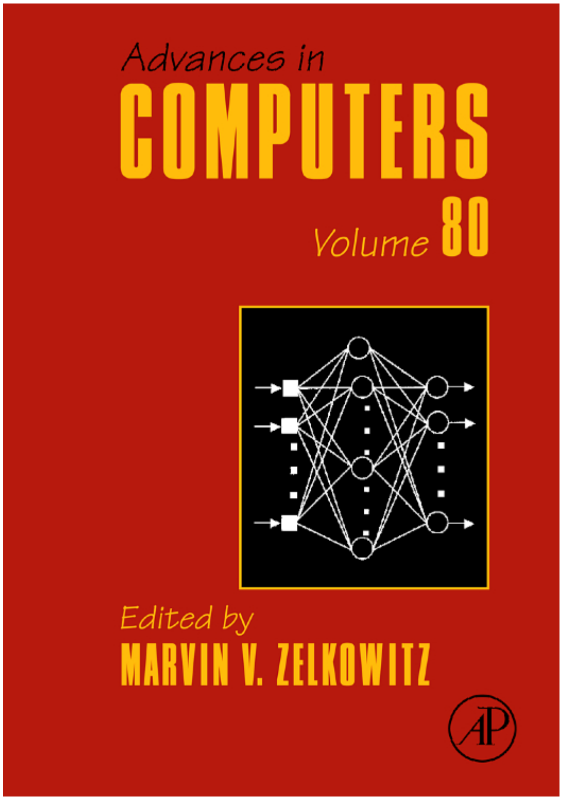

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Parameters Effecting 2D Barcode Scanning Reliability

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Abstract

This paper describes a case study to identify the various parameters that affect the scanning reliability of 2D barcodes for high content density applications. A review of the numerous options for 2D symbologies showed that, in theory, these symbologies are capable of encoding relatively large amounts of data, but in practice, barcode scan-ability decreases as the encoded content increases. With specific attention to higher content (or capacity) applications, a case study was performed to identify the 2D symbologies with the highest scanning reliability, to be termed ''scan-ability,'' as well as the various parameters that impact this scan-ability. The paper is divided into four logical sections. The introduction section covers the goal and the specific requirements of the project. Section 2 discusses in detail the various parameters that impact the scan reliability of high-capacity 2D barcodes. Section 3 focuses on the testing methodology employed and Section 4 summarizes the conclusions of the detailed testing. Based on our requirements, our findings indicated that the best three scan reliability measurements of 96%–99% were all obtained using the PDF417 symbology with different media types and scanners.

1. Introduction

A barcode is a symbol that contains encoded plaintext data that can be read by standard optical scanners/decoders, thereby automating data representation and retrieval while eliminating potential human error. Common barcode applications include tracking of consumer goods at grocery stores, checkout terminals, document management tools, inventory management, ticketing, mobile tagging, mobile airline boarding passes, etc. The corelation between the barcodes and the corresponding messages is termed as *symbology*. Symbologies are classified as linear and two-dimensional (2D).

The goal of this case study was not only to identify the various parameters that affect the scanning reliability of 2D barcodes but also to identify the most reliable barcode and its appropriate configuration for high content density applications. The need for this study is rooted in a project for developing a secure credentialing system, where there is a need to have data encoded in high-capacity 2D barcodes on viz. Polyvinyl chloride (PVC) and polyester media.

Initial experimentation showed that the scanning reliability of these high-capacity 2D barcodes was not as high as a typical ‘‘grocery store checkout’’ system. Since the average user’s typical experience with barcodes is the checkout line at the grocery store, the expectation from using a barcode is quick and reliable scanning. The primary difference between this expected result and a second-generation 2D barcode was in the data content density. The typical ‘‘grocery store’’ items use a very small amount of data in the barcode, mainly a ‘‘primary key,’’ which requires referencing a backend database to read the complete information about the scanned item. Our particular application required eliminating this dependency on a backend database, thereby requiring a large amount of data to be encoded directly in the barcode itself. Even though the barcodes that we used were within the theoretical data capacity limits for different barcode symbologies, the less than perfect scan reliability prompted us to explore other potential factors.

These secondary factors included the barcode symbology itself, the encoder which conforms to the relevant barcode symbology, the printer which creates the physical barcode, the media on which the barcode is printed, and the decoder that interprets the encoded content. This case study describes a series of internally designed tests, and interpretation of the test results, to precisely identify the impact of data content density, error correction level, type of encoding, scanner characteristics, type of media, and printer on the scan-reliability of 2D barcodes.

2. Factors that Affect Barcode Scan Ability

As per the Layman's guide to ANSI, CEN, and ISO bar code print quality documents published by the Association for Automatic Identification and Mobility (AIM) [1], *''through the years, bar codes had been printed that met the existing standards, but would not scan. And often bar codes printed out of specified standards did scan.''*

Years of extensive testing by different groups from ANSI, Committee for European Normalization (CEN), and ISO, have identified the following critical parameters for bar code scan reliability: Aperture and wavelength of the scanner, reflectance and surface opacity of the media, printer characteristics, scan grade and reflectance profile, and symbol grade and the operative scanning environment. In addition to these factors, our case study considered other parameters such as the type of symbology used, the content density of the encoded data, the error correction level used, and the method of encoding. Each of these factors, as they relate to this particular case study, is examined in detail in the subsequent sections. The symbologies used may be linear or 2D. Error correction techniques are used to increase the scan-ability to handle partial data corruption. The barcode may be printed on different kinds of media such as paper, polyester, and PVC. Each of these media offer different benefits and are typically selected based on the intended usage profile for the barcode. Once the barcode is physically printed on the media, various decoders or scanners may be used to decode it based on the type of barcode used.

2.1 Barcode Symbologies

While linear symbologies, such as Universal Product Code (UPC), Code 39, Code 128, EAN, MSI, Intelligent Mail Barcode, Pharmacode, to name a few, were limited in their data-carrying capacity, the 2D symbologies enable large amounts of data to be encoded and decoded in machine-readable formats [2, 25]. Common examples of 2D symbologies include DataMatrix, PDF417, Aztec Code, Codablock, MaxiCode, QR Code (Quick Response Code), Datastrip 2D, etc. [3]. Some common examples of various barcode symbologies are shown in Table I (the Kaywa website [20] was used to generate the QR Code).

Based on the volume of usage, the symbologies may be classified as:

- 1D or stacked symbologies, such as UPC and Code 128. These barcodes are not the focus of this study and will not be discussed in detail.
- Symbologies having widespread industry usage such as PDF417, QR Code, DataMatrix, and Aztec Code.
- Proprietary and Emerging symbologies such as Datastrip 2D [24] and Microsoft's High Capacity Color Barcode (HCCB).

TABLE I
BARCODE SAMPLES

UPC-A	Code 128	PDF417	QR code
DataMatrix	Aztec code	High capacity color barcode (HCCB)	DataStrip 2-D

2.1.1 Symbologies Having Widespread Presence

One of the most widely known barcode symbologies is the UPC symbology, which is a linear barcode used for tracking retail merchandise and other point-of-sale management functions. UPC implementation has different variations, including UPC-A, UPC-B, UPC-D, UPC-E, and UPC-5, although UPC-A is by far the most widely used symbology [28]. It is able to encode 12 bytes of numeric data wherein 11 digits constitute the data and 1 extra digit is used as a check digit for error correction [4]. Each digit is represented graphically as a combination of two bars and two spaces. While UPC-B does not use a check digit, UPC-D differs from UPC-A in that it uses a variable-length code instead of the standard 12 digits used by UPC-A. UPC-E is optimized for applications that require a smaller barcode and produces a compressed code with only 6 digits as opposed to 12 digits [5]. UPC-5 is a 5-digit extension to standard UPC codes used for encoding retail pricing for books. The printed symbol contains both a machine-readable part as well as a human-readable part. The structural breakdown of a typical UPC barcode is shown in Fig. 1.

The following sections provide a brief overview of the 2D symbologies evaluated for this particular project as well as a comparative summary, which may be referenced for quick interpretation.

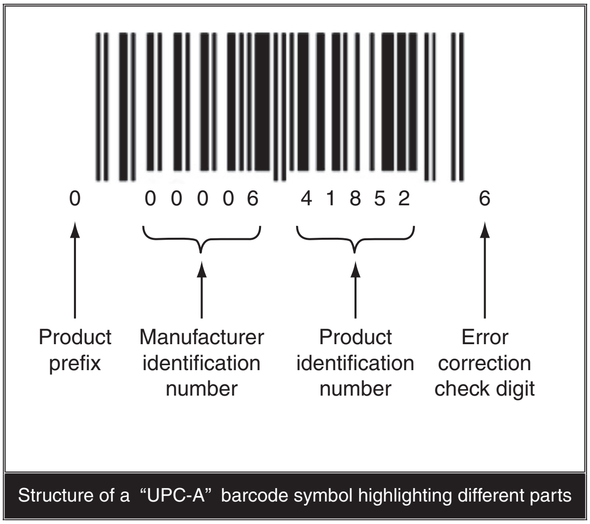

FIG. 1. UPC-A barcode structure.

2.1.1.1 The PDF417 Symbology. Portable Data File 417, though classified as a 2D barcode, is in fact a multirow, variable-length ''stacked'' symbology developed in 1992 by Symbol Technologies. This unique characteristic allows it to be decoded by many 1D hybrid scanners, apart from regular 2D scanners. The symbol is composed of 3–90 stacked rows. A PDF417 symbol character, or codeword, is the individual building block for the barcode and consists of 17 modules arranged into four bars and four spaces, thereby giving it the name of 417 [17]. The integral sections of the barcode as depicted in Fig. 2 include clearly defined *Start* and *Stop* patterns, the data columns, and the quiet zone.

PDF417 offers encoding a maximum data character capacity of 1850 text ASCII characters, 2710 numerals, or 1108 bytes [2]. This amount of data encoded is a result of the manner in which the algorithm encodes the type of data, for example, numerals require a smaller codeword size to encode than an alphabet letter (Table II).

PDF417 uses Reed Solomon error correction [6]. Error correction levels are user selectable and can be set from 0 (zero) for no error correction to 8 (eight), which is the highest level. This level indicates the amount of redundancy that is added to the encoded barcode. The benefit is the increased scan-ability; however, the downside is that the effective content size is reduced because the error correction takes up content space. Table III illustrates the specifications [2] pertaining to codewords and error correction.

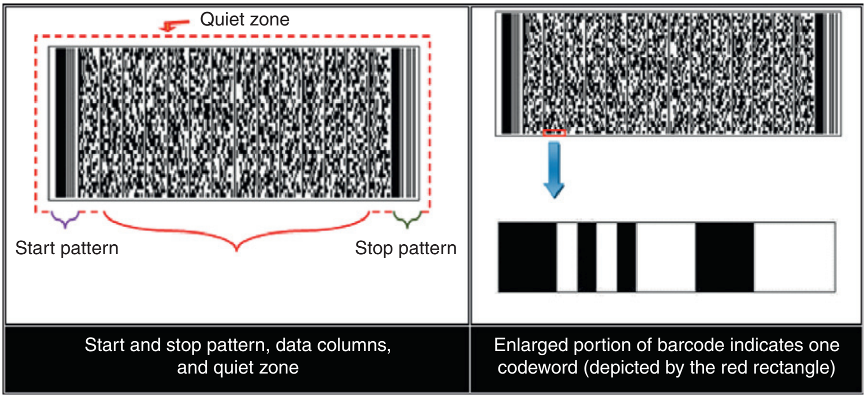

FIG. 2. PDF417 barcode characteristics.

TABLE II
PDF417 CODEWORDS PER CHARACTER TYPE

Character type	Character	Codeword
Alphabetical	1	0.5263
Numeric	1	0.3448
ASCII	1	0.8333

TABLE III
COMMONLY USED ERROR CORRECTION LEVELS FOR PDF417

No. of data codewords	Error correction level	No. of error correction codewords
1–40	2	8
41–160	3	16
161–320	4	32
321–863	5	64

2.1.1.2 The QR Code Symbology. QR Code, or Quick Response code, is a 2D matrix code created in 1994 by the Japanese Denso Corporation. As opposed to a stacked barcode, a matrix code is one in which encoding is based on the positioning of the elements or black dots in the matrix. These are among the most popular barcodes being used for mobile tagging (providing information using 2D barcodes on cell phones) applications today. The QR Code data capacity for different encodings is shown in Table IV [7].

TABLE IV
DATA ENCODING CAPACITY FOR QR CODE

Data encoding	Max. number of characters
Numeric	7089
Alphanumeric	4296
Binary	2953
Japanese Kanji characters	1817

TABLE V
QR CODE ERROR CORRECTION LEVELS

Level of error correction	Data retrievable (%) (% CW that can be restored)
Level L	7
Level M	15
Level Q	25
Level H	30

TABLE VI
DATA ENCODING CAPACITY FOR DATAMATRIX

Data encoding	Max. number of characters
Numeric	3116
Alphanumeric	2335

The QR Code uses Reed Solomon error correction and supports four different levels of error correction as detailed in Table V [29].

2.1.1.3 The DataMatrix Symbology. DataMatrix, shown in Table I, is a highly scalable 2D matrix symbology popularly used for marking small inventory articles and electronic components [18,19]. As shown in Table I, it is characterized by an ''L'' shaped centering pattern which has solid black lines along the left and bottom sides of each of its square or rectangular data regions [31]. Each data region is composed of a collection of modules arranged in an even number of rows and columns. Based on data content density, a data matrix code can have a symbol from 1 mil to 14 in. per side [26]. The newer version of DataMatrix supports Reed Solomon error correction and reconstructs data by using polynomial—over-sampling [21]. The DataMatrix Code data carrying capacity for different encodings is shown in Table VI [8].

TABLE VII
DATA ENCODING CAPACITY FOR AZTEC CODE

Data encoding	Max. number of characters
Numeric	3832
Alphabetic	3067
Bytes	1914

TABLE VIII
COMPARISON OF THE DATA CAPACITIES OF VARIOUS SYMBOLOGIES

2-Dimensional barcode symbology	Data carrying capacity (max number of characters)			
	Numeric	Alphanumeric/ alphabetical	ASCII/binary/ bytes	Japanese Kanji characters
PDF 417	2710	1850	1108	
QR Code	7089	4296	2953	1817
DataMatrix	3116	2335		
Aztec Code	3832	3067	1914	

2.1.1.4 The Aztec Code Symbology. The Aztec Code, shown in Table I, is another popular 2D matrix symbology that has been in use since 1995. Based on a square grid, its characteristic ''bulls-eye'' pattern of concentric square rings facilitates quick centering for the encoder irrespective of the barcode orientation. The grid grows in size around the bulls-eye center with additional square modules as more data are added. Based on the data content density, the symbol size varies from 15×15 to 151×151 modules per square. The Aztec Code supports Reed Solomon error correction and the permissible values are 5–95% [9].The Aztec Code data capacity for different encodings is shown in Table VII.

A quick comparison of the data capacities of these symbologies is shown in Table VIII.

2.1.2 Proprietary and Emerging Symbologies

A number of emerging 2D symbologies are optimized for high content density applications. The following symbologies were considered but not included for actual testing as they include proprietary elements that did not fit our vision of the secure credentialing project.

2.1.2.1 The Datastrip 2D Symbology. Datastrip 2D is a high-density 2-dimensional matrix symbology optimized to hold high-capacity data including encrypted color photographs and other biometric data used for secure credentialing [3,27]. It was developed by Softstrip Systems and was originally known as Softstrip. It can support a data density of up to 1000 bytes/sq. in. Its biggest advantage is that it can store large amounts of data in a fraction of the space used by other popular 2D barcode symbologies [30]. However, since certain implementation aspects were not in conformance with the project requirements, this symbology was not considered for our testing.

2.1.2.2 The HCCB Symbology. Announced at CES in 2009, Microsoft's High Capacity Color Barcode (HCCB) is currently one of the newer symbologies that was developed with the intention of enhancing the encoding of higher capacity content. Similar to the matrix barcodes, HCCB uses a grid of colored triangles referred to as symbols to encode data and has an announced capacity of encoding 3500 characters per square inch [10]. The factors that impact on this encoding amount are the grid size, the symbol density, and the number of colors used for the symbols, which is either eight or four. The actual encoding and decoding however is proprietary and must be licensed. Printing may be performed with off-the-shelf inkjet or color printers. Current usages of this symbology is limited because of its proprietary status and include the Microsoft Tag, which is a mobile tagging service that accesses product information, and the ISAN-IA, which is a version method for audio and video products. Somewhat unique to this particular symbology, the HCCB incorporates tamper-proof quality through the use of digital signing based on Elliptic Curve Cryptography. All in all, the HCCB addresses the concern of encoding higher capacities and is also rumored to be more forgiving when it comes to poor barcode image quality.

2.2 Content Density

Testing showed that data content density played an important role in the scanning reliability of 2D barcodes. Barcodes can be classified based on their data content density or capacity. For the purpose of this case study, lower content density is defined as content density, including optimum error correction, that does not exceed 50% of the theoretical data capacity limit of the respective barcode type. On the other hand, higher content density is defined as content density including optimum error correction that exceeds 50% of the theoretical data capacity limit of the respective barcode type.

2.3 Error Correction

Error correction is an important feature supported by most 2D barcode symbologies. This involves encoding additional data in the barcode that helps in reconstructing the data in case of partial damage or defect in the generated barcode. This ability to compensate for partial damage improves the credibility of barcodes as a reliable machine-readable format. There are error corrections settings associated with most symbologies with the intention of increasing the readability. However, there is a fine balance when selecting the desired setting because of an increase in the overall encoded barcode content (and a corresponding decrease in the actual information that can be encoded within the prescribed capacity limits) that results from using the error correction. One must balance this value with the string to be encoded in order to stay in line with the capacities associated with the specific symbology. Error correction levels for PDF417 and QR Code are tabulated in Table III and Table V, respectively.

2.4 Scan Grade and Reflectance Profile

A scan reflectance profile (SRP) is a collection of % reflectance values measured across a barcode by a scan line. As per the American National Standards Institute bar code print quality specification, ANSI X3.182 [11], the SRP considers the following eight parameters to obtain a scan grade:

- Edge determination
- Minimum reflectance
- Minimum edge contrast
- Symbol contrast
- Modulation
- Defects
- Decode-ability (printing accuracy as compared to the algorithm)
- Decode (pass/fail)

The minimum grade achieved by any of the parameters above represents the overall SRP grade.

2.5 Symbol Grade

The average of 10 SRP grades gives what is known as the ''Symbol Grade.'' As per the ISO/IEC 15416 and ANSI X3.182, and EN 1635 standards, these 10 scans should be conducted at different heights [16].

The numeric values and the corresponding symbol grades are defined as given in Table IX.

TABLE IX
SYMBOL GRADE AND NUMERIC VALUE CORRESPONDENCE

Numeric value (x)	Symbol grade
4.0 = x = 3.5	A
3.5> x = 2.5	B
2.5> x = 1.5	C
1.5> x = 0.5	D
0.5 > x	F

2.6 Encoder

For the purpose of this chapter, barcodes were printed using two separate encoders, viz, Bartender Enterprise edition 9.01 from Seagull Scientific and CardFive Vision 8.1 Professional from Number Five Software. While Bartender is an industry-standard software optimized for encoding barcodes, CardFive Vision is primarily an ID card design software that also supports encoding of barcodes. While initial testing suggested 100% positive results for barcodes generated using Bartender, the encoding quality achieved through CardFive was not found to be that encouraging. Hence, for reliability and consistency, all further tests including the preliminary as well as extensive tests detailed below were done using barcodes generated by Bartender. It may be noted here that apart from Bartender, any standard commercial barcode encoder may be suitable as long as the barcodes generated are of a high quality. To eliminate any potential of the encoder adversely impacting the readability, independent external testing using barcode verifiers indicated that our barcodes received a quality grading of ''A.''

2.7 Printer

The scanning reliability of barcodes is impacted significantly by the quality of printing which is determined to a great extent by the printer resolution and the type of print head being used. As per the AIM and GS1 publications [1,12], the following print considerations are important:

- The generated barcodes should always be an even multiple of printer pixels.
- There must be sufficient quiet zones around the bar code as required by the respective barcode specifications

TABLE X
COMPARISON OF PRINTER SPECIFICATIONS

Name and model number	Media type	Resolution (DPI)	Dot shape	Printing technology
Zebra S4M	Label printer	203	Square	Direct thermal
DataCard SP75	Card printer	300	Square	Dye-sublimation/resin thermal transfer
Xerox Phaser 6360 DN	Document printer	600	Round	Laser

- The distortion introduced by general-purpose printers (with round dot shape) should be catered for. The round dot-shape results in printing wider bars and narrower spaces because the printed dot size is bigger than the pixel size.

For the purpose of this case study, the following printers were used for printing the barcodes:

(i) Zebra S4M label printer
(ii) DataCard SP75 card printer
(iii) Xerox Phaser 6360 DN laser printer

A brief comparison of the relevant specifications of these printers is tabulated in Table X [13–15].

When considering the printer as a factor, it must be noted that a direct comparison of resolution alone without taking the printing technology into consideration would be misleading, since a square dot-shape produces a straight edge thus having the ability to print higher density barcodes more accurately as opposed to a printer with a round dot shape of the same DPI value. Since the direct thermal and thermal transfer technologies are optimized for printing high-capacity bar codes and since our target media for the case study was labels and PVC cards, only the first two printers mentioned above were used for most of the tests. The laser document printer was used for testing the effect of glossiness on scan reliability as it allowed a direct comparison between glossy and nonglossy media.

2.8 Media

For the purpose of this case study, we focused on our target media, viz. labels and PVC cards that are both glossy in nature. The absorbance or the optical density of the media affects the quantum of refraction and is thus another important factor that impacts on the scan-ability of the barcodes. There is a marked difference in the optical density of glossy as well as nonglossy media and though glossy media provide a much higher optical density, they also provide a higher level of reflectivity from the printed surface. While reflectivity is the fraction of incident light reflected by the surface in question; the optical density or absorbance, A, is defined as

$$A_\lambda = -\log_{10}(I/I_0)$$

where I is the intensity of the transmitted light at a given wavelength λ and I_0 is the intensity of the incident light.

To cater for the difference in absorbance and reflectivity of different media, a specific test, the ''Effect of Glossiness on scan reliability test,'' was carried out with the following two types of media:

- Normal nonglossy paper
- Glossy paper

2.9 Decoder/Scanner Characteristics

The scan reliability of barcodes is also affected by the type of scanner/decoder, or the actual hardware that will decode the encoded barcode. The scan reliability is greatly affected by the combination of the scanner light-wavelength and aperture size (size of the scanning spot relative to the bar-width) used. The angle at which scanner light is incident on the surface affects the reflectance. Light incident at 45° to the surface will minimize reflection from glossy surfaces, thereby producing optimum scan reliability. As per the Layman's guide [1], variations in these two parameters might drastically alter the overall scan grade quality (Table XI).

As per GS1, a global leader involved in the design and implementation of standards including those of bar codes, depending on scanner technology, there are six functional bands. For optimum scan-reliability, scanners should be chosen on the basis of applications that pertain to these bands [12].

TABLE XI
SCAN GRADE W.R.T. APERTURE DIAMETER AND WAVELENGTH

Aperture diameter (mil)	Aperture diameter (mm)	Wavelength (nm)	Scan grade	Quality
5	0.125	633	1/D	Poor
10	0.25	633	3/B	Good
10	0.25	900	0/F	Fail

TABLE XII
COMPARISON OF SCANNER SPECIFICATIONS

Characteristic	Symbol DS 6707SR	Symbol DS 3478
Light source	650-nm laser diode	650-nm laser diode
Field of view	40° horizontal	30° horizontal
	30° vertical	22.5° vertical
Yaw tolerance	±60° from nominal	±50° from nominal
Pitch tolerance	±65° from nominal	±60° from nominal
Roll tolerance	±360° from nominal	±180° from nominal

Since Motorola (a.k.a. Symbol) scanners possess a majority of the scanner hardware market share; the following two different Symbol scanners were used for testing:

- Symbol DS 6707SR wired scanner with SE6707 scan engine
- Symbol DS 3478 wireless scanner with SE4400 scan engine

The specific difference between these two scanners is the embedded scan engine, which is the heart and soul of the scanner and responsible for the actual decoding process [22, 23]. A brief comparison of the technical specifications that are directly relevant to our tests is given in Table XII.

3. Testing Methodology

Our comprehensive testing involved internal as well as external testing. The internal testing methodology, which is described in Section 3.1, used a series of carefully designed tests to evaluate the impact of various parameters that influence barcode scanning reliability. The internal testing comprised several stages including preliminary sampling followed by more extensive testing with the results of each test leading to the need for the successive tests.

The external testing, which is described in Section 3.2, was used to assess the quality–grade of the barcodes by using an independent and verifiable industry standard process. This external testing augmented the internal testing where resources were not available to actually perform the testing.

3.1 Internal Testing

To provide a point of reference and for the sake of comprehensive testing, 1D as well as 2D barcodes with lower content density were also tested. Since the focus of this paper is higher capacity barcodes, the results of the lower capacity testing are mentioned without going into further details. Testing was performed by performing individual scans, termed iteration, of the sample barcodes and then calculating success rate, which is called the barcodes *scan-ability*.

3.1.1 Barcodes with Lower Content Density

Multiple scan iterations using different types of scanners as well as encoders for all 1D as well as lower content density 2D barcodes tested produced 100% scan reliability.

3.1.2 Barcodes with Higher Content Density

Samples of various barcode symbologies were subjected to preliminary testing involving twenty scan-iterations each and all samples that achieved a scan reliability of 40% or more were then subjected to extensive testing involving fifty scan-iterations each. The testing methodology is explained in detail in the succeeding sections.

3.1.2.1 Preliminary Testing. In order to narrow the scope of viable barcodes, and based on the specific requirements of our project wherein the physical print size was a limiting factor, the four commonly used 2D barcodes (Table XIII) were encoded for preliminary testing. This test involved twenty scan iterations of each barcode sample and the result was a percentage of successful scan

TABLE XIII
PRELIMINARY TESTING

S. No.	Barcode type	Scanning reliability
1	PDF417 9.8 mil 2x, 13 col EC : 6	95 %
2	QR cvode 14.8 mil error correction M (15%)	90 %
3	Aztec 14.8 mil with error correction 40%	45 %
4	Aztec 14.8 mil with error correction 45%	80 %
5	Aztec 19.7 mil (no image)	90 %
6	DataMatrix 14.8 mil with ECC 200	50 %
7	DataMatrix 9.8 mil	0 %

reliability. This preliminary scan test served as a smoke test to provide a quick initial point of reference, based on a wide range of possible barcodes and the settings associated with each particular barcode. In particular, the suggested settings for each symbology were used to encode the barcode.

Based on the results of this preliminary testing, the low-performing barcode namely *DataMatrix 9.8 mil* (S. No. #7) was eliminated from further testing. On the other hand, for the mediocre-performing *Aztec 14.8 mil with error correction 40%* (S. No. #3), an additional sample with a 50% error correction was added for further testing. Similarly, an additional *QR Code sample with an error correction of 30%* was also included for further testing.

3.1.2.2 Extensive Testing. This involved fifty scan iterations for each sample barcode and enumerating the results as a percentage scan reliability value. The number of scans was suggested by the scanner vendor as being sufficient to successfully sample the success rate. For a better understanding of scan results and to ensure that our testing results were not biased by the use of only one type of scanner, reliability was enumerated separately for different scanners, viz. the Symbol DS 6707SR (SE6707) wired and the Symbol DS 3478 (SE4400) wireless scanners. For the purpose of this testing, a ‘‘good scan’’ is defined as a successful scan in less than 2 s, a ‘‘delayed scan’’ is a successful scan that takes 2–7 s, and a ‘‘No scan’’ is failure to scan even after 7 s. The delayed scan measurement was introduced to account for the fact that while not actually a ‘‘No Scan,’’ longer than a 2-s scan time is less than optimal in a deployed situation; however, the tracking of such scans becomes valuable for measurement when longer scan times are acceptable. Delayed scans are acting as a buffer between the two possibilities.

3.1.2.2.1 Reliability testing. The first in a series of specific extensive tests, ‘‘Reliability Testing’’ involved extensive scanning of different types of 2D barcodes, viz. the PDF417, DataMatrix, Aztec, and QR Code with both the scan engines. The goal of reliability testing was to identify barcode symbologies along with the corresponding scan engine that produced the highest percentage scan reliability.

These test results, summarized in Table XIV with the relevant rows highlighted with the arrow marking 🡸, indicate that PDF417 9.8 mil 13 col, error correction: 6 with SE6707 and QR Code 14.9 mil, error correction (30%) with SE4400 emerged as the most reliable scans, which were then subjected to further testing.

3.1.2.2.2 Content density testing. Having shortlisted PDF417 and QR Codes based on the reliability testing results, each of the two barcode symbologies was subjected to rigorous ‘‘content density testing.’’ The purpose of this test was to determine the impact of the content density on the scan reliability of the barcodes.

TABLE XIV
RELIABILITY TESTING

Symbology	Scan engine	% Good scan	% Delayed scan	% No scan	
PDF417 9.8 mil 13 col EC:6 (label)	SE6707	94%	6%	0%	←
	SE4400	68%	22%	10%	
QR code 14.8 mil error correction M (15%) (Label)	SE6707	60%	38%	2%	
	SE4400	70%	18%	12%	
QR code 14.8 mil, error correction M (15%) (Card)	SE6707	40%	38%	22%	
	SE4400	82%	16%	2%	
QR code 14.8 mil, error correction (30%) (card)	SE6707	56%	32%	12%	
	SE4400	94%	2%	4%	←
Aztec 14.8 mil with error correction 40% (label)	SE6707	60%	26%	14%	
	SE4400	32%	10%	58%	
Aztec 14.8 mil with error correction 45% (label)	SE6707	70%	22%	8%	
	SE4400	32%	12%	56%	
Aztec 14.8 mil with error correction 50% (label)	SE6707	52%	36%	12%	
	SE4400	22%	8%	70%	
Aztec 19.7 mil (no image) (label)	SE6707	60%	26%	14%	
DataMatrix 14.8 mil with ECC 200 (label)	SE6707	28%	48%	24%	

We designed different capacity barcodes ranging from 162 bytes to 929 bytes. The different byte sizes were selected based on the specific requirements of the project and thus subsequent test samples do not have a uniform data capacity difference.

In Table XV, the rows indicating test results for a data capacity of 844 bytes are highlighted with the arrow marking, ← as that is the preferred data capacity for our project. This test indicated that for PDF417, the scan reliability starts dropping after content density increases more than approx. 60% when the wireless scanner (SE4400) is used. However, the content density has no effect whatsoever on scan reliability with the wired scanner (SE6707).

For the QR Code, the testing indicated a substantial drop in scan reliability as the content density increased to more than 844 bytes with either the SE6707 or SE4400 Scan Engines (Table XVI). This indicates mixed results for the effect of content density on scan reliability of QR Code. There is a trend toward a decrease in the reliability as the content of the barcode increases. The success rate is higher with the

TABLE XV
CONTENT DENSITY TESTING FOR PDF 417

SE 4400	Size in bytes, %capacity	% Good scan	% Delayed scan	% No scan	
PDF4179.8 mil EC = 6	162, 14%	100%	0%	0%	
	224, 20%	100%	0%	0%	
	492, 45%	98%	2%	0%	
	625, 56%	100%	0%	0%	
	694, 63%	96%	2%	2%	
	844, 76%	88%	8%	4%	←
	929, 84%	78%	16%	6%	
SE 6707	**Size in bytes, %capacity**	**% Good scan**	**% Delayed scan**	**% No scan**	
PDF4179.8 mil EC = 6	162, 14%	100%	0%	0%	
	224, 20%	100%	0%	0%	
	492, 45%	100%	0%	0%	
	625, 56%	100%	0%	0%	
	694, 63%	100%	0%	0%	
	844, 76%	100%	0%	0%	←
	929, 84%	100%	0%	0%	

wired scanner when one takes into account the delayed scans because in essence these are successful scans though just not as ideal.

3.1.2.2.3 Error correction level based testing for QR Code and PDF417. To fine-tune the results of the previous test and to achieve high scan reliability with high content density barcodes, the required 844 byte samples (of PDF417 and QR Code) were tested with different levels of error correction encoded into them. The purpose of this test was to determine the impact of error correction level on the scan reliability of the 2D barcodes. For QR Code, samples with a content density of 844 bytes with error correction levels of 7%, 15%, 25%, and 30% were tested. The results are tabulated in Table XVII.

The rows highlighted with the arrow marking ← indicate the best scan results for the two different scanners. It was observed that the size of the actual barcode, not just the amount of data, seemed to play a role in the scanning reliability. It was observed that barcodes with a 30% error correction were so big that it seemed to

TABLE XVI
CONTENT DENSITY TESTING FOR QR CODE

QR code 14.8 mil EC = 15%	Size in bytes	% Good scan	% Delayed scan	% No scan	
SE 4400	162	98%	2%	0%	
	224	94%	6%	0%	
	492	66%	22%	12%	
	625	92%	6%	2%	
	694	96%	2%	2%	
	844	76%	12%	12%	←
	929	44%	24%	32%	
SE6707	162	100%	0%	0%	
	224	92%	8%	0%	
	492	88%	12%	0%	
	625	50%	46%	4%	
	694	74%	26%	0%	
	844	82%	18%	0%	←
	929	46%	48%	6%	

adversely affect the scan reliability. Based on data content requirements of the present project, our recommendation is to use 25% error correction to achieve optimum scan reliability.

For PDF417, samples with a content density of 844 bytes with error correction levels of 3, 4, 5, and 6 were tested with both the scan engines. The results are tabulated in Table XVIII.

For PDF417, the results indicate that the higher the error correction, better the scan reliability.

3.1.2.2.4 Effect of Glossiness on scan reliability. After taking into consideration the primary factor of data content density, we shifted our focus to other secondary factors that impact on the scan reliability of barcodes. Since the primary technique used by most 2D scanners is imaging, which involves taking a photo of the barcode before trying to decode it, the difference in absorbance and reflectivity of glossy and nonglossy media impacts on their readability. The purpose behind this

TABLE XVII
IMPACT OF ERROR CORRECTION LEVEL FOR QR CODE

QR Code 844 Bytes	Error correction	% Good scan	% Delayed scan	% No scan	
SE 6707	7%	88%	12%	0%	
	15%	84%	16%	0%	
	25%	98%	2%	0%	←
	30%	60%	40%	0%	
SE 4400	7%	90%	10%	0%	
	15%	88%	10%	2%	
	25%	92%	6%	2%	←
	30%	74%	20%	6%	

TABLE XVIII
IMPACT OF ERROR CORRECTION LEVEL FOR PDF 417

PDF417 844 bytes	Error correction	% Good scan	% Delayed scan	% No scan	
SE6707	3	84%	16%	0%	
	4	94%	6%	0%	
	5	98%	2%	0%	
	6	98%	2%	0%	←
SE4400	3	26%	26%	48%	
	4	60%	18%	22%	
	5	78%	14%	8%	
	6	86%	10%	4%	←

test was to determine the potential impact of the finish of the physical media, in particular glossy versus nonglossy, on the scanning reliability. To resolve this concern, the symbologies were scanned separately on a ''glossy'' as well as a ''nonglossy'' media. The results are tabulated in Table XIX.

3.1.2.2.4.1 Effect of glossiness testing for QR Code 844 bytes data capacity. The highlighted rows indicate the best scan reliability for glossy as well as nonglossy paper using different scan engines. The results indicate a clear drop in the scan reliability of QR Code barcodes when printed on glossy surface (cards as well as labels) as compared to nonglossy plain surface.

3.1.2.2.4.2 Effect of glossiness testing for PDF417 844 bytes data capacity. The test results indicate a significant degradation in the scan reliability on glossy surface compared to nonglossy surface at lower error correction levels for the SE6707 as shown in rows highlighted by a ⌫ marking. For the SE4400, the corresponding rows highlighted by the arrow marking ← indicate significant degradation in the scan reliability on glossy surface at all levels of error correction (Table XX).

3.1.2.2.5 Comparison of target media (card and label) with optimal scan settings. Since our target media (label or PVC card) are glossy, we decided to do yet another test to determine which of the two target media (card or label) produced a

TABLE XIX
EFFECT OF GLOSSINESS TESTING FOR QR CODE

Non-glossy paper	Error correction	% Good scan	% Delayed scan	% No scan	
SE 6707	7%	88%	12%	0%	
	15%	84%	16%	0%	
	25%	98%	2%	0%	←
	30%	60%	40%	0%	
SE 4400	7%	90%	10%	0%	
	15%	88%	10%	2%	
	25%	92%	6%	2%	←
	30%	74%	20%	6%	
Glossy paper	**Error correction**	**Good scan %**	**Delayed scan %**	**No scan**	
SE6707	7%	70%	28%	2%	
	15%	70%	30%	0%	←
	25%	66%	34%	0%	
	30%	44%	44%	12%	
SE4400	7%	96%	4%	0%	
	15%	98%	2%	0%	←
	25%	82%	14%	4%	
	30%	44%	20%	36%	

better scan reliability. It may be pertinent to mention here that there is a difference not only in the glossiness of the media (card and label) but also in the printing quality as cards were printed using the DataCard SP75 card printer while the labels were printed using the ZebraS4M label printer having different characteristics (as mentioned in Section 2.7).

These results in Table XXI indicate that PDF417 is the better choice for labels; however, for badges, the wireless scanner produced identical scan reliability results of 76% for both PDF417 and QR Code.

TABLE XX
EFFECT OF GLOSSINESS TESTING FOR PDF 417

Media	Scan engine	Error correction	% Good scan	% Delayed scan	% No scan	
Non glossy	SE6707	3	94%	6%	0%	⌫
		4	100%	0%	0%	
		5	98%	2%	0%	
		6	100%	0%	0%	
	SE4400	3	50%	30%	20%	
		4	80%	14%	6%	
		5	94%	4%	2%	
		6	94%	4%	2%	←
Glossy	SE6707	3	84%	16%	0%	⌫
		4	94%	6%	0%	
		5	98%	2%	0%	
		6	98%	2%	0%	
	SE4400	3	26%	26%	48%	
		4	60%	18%	22%	
		5	78%	14%	8%	
		6	86%	10%	4%	←

3.2 External Testing

In order to address the potential for the encoder or the printers to influence the performed testing, it is necessary to set a baseline for the quality of created barcodes. This took the form of grading the test samples that was performed independently and externally by Motorola Technical and Engineering Services using barcode verifiers and they confirmed the quality of the internally encoded barcodes as ''Grade A.'' This eliminates the potential of encoder and printer errors on the scan reliability of the barcodes.

TABLE XXI
COMPARISON OF TARGET MEDIA

Symbology	Scan engine	Media printed on	Good scan %	Delayed scan %	No scan %
PDF 417 844 EC 6	SE 6707	Label	99%	0%	1%
		Card	96%	4%	0%
	SE 4400	Label	98%	2%	0%
		Card	76%	12%	12%
QR code 844 14.8 25%	SE 6707	Label	52%	40%	8%
		Card	52%	36%	12%
	SE 4400	Label	64%	10%	26%
		Card	76%	14%	10%

4. Conclusion

For our target material (card or label, which are both glossy), and with a data content capacity of 844 bytes,

- The best case scenario is a 96–99% scan reliability for cards and labels, respectively, using PDF417 Barcodes with the SE6707 scan engine.
- The scanning reliability of PDF417 with the SE4400 scan engine varied from 76% for cards to 98% for labels.
- For QR Code with 844 bytes and 25% error correction, the SE4400 scan engine produced a success rate of 76% for cards and 64% for labels, whereas the SE6707 Scan engine produced a success rate of 52% for both labels and cards.

These results are summarized in Table XXII.

Comparing these results to the standards for each of the tested symbologies, theoretically they are capable of encoding high content-data; however, testing showed that the content for readable symbols was greatly impacted by many factors. The results thus indicate that for our specific application, the scan reliability of PDF417 barcodes was much better than that of QR Code barcodes with high-capacity data encoding (more than 800 bytes) printed on glossy media and read using either SE6707 scan engine or SE4400 scan engine.

TABLE XXII
SUMMARY OF RESULTS

Rank	Scan-reliability	Symbology	Scanner	Media
Best	99%	PDF 417	SE 6707	Label
2nd	98%	PDF 417	SE 4400	Label
3rd	96%	PDF 417	SE 6707	Card
4th	76%	QR Code	SE 4400	Card
5th	76%	PDF 417	SE 4400	Card
6th	64%	QR Code	SE 4400	Label
Worst	52%	QR Code	SE 6707	Card & Label

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