COGNEX
ID PRODUCTS

Part II

Direct Part Mark Considerations:
Verification

Implementing Direct Part Mark Verification: 10 Important Considerations

INTRODUCTION

With so many manufacturers today implementing direct part mark (DPM) identification programs for part traceability, the need to control the part marking process is becoming increasingly important. The original quality of a two-dimensional code – which serves as a part's permanent identity – can greatly affect the readability of a part as it travels throughout the manufacturing process, throughout the supply chain, and ultimately through to the end use of the part.

Because the quality of a direct marked 2D code is so critical to the success of lifetime part traceability, many manufacturers view the 2D mark as a critical attribute of the part itself. A loss of a part's identity due to poor mark quality means that the part cannot be processed in the manufacturing plant, or used in the supply chain. For this reason, parts suppliers and manufacturers are beginning to require a 2D mark verification capability in order to confirm that part marks meet the quality levels set forth by industry standards.

While 1D bar code verification technologies have been in place for years, the use of verification systems for evaluating and optimizing the quality of DPM 2D codes has just begun to emerge. In fact, a growing number of companies are just now beginning to incorporate direct part mark verification (DPMV) systems into their processes. For some companies, the goal of DPMV is process control. For others, the goal is contract compliance. In either case, DPMV can help manufacturers improve the marking process, increase read rates, lower the cost of rejecting parts due to unreadable codes, and help ensure that parts don't lose their lifetime identity.

From a process control standpoint, controlling the quality of the mark that gets applied to the part is a critical element to successful part tracking applications. By understanding the root cause of poorly formed codes using universal standards, manufacturers can easily trouble shoot marking equipment, better maintain the equipment, and prevent bad codes from entering the manufacturing and supply chains.

From a contract compliance standpoint, a growing number of companies today need DPM verification systems to ensure that they are marking codes that comply with specific contract requirements. For example, to meet the objectives of the U.S Department of Defense (DoD) Unique Identification (UID) Program initiative, suppliers are now required by contract to mark and verify DPM codes on items having an acquisition cost of over $5,000, serialized items, mission-critical items, and spared/repaired items. By complying with this regulation, suppliers improve their own ability to read codes, while helping the DoD improve data capture, part lifecycle management activities, and logistics support. Contract compliance is also starting to come into play in other industries. Automotive companies, for example want to be confident about the readability of parts before the parts arrive at the assembly plant. Thus, many of these companies are beginning to push the burden of DPM verification down the supply chain.

This paper discusses ten important considerations to make when choosing a DPMV system, and offers guidance with respect to which verification standards will best apply to your particular process.

Cognex can help ensure the success of your DPMV project. For additional information about DPM verification systems, please contact Cognex at (877) 264-6391 or visit www.cognex.com.

1. What is verification and how is it used?

In its most basic form, DPM verification is the process of visually inspecting the quality of a direct marked 2D code. A DPM verification system, which may be deployed directly on the marker or as an independent station, consists of integrated lighting, optics, camera, part fixturing and verification software. DPM verification systems operate by capturing and analyzing the image of a code, and rating the image on a number of quality assessment metrics. These quality metrics are based on industry specifications, as well as supplemental quality metrics a vendor may have designed into the DPM verification system to optimize process control.

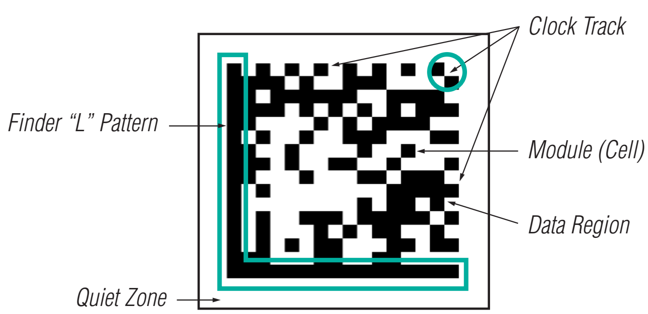
The DPM verification system then generates an overall score or "grade" for the code, and provides process feedback about the marking equipment that manufacturers can use for preventive maintenance. From a process control standpoint, DPM verification systems, by monitoring variations in the quality of a just-applied code, can quickly detect problems at the marking station.

For example, a verification system may report inconsistencies in the shape or size of dots applied by a dot peen machine. This may suggest that the machine's stylus tip is worn or broken, or that part fixturing needs to be adjusted. In inkjet marking, incomplete marks might suggest that printing jets have become clogged. Finally, changes in code appearance during laser marking may indicate that the machine's power settings need to be adjusted.

In addition to helping diagnose problems with marking equipment, DPM verification systems can assist in the initial set up of marking equipment. Instant feedback on mark quality allows operators to fine-tune machine set-up and optimize the marking process from the outset.

System set-up information, verification results data and part images can all be stored by the system for archiving and documentation. This is useful, for example, when a supplier needs to provide proof to its customer that a part was marked to a certain grade.

DPM verification systems can help eliminate variables that affect the readability of a mark, and confirm that a mark is a good one from the start. The process of decoding a DPM mark involves finding the mark, determining the symbol size; identifying "on" and "off" cells; applying error correction; and reporting results.



Consequently, there are several attributes of the Data Matrix symbol that contribute significantly to its overall readability. The quiet zone, or clear area surrounding the symbol on all four sides, should be free of defects. The finder pattern should be well formed, and the modules or light and dark cells that make up the clock track and data region should be uniform and easily distinguishable.

Though verification systems can assess these attributes, they cannot, however, guarantee readability once the part enters the process. Manufacturing process variations, part handling, and part usage over time can degrade the appearance of even the highest quality 2D marks. Downstream reading success will depend largely on the capabilities of the DPM reader itself and how well it is able to tolerate code degradation. Not all readers that offer the capability to read 2D codes are able to handle the difficult challenges of DPM identification. While some traditional bar code readers designed for high contrast code identification support 2D code reading, these readers will not be able to successfully read DPM 2D codes.

2. Reading vs. Verification

When considering a DPM verification system, it's important to understand the difference between DPM code reading and verification. While both are necessary for successful parts tracking, reading and verification systems are designed to accomplish different things, and have their own set of unique challenges.

The goal of DPM code reading is to read a code as quickly as possible despite the appearance of a code, and report the results. Code appearance can vary widely from part to part depending on the quality of the code, part presentation, process effects, and part surface characteristics. For instance, in the case of dot peen marks part presentation to the reader can vary from part to part causing inconsistent lighting effects that challenge readers even though the mark itself is very good.

In other cases, the reader may need to read a variety of parts with different surface characteristics and/or marking methods such as in an aerospace kitting application. Since it is impossible for the operator to optimize the reader for each read attempt the reader must be able handle the wide range of variations it will encounter.

No matter what the surface characteristics of a part are, or what marking method is used to apply a code, a reader's purpose remains the same: to read codes as quickly as possible. It is important to note that just because a code is readable by a DPM reader does not mean that the quality of the code is high and therefore should not be used as a basis for determining mark quality.

With DPM verification systems, the goal is to confirm that the mark meets an acceptable level of quality as defined by particular quality specifications and industry standards. In order to achieve this, the DPM verification system must generate a consistently formed image of a 2D mark that is free from variations in lighting, part presentation, or process degradations. Verification takes into account part surface characteristics and marking methods, as both are factors that can impact readability. By isolating a mark from variables such as lighting changes and variations in part position, a DPM verification system can focus entirely on mark quality and thus provide meaningful measurements of how well the mark was made.

Image appearance at verification station

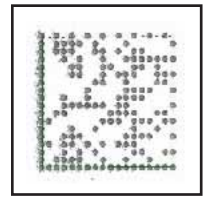
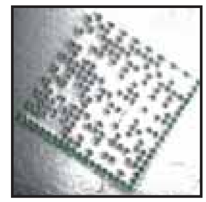
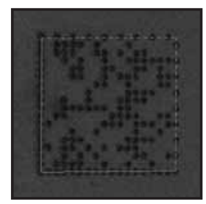


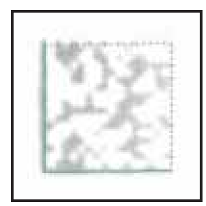
Image appearance as seen by readers



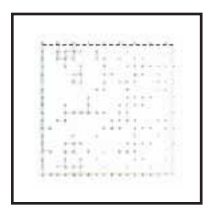
Uneven illumination



Low contrast



Poor focus



Inconsistent dot size

3. DPM Verification Challenges

The goal for any verification system is to achieve accurate and repeatable results. The greatest challenge for a DPM verification system is to achieve this goal despite wide variations of mark type and surface conditions. It is the combination of effective image formation, prescribed set-up routine, and reliable and accurate verification software tools that enable this to be achieved.

When performing DPM verification, inspections are made on the "image" of the mark, which is formed by the lighting and optics of the system at the time of the inspection. As mentioned earlier, in order for a verifier to analyze the attributes of a mark that affect readability, it needs to be able to form a consistent image of the mark.

To form such an image, a DPM verification system must operate under tightly controlled conditions. Lighting, part fixturing, camera resolution and optical settings all need to be configured based on the specific surface characteristics of a part and the marking method used, and redefined for each new verification application. Specific guidelines on various aspects of image formation will be discussed in a later section.

Once proper image formation has been achieved, the next challenge for a verification system becomes accurately locating the code in the camera's field of view and performing the quality analysis. Once the position of a mark is accurately located, various reference points such as the cell grid, finder pattern, clocking pattern, and quiet zones are more accurately identified. The verification and process control metrics can then be applied.

To generate a consistently formed image from which accurate and repeatable measurements can be made, DPM verifier settings must be redefined for each new application to achieve meaningful and consistent results.

4. DPM Marking Methods

Two-dimensional (2D) codes have been selected for DPM Identification applications due to advantage in their small size, error correction, and amount of data that can be stored as compared to 1D codes. The Data Matrix 2D symbology has emerged as the standard code type for parts tracking. These Data Matrix codes are marked on the part using several methods. Common methods include dot peening, laser engraving, electro-chem etch, and ink jet marking.

The marking method used is typically defined by engineering and takes into consideration acceptable marking methods for a particular part and/or material, the life expectancy of the part, material composition, environmental wear and tear, surface texture, the amount of space allotted for a code, and the amount of data to be encoded on each part. For more details about DPM marking methods, please refer to Cognex's white paper, *Implementing Direct Part Mark Identification: 10 Important Considerations.*

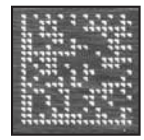
While the marking method used has some bearing on DPM reader performance, it plays an even more important role in DPM verification. Unlike reading, a verifier must provide an optimal image in order to provide meaningful results. The lighting must be of consistent intensity, direction and uniform throughout the field of view. The marking method and material will dictate what lighting method to use.

For example, in laser-etch marking techniques, the quality of a mark is directly affected by how the laser interacts with the surface material of the part being marked. In order to determine how well the laser marked the part, a diffuse bright field light may provide the best image. In dot peen marking applications, the indentations can impact quality by causing an uneven distribution of light and dark pixels when an image of the code is formed. In this case, a low angle light will likely provide the optimal image to determine mark quality.

Finally, no matter what marking method is used, the goal is to produce a mark that is readable throughout the entire lifecycle of a part to achieve full traceability. Part lifecycle requirements vary from industry to industry. For example, the aerospace industry might expect a 25-year lifecycle for parts, whereas the automotive industry may expect parts to have a ten-year lifecycle.

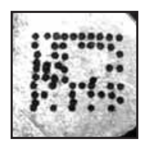
Marking Methods

Dot Peening *is achieved by pneumatically or electromechanically striking a carbide- or diamond-tipped stylus against the material being marked.*



Laser marking *applies heat to the surface of a part that causes the surface of the part to melt, vaporize, or change in some way to produce a mark.*

Inkjet printers *precisely propel ink drops to the part surface, after which the fluid evaporates and leaves a colored die that creates the pattern of modules that make up the mark.*



Electrochemical etching (ECE) *is a process whereby the mark is produced by oxidizing metal from the surface being marked through a stencil impression.*

5. An Introduction to Standards

In DPM verification applications, the quality of Data Matrix marks are typically verified to specifications set forth by the International Standards Organization (ISO) and other recognized industry groups such as SAE. There are three different areas addressed by ISO standards: symbology, print quality and conformance testing specifications. Industry-specific application specifications reference these ISO as well as other specifications to guide users on how to mark and verify print quality of the mark on a part. It is important to understand the three different areas defined by ISO specifications, and how the various industry application standards reference them as they are all targeted at accomplishing something different.

Symbology specification – Defines what the code is, the code structure, symbol formats, error correction rules, and decoding algorithm. In the case of Data Matrix, the ISO specification is ISO 16022.

Print quality test specification – Defines the underlying quality assessment metrics, methods and grading used to analyze code quality. ISO defines “print” as any method to put a code on a substrate. For Data Matrix, the ISO specification is ISO 15415. However, because this standard was originally developed for codes marked on paper labels, its usefulness has been limited in direct part mark 2D code applications. Because a 2D print quality specification did not exist when ISO 16022 was created, this standard provided quality assessment metrics as part of its appendix. These metrics are often referred to as “AIM” metrics. SAE AS9132 Standard “Data Matrix Coding Quality Requirements for Parts Marking” is an aerospace industry standard designed to address the unique aspects of DPM relative to metallic parts.

Conformance specification – Defines the testing that a DPM verification supplier needs to perform on its systems to ensure that results are within a certain tolerance of the expected results of the ISO print quality standard. For Data Matrix, the ISO specification is ISO 15426-2. Because conformance is reliant on a fundamentally sound “print” (i.e. mark) quality specification, a new print quality test specification which is currently being developed by AIM must be completed before conformance can be achieved.

2D DPM Verification Standards Still Evolving

In the world of 1D barcodes, verification standards have been in place since the early 1980s, and are still widely used today. In the 2D matrix code world, DPM verification standards are still evolving. Reasons for this include the relative infancy of DPM 2D code marking, and the wide range of part surface types, part materials, and marking methods used throughout different industries. Whereas 1D barcodes are typically high quality, high-contrast printed codes to begin with, DPM 2D codes take on many different forms, and are subject to significant variability.

Application standards – Application standards are industry-specific, and define the symbol type that should be used in various industries and the data content. Application standards also provide general guidance on what is considered a “good” or “passing” mark within various industry applications. For example, MIL-STD-130 defines code and quality requirements for marking parts supplied to the U.S. Department of Defense. This standard defines Data Matrix as the symbology, what data needs to be encoded, how the data should be encoded, and the mark quality requirements. Similar application standards and/or guidelines exist for other industries.

It is important to note that certain verification standards that exist today for printed, high-contrast 2D marks are frequently not useful in the verification of DPM 2D marks. Today, verifiers will provide results based on a the quality assessment metrics defined in the following three standards and specifications:

1. This SAE AS9132 standard defines metrics for dot peen, laser, and electrochemical etch marking methods for metallic parts. In the case of dot peen, the standard calls for measurements of dot size, dot position, and dot ovality to indicate whether a mark is acceptable or unacceptable. AS9132 provides guidelines for first article inspection performed by an inspector with magnification aids, and subsequent process monitoring as defined by a quality assurance plan. AS9132 measurements can alternatively be performed using electro-optical devices.

2. ISO 16022 "International Symbology Specification – Data Matrix" – This is the international symbology specification for Data Matrix. Reference verification criteria are provided for measuring symbol contrast, print growth, axial non-uniformity, and unused error correction. Marks are graded using an A-F scale where A is excellent and F is fail.

3. ISO 15415 "Bar code print test specification" – This specification provides print quality test specification for 2D symbols, including Data Matrix. ISO 15415 encompasses a subset of the metrics defined by the ISO 16022 such as symbol contrast, unused error correction and axial non-uniformity, with the addition of metrics for modulation, grid non-uniformity, and fixed pattern damage.

See Appendix A on pages 11 and 12 for more detailed information on each of these.

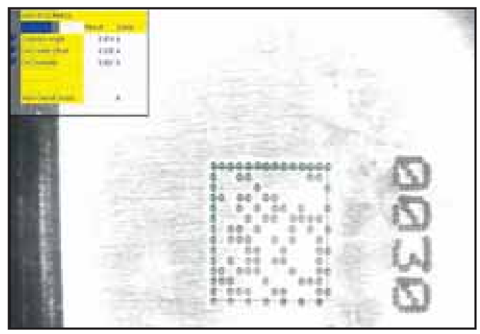
6. Choosing the Right Quality Metrics for the Job

While much progress has been, and will continue to be made in defining useful DPM verification standards, choosing the right standards and metrics for the job at hand can still be a challenge.

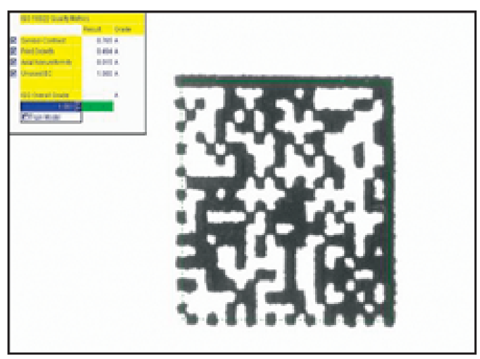
When evaluating DPM verification systems, it is important to make sure that the verification system supports the AS9132 and ISO 16022 standards. Additionally, the verifier should support ISO 15415 verification standards in situations where contract compliance requires its use. Also the DPM verification system should enable you to run multiple quality metrics on a part simultaneously.

It is also a good idea to look for a vendor that has incorporated its own set of supplemental metrics into the system. Vendors with extensive experience in solving DPM reading applications should be able to offer supplemental metrics that leverage the company's understanding of the attributes of a mark that contribute to readability. These metrics are not intended to be used in place of industry standards, but rather, to supplement industry standards for improved process control.

If you are working under a contract compliance requirement from a customer you will need to follow the requirements outlined in their part marking standard when determining mark quality. For example, DoD suppliers will need to follow the existing MIL-STD-130 (Rev. L Change 1), which requires ISO 15415 for paper based labels and AS9132 for dot peen, laser and electro-chemical etch.



AS9132 metrics are recommended for codes made up of round cells with non-continuous L pattern.



ISO 16022 metrics are recommended for codes made up of square cells with continuous L pattern.

If you are implementing DPMV for process control for an internal direct part marking program, the following guidelines are suggested for determining mark quality:

- Marks formed by round cells and non-continuous finder patterns – AS9132.
- Marks formed by square cells and continuous finder patterns – ISO 16022.

Note: Use of supplemental metrics in conjunction with industry specifications and standards can provide additional process control metrics.

7. Implementation Guidelines

Proper set-up of lighting, optics, and other components is necessary to achieve effective image formation, and critical to the success of any DPM verification application. Following are some general image formation guidelines to follow when setting up a DPM verifier:

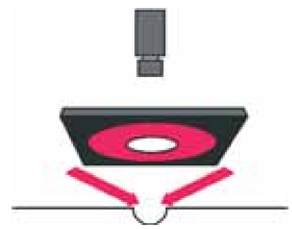
- *Camera resolution* – In verification applications, a good rule of thumb is to have a minimum cell resolution that is 2-3 times higher than that required for reading DPM codes. In order to achieve consistent, repeatable results, this means a verification system should be equipped with an optical magnification that provides a minimum resolution of 100 square pixels (picture elements) per module.

Bright Field

- *Lighting* – Because they need to handle a wide range of marking methods and part surface characteristics, DPM verification systems need to have the ability to accommodate a variety of lighting approaches, including:

  - Bright-field illumination – Diffuse light is directed at the marked code 90 degrees (+/- 5 degrees). This method is ideal for high-contrast printed or marked codes on non-reflective surfaces.

  - Dark-field illumination – Light is projected at a low angle to the part surface, causing any variations to deflect light up into the camera. This technique is ideal for dot peen and highly reflective laser etched codes.



Dark Field

  - Diffuse dome illumination – Provides a non-directional, soft illumination free of harsh shadows that is well suited for highly specular objects. This technique is ideal for imaging marks on curved highly reflective surfaces and dot peen codes on rough surfaces.

Diffuse Dome

- *Ambient Lighting* – The result of a verifier should not be influenced by changes in ambient lighting conditions. This means the verifier should either be shrouded to eliminate the effects of ambient light or should apply a cut filter that only allows light from the verifier's light source into the camera.

- *Part fixturing* – How a part is presented to the verification system has a significant impact on a DPM verification system's ability to generate consistent and meaningful results. As a general rule of thumb, parts should be consistently positioned in the center of the camera's field of view and at a consistent working distance.

- *Set-up routine* – To establish a baseline during system set-up for lighting, optics and resolution, it is recommended that a set-up routine be performed. This is essential for achieving a repeatable and reproducible set-up of the DPM verification system.

8. Data Validation, Collection and Reporting

The goal of "Data Validation" is to ensure that the correct syntax, semantics and data has been encoded within the Data Matrix in the right format. The application standard normally defines how the data should be encoded. By providing a standard means of encoding the data, application developers will know how to interpret, use and log the data into a data base in the plant as well as through the entire supply chain. Most application standards not only define what the code is and how to grade the print quality, but also define specifications for data formats, identifiers and transfer structures. For example, MIL-STD 130 requires that the encoded data use ISO 15434 syntax and ISO 15418 semantics.

The ability to log, report, and communicate verification results, images, and information about system set-up is a key feature to look for in a DPM verification system. The system should be able to record the overall score and quality metrics for each part that is verified, time and date stamp each verification, and store bitmaps of each image.

The system should also provide a simple and intuitive graphical user interface that enables operators to enter important system set-up information, such as operator name, type of lighting used, camera exposure values, and optical settings.

Finally, the verification system should enable operators to easily export logged data to PC spreadsheet programs such as Excel, and third party databases and/or applications via an industry standard connectivity protocol such as OPC (OLE for Process Control).

DPM verification systems should include easy to use software for reporting results.

9. Types of DPM Verification Systems

Users today want to perform DPM verification using in-line fixed mount, benchtop, and hand-held verification systems.

- In-line fixed-mount DPM verification systems can be mounted on the marking machine, directly after the marking station, or above the fixtured part at the marking station. As its name suggests, fixed-mount systems incorporate precisely mounted components, and are designed so that the entire image formation system is configured to the specific marking method and surface characteristics of the parts being marked. These systems typically provide extremely consistent and repeatable performance.

- Stand-alone or benchtop fixed mount verification systems are used as first article inspection tools, or as incoming quality inspection stations. Stand-alone verifiers incorporate stand, verifier, and lighting to accommodate flat parts, nameplates, and other small parts that can be brought to the station.

- The demand for hand-held devices that can provide both verification and reading capabilities is being driven by applications where parts are too large to be placed onto a fixed mount station. While hand-held solutions promise a high level of ease-of-use and convenience, there are currently no hand-held verification systems on the market that take into account the considerations of implementing repeatable DPM verification. Solutions are now under development to address this need.

10. Vendor Selection

When selecting a DPMV vendor, there are a number of considerations to make. Look for a vendor with extensive experience in solving direct part mark identification applications. In knowing what it takes to read codes, the vendor is likely to have a solid understanding of the myriad of variables that affect readability. Ask the vendor about their own set of supplemental metrics and how those metrics will help improve system accuracy and repeatability.

The vendor should also have expertise in machine vision-based image formation and image analysis techniques, since the consistency and repeatability of your verification results will depend on it.

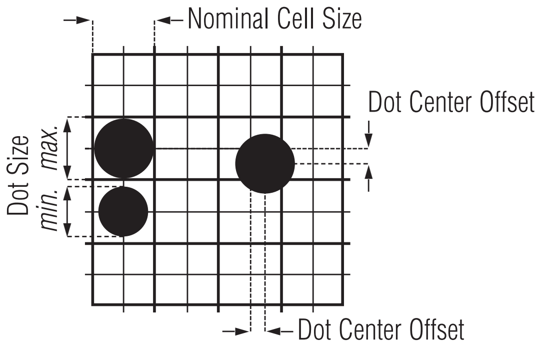
The vendor should provide the support necessary to thoroughly qualify your DPMV application, guide you through the considerations in assuring success, and ensure that the installation is a success.

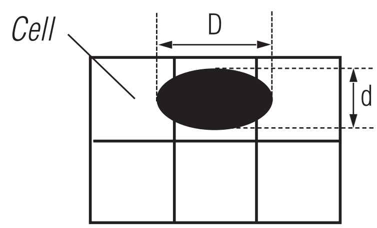
It is also important to look for a vendor with a global network of offices offering both pre- and post-sales support. This way, you can receive the same consistent high level of product support anywhere in the world. This can be particularly important if the verification system is commissioned in one location and shipped to another.

Finally, the selected vendor should have a successful track record and financial stability to maintain their role as your DPMV solutions provider for the long term.

appendix A

AS9132 - Dot Peen Quality Assessment Metrics				
	Dot Size	Dot Center Offset	Dot Ovality	Angle of Distortion
Description	Measures and compares the actual “dot size” to the nominal cell size. No more than 2% of the dots should be outside this limit.	Measures and compares the actual “dot position” to the nominal cell position. All dots should be within this limit.	Measures the ovality (or roundness) by comparing the difference between the height (“D”) and width (“d”) of each dot. Both “D” and “d” are expressed as percentage difference from nominal.	Tests and measures the vector deviation of the grid intersections
Result	“Acceptable” = 60% to 105%	“Acceptable” = 0 to 20%	“Acceptable” < = 20%	“Acceptable” = + / - 7%





Definition of Ovality
D-d <= 20% of the Cell Size

appendix A continued on page 12

appendix A

ISO 16022 - Quality Assessment Metrics					
Aim Verification Test	Symbol Decode	Symbol Contrast	"Print" Growth	"Axial" Non-uniformity	Unused Error Correction
Description	Test whether the symbol was decodable. If not, no additional information is returned	Compares the contrast between the darkest 10% & the lightest 10% of the pixels within the code	Checks the extent to which dark & light markings appropriately fill their module boundaries	Is a measure of how much the spacing between cells differs from one axis to another	Tests the extent to which damage to the code has eroded the reading safety margin that error correction provides
Results	"A"= Successful decode "F"= Failed to decode	"A" if > = 70% "B" if > = 55% "C" if > = 40% "D" if > = 20% "F" if < 20%	"A" if > = -0.50 and < = 0.50 "B" if > = -0.70 and < = 0.70 "C" if > = -0.85 and < = 0.85 "D" if > = -1.00 and < = 1.00 "F" if < -1.00 or > 1.00	"A" if < = 0.06 "B" if < = 0.08 "C" if < = 0.10 "D" if < = 0.12 "F" if > 0.12	"A" if UEC > = 0.62 "B" if UEC > = 0.50 "C" if UEC > = 0.37 "D" if UEC > = 0.25 "F" if UEC < 0.25

ISO 15415 - Quality Assessment Metrics							
	Decode	Symbol Contrast	Modulation	Fixed Pattern Damage	Axial Nonuniformity	Grid Nonuniformity	Unused Error Correction
Description	Uses the reference decode algorithm as defined by ISO 16022 to determine if the code has all its features sufficiently	Test the reflective difference between light and dark modules	Is a measure the uniformity of dark and light symbols throughout the symbol	Tests that damage to the finder pattern, quiet zone and clocking pattern in a symbol does not unacceptably impact readability	Tests for uneven scaling of the symbol that might hinder readability	Tests and measures the largest vector deviations of the grid intersections	Tests the extent to which damage has eroded the safety margin that error correction provides
Result	"A" = Successful Decode "F" = Unsuccessful Decode	"A" > = 70% "B" > = 55% "C" > = 40% "D" > = 20% "F" < 20%	Based on several test methods, see ISO 15415 specifications for underlying detail.		"A" < = .06 "B" < = .08 "C" < = .10 "D" < = .12 "F" > .12	"A" < = .38 "B" < = .50 "C" < = .63 "D" < = .75 "F" > .75	"A" > = .62 "B" > = .50 "C" > = .37 "D" > = .25 "F" < .25

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