
7.6 Grading procedure	7	“Stick” algorithm added between the steps of binarized image and performing the initial decode
7.8.3 Symbol Contrast	8.1	Replace SC with CC.
7.8.4 Modulation	8.2	Replace Modulation with CM, using new calculation for threshold and formula for CM and reduce the number of UEC levels to 4, 3, and 0 (A, B, and F).
7.8.5 Fixed Pattern Damage	7	New calculation of threshold for “modulation overlay”
Annex A.2.4	9.4	Redefined “average grade” as distributed damage grade using relaxed modulation overlay.