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2D in Retail – Tier 3.2 Test Report

2D Barcode Scanning: X-dimension Stress Test

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Contributors

Name	Organisation
Kevin Berisso	University of Memphis
Rajesh Balasubramanian	University of Memphis
Joshua Edwards	University of Memphis
Christopher Madlinger	University of Memphis
Robert Glover	University of Memphis
Vamshidhar Cherumani	University of Memphis
Kurt Hecht	SME - DBA moon3.14.tech
Amber Walls	GS1 US
Gena Morgan	GS1 US
Vivian Underwood	GS1 US
Carrie Wilkie	GS1 US
Dan Mullen	GS1 Global Office
Robert Beideman	GS1 Global Office
Steven Keddie	GS1 Global Office

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1 Introduction

Globally, stakeholders are adopting 2D barcodes that contain more data encoded in different data structures, known as syntaxes. Retail environments have largely already deployed high-volume point-of-sale (POS) solutions capable of scanning 2D barcodes. The environment is poised to enable 2D on retail packaging for POS processes. However, details on scanning system capabilities and best practices for scanning 2D barcodes in retail are unclear in some areas. Unbiased, independent data remains critical in support of:

- Retail scanner improvements
- Key retail sector questions
- Scalable, interoperable solutions that leverage the data capacity of 2D barcodes

GS1 is working with retail scanner manufacturers and conducting tests to quantify the performance of 2D barcodes in retail POS scenarios. This report covers the fourth iteration of this testing.

The University of Memphis Automatic Identification Lab has been engaged to conduct unbiased, independent testing to establish common baselines on a variety of barcodes to understand how they scan on existing POS hardware.

Tier 1 testing focused on linear and 2D barcodes with only a Global Trade Item Number (GTIN) contained within them. Tier 1 determined the baseline scanning performance of 2D barcodes to compare against current EAN/UPCs on-pack. Tier 2 testing was an incremental challenge for the scanner solution providers, requiring them to decode linear and 2D barcodes containing GTIN plus additional data (GTIN+). Tier 3.1 testing investigated the performance impacts of co-located symbols on products, while retaining the GTIN+ data used in Tier 2 in addition to supporting GS1 Digital Link URI syntax.

- **Note:** The full Tier 1 report was published in May 2022. The Tier 2 report was published in July 2022. The Tier 3.1 report was published in December 2022. All reports can be found, alongside other 2D barcode resources, at *https://www.gs1.org/industries/retail/2D-barcodes*.

Tier 2 and 3.1 testing confirmed that updated scanner software could convert barcodes encoded with GS1 Digital Link URI syntax to GS1 element string syntax. This ensured that retailer POS systems could process GS1 Digital Link URI syntax without requiring out of cycle system upgrades. The syntax conversion capability was included in the Tier 3 software update.

At the conclusion of Tier 3.1, there remained the question of how the updated software would handle smaller X-dimensions[1] that fall below the current GS1 General Specifications standards (Figure 5.12.2.6-1). The existing testing setup from Tier 3.1 was used with a new set of test cards that isolated the X-dimension of the barcodes, and the test identifier was incremented to Tier 3.2.

For those transitioning to 2D barcodes before 2027, items will need to be marked with both an EAN/UPC or GS1 DataBar retail family barcode and 2D barcode, as 2D readiness will vary at POS and in other scanning environments. However, the available space for the barcodes on the packages is not able to be modified for all products and there is a desire to decrease the size of the barcodes to fit both a linear and 2D barcode on-pack, in addition to ongoing requests to reduce the size of barcodes overall.

The Tier 3.2 testing outlined in this report, aims to determine the impacts of X-dimension on performance in POS retail scanning environments and to answer three important questions:

1. Can the size of an EAN-13, UPC-A or a retail 2D barcode be reduced to fit within the dimensions of today's smallest allowable UPC-E or EAN-8 and will the barcodes be capable of retail scanning requirements?

[1] X-dimension refers to the width of the narrowest bar or space in a linear barcode and individual module in a 2D barcode.

Figure 1-1[2]**.** From left to right, UPC-E symbol sized at 0.264 millimetre (0.0104 inch), followed by a QR Code (GS1 Digital Link URI) sized at 0.297 millimetre (0.0117 inch), a QR Code (GS1 Digital Link URI) sized at 0.396 millimetre (0.0150 inch) and a UPC-A sized at 0.140 millimetre (0.0055 inch). The dotted lines indicate the space a UPC-E requires, including Quiet Zones.

2. Will an EAN/UPC barcode and 2D barcode fit in the space of an EAN/UPC barcode printed at 0.25 mm (0.010 inches) and will barcodes be capable of retail scanning requirements?

Figure 1-2[3]. UPC-A symbol sized at 0.264 millimetre (0.0104 inch) compared to a combination of a QR Code (GS1 Digital Link URI) sized at 0.264 millimetre (0.0104 inch) and UPC-A symbol sized at 0.169 millimetre (0.0067 inch) for placement within the same space. The dotted line indicates the space a UPC-A requires, including Quiet Zones.

3. What is the smallest viable X-dimension size for the retail point-of-sale scanning environment?

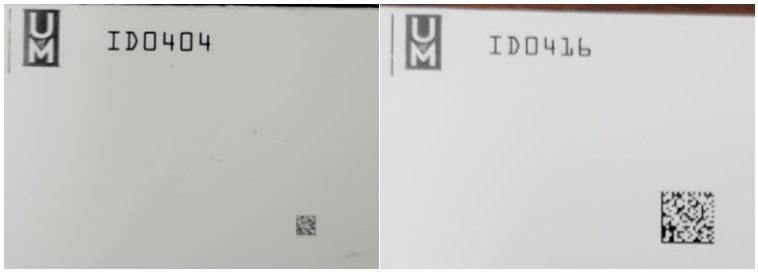

Figure 1-3. Example of a small X-dimension 0.169 millimetre (0.0067 inch) barcode test card next to a 0.466 millimetre (0.0183 inch) barcode test card. The test card on the right represents a size currently allowed in the GS1 General Specifications.

The Tier 3.2 tests were designed to evaluate if recent software updates made to bi-optic scanners from major manufacturers can sufficiently decode smaller linear barcodes and 2D barcodes at retail speeds. One of the five scanners under test had no software updates and represents how an unchanged scanner would react to decoding smaller X-dimension linear barcodes and 2D barcodes at retail speeds.

The testing included:

- Linear and 2D barcodes encoded with GS1 syntaxes (i.e., plain, GS1 element string, GS1 Digital Link URI) with expiration date and batch/lot number. For GS1 Digital Link URI syntax barcodes, a domain name is also included.
- Varying linear barcode X-dimension sizes from 0.084 millimetre (0.0022 inch) to 0.330 millimetre (0.0130 inch)

[2] Scale is approximate.
[3] Scale is approximate.

- Varying 2D barcode X-dimension sizes 0.127 millimetre (0.0050 inch) to 0.508 millimetre (0.020 inch)
- Variables including barcode orientation, speed, angle and distance from the scanner

2 Executive summary

As industry continues to migrate to 2D barcodes at retail point-of-sale (POS), the area available on some packages for barcode placement has been a concern. To support determination of whether barcodes can be made smaller and still successfully scan, a series of tests isolating how size impacts barcode performance were defined, executed and analysed. Tests were conducted within a controlled environment using five retail POS bi-optic barcode scanners from three manufacturers to capture data. This data was required to evaluate the scan performance of barcodes that were specifically designed to test the impact of X-dimension size.

Tier 3.2 testing resulted in the following answers to key industry questions:

- Can the size of an EAN-13, UPC-A or a retail 2D barcode be reduced to fit within the dimensions of today's smallest allowable UPC-E or EAN-8 and will the barcodes be capable of retail scanning requirements?
  - EAN-13 and UPC-A barcode X-dimension sized to fit within an EAN-8 or UPC-E could **not** reliably be scanned at the 40+ items per minute (IPM) required for retail point-of-sale (POS).
    - The scan rates were as low as 60% for items crossing the POS scanner at 150 mm/min, 36 IPM.
  - GS1 DataMatrix and QR Code (GS1 Digital Link) encoded with data used in retail fresh food use cases of 36 and 61 characters respectively **can** fit within the space currently used by EAN-8/UPC-E and be scanned reliably at greater than 40 IPM.
- Will an EAN-13/UPC-A barcode and 2D barcode fit in the space of an EAN-13 or UPC-A barcode printed at 0.25 mm (0.010 inches) and will barcodes be capable of retail scanning requirements?
  - Scanners could **not** reliably read individual barcodes sized to fit both an EAN-13 or UPC-A and retail 2D barcode within the current minimum size of EAN-13/UPC-A allowed in the GS1 General Specifications for retail POS use.
    - The scan rate was as low as 56% for linear barcodes and 0% to 19% for 2D barcodes crossing the POS scanner at 150 mm/min, 36 items per minute.
- What is the smallest viable X-dimension size for the retail point-of-sale scanning environment?
  - The current minimum GS1 General Specifications X-dimension of 0.264 mm (0.0104 inches) for linear and 0.396 mm (0.0150 inches) for 2D barcodes are still most appropriate for todays of bi-optic scanners.
    - Barcode scan rate performance began to drop below acceptable retail POS levels at approximately the minimum X-dimension for both linear and 2D barcodes.

Additional, noteworthy observations include:

- The orientation of linear barcodes when being read impacts scan performance. It is believed this is due to motion blur that occurs during scanning motions. While this can occur with all linear barcodes, the negative impact is magnified as the X-dimension decreases.
- As with previous iterations of 2D in Retail testing, there was a noticeable difference observed where QR Code performed better than GS1 DataMatrix. Note that GS1 DataMatrix is fully appropriate for retail POS use and the performance differences between 2D barcode options will continue to be explored in future iterations of testing.

  - **Important**: Older scanners with slower processors or lower resolution cameras may not have similar results. Lower print quality for smaller X-dimension barcodes will also impact the results found in Tier 3.2 testing. In addition, real-world environmental

factors such as lighting and human movement may result in lower scan performance than what has been captured in the controlled environment. Lowering X-dimensions below what is currently defined in the GS1 General Specifications is likely to cause poor barcode performance.

This report is the result of the collaborative efforts of solution providers in the barcode label software sector, the printing and retail scanning sectors, the University of Memphis and GS1. The scanner tests described herein were designed to support solution providers, brand owners and retailers in the transition to 2D barcodes with GS1 data structures at retail point-of-sale.

3 Methodology

Like the previous Tier 1, Tier 2, and Tier 3.1 tests, Tier 3.2 testing was an iterative process where sample barcodes were subjected to a series of incremental tests selected to allow the research team to isolate and analyse the impacts of various real-world variables (e.g., X-dimension, angle of barcode relative to the scanner, which camera was doing the decoding, etc.). The selection of the variables and the number of permutations of each variable were made with input from various GS1 workgroups and discussions with solution providers, brands and retailers.

The primary test design considerations were:

- The 2D barcodes needed to encode GTIN plus additional data attributes (GTIN+) in the format required by the barcode and syntax.
- The use of consistent and repeatable printing methods and materials ensured quality was representative of real-world barcodes. Barcodes were printed on standard width 6X3 inch labels using a 600 dpi thermal transfer printer with resin ribbon.
- The use of the current-generation retail scanners listed below. All scanners were reset to factory default settings and then four scanners had Tier 3.1 software updates and specific configurations applied (i.e., data formatting, communications ports, etc.). One scanner was left at factory default.
  - Datalogic (9400i and 9800i)
  - NCR (RealScan 7879)
  - Zebra (MP7000, MP7001)
- The test data must be as statistically robust as previous tests.

> **Note**: In this report the scanners are given aliases (Alpha#, Beta#, Delta#, etc.). The aliases are the same as in previous Tier 1, 2, and 3.1 reports.

3.1 Test profile overview

Tier 3.2 testing, similar to the previous Tiers, used a variety of testing scenarios, called "test profiles", that were determined through a series of beta tests, historic tests and use of rules and standards outlined in the GS1 General Specifications. Test profiles are detailed below. For Tier 3.2, the same thirty-eight tests from Tier 3.1 were run on updated test cards to understand how barcodes would read when the X-dimension was reduced beyond the current General Specification standards (see B Annex: Test profiles). The thirty-eight tests consisted of nineteen unique test profiles, each run under two different barcode decoding (i.e., auto-discrimination) configurations.

Both the variation of parameters in the test setup and the variation of barcode characteristics are important to ensure a robust understanding of how a range of barcodes will perform outside of the lab environment. Below is an outline of the parameter variations that were used in the Tier 3.2 testing. A detailed spreadsheet of the barcodes is available as an appendix to this report. See A Annex: Tier 3.2 barcodes.

The nineteen test profiles varied by:

1. Distance (~12.5 mm and 55 mm from scanner horizontal and vertical surfaces)

2. Horizontal offsets (scanner optimal scan location, optimal +25 mm, optimal -25 mm)
3. Speed (from 150 mm/s to 1,200 mm/s)
4. Pause (movement/travel at 1200 mm/s with 0.25 second stop)
5. Tilt angle from horizontal (0°, 45°, 90°)
6. Clockwise rotation in plane (0°, 45°, 90°, 180°)
7. Barcode decoding algorithms that were activated/enabled in the scanners
    a. Linear and 2D barcodes (EAN-13, UPC-A, GS1 DataBar Expanded Stacked, GS1 DataMatrix, Data Matrix (GS1 DL URI) QR Code (GS1 DL URI))
        i. Configuration 1: EAN/UPC, GS1 DataBar Expanded Stacked, GS1 DataBar Omnidirectional, Data Matrix and QR Code
        ii. Configuration 2: EAN/UPC, GS1 DataBar Expanded Stacked, GS1 DataBar Omnidirectional, Data Matrix, QR Code, ITF-14, PDF417, Code 128, ISBN, digital watermark

3.2 Test rig design

Tier 3.2 used the same test rig (see Figure 3-1) that was used in Tier 3.1. Five tabletop bi-optic, imager-based scanners were used for the test. Custom Microsoft .NET software and a simple database were developed for collecting scan data. All scanners were configured with physical RS-232 serial or USB serial connections and a computer with multiple serial ports.

To ensure timing consistency, photoeye sensors were tied to the computers and the custom software was configured to capture the photoeye events. Each computer has only one scanner and one photoeye connected. The leading edges of the scan windows and sensors were optimised to each scanner/sensor combination. Finally, the scan path for the samples was adjusted to comply with specific test profiles.

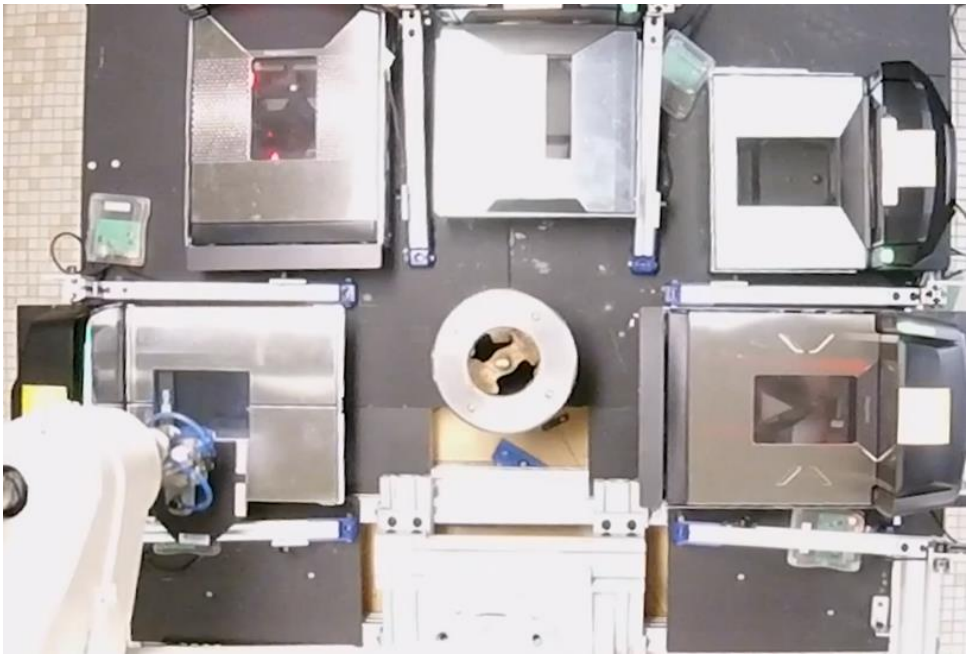

Figure 3-1 Scanning setup with robotic arm and POS scanners

The determination of the optimal test paths was conducted by determining the 2D barcode read zones for each scanner and then overlaying them so that a single common read zone was generated (see Figure 3-2 below).

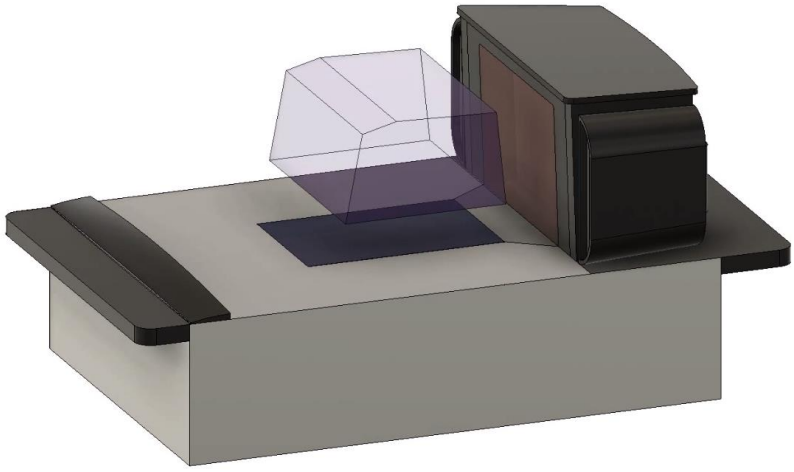

Figure 3-2 Optimal common 2D scanning envelope (transparent shape)

Based on the optimal, common path, locating fixtures were created to ensure proper robot positioning. Scanner-specific horizontal plates and common 45° and 90° plates were created to aid in the positioning on the scanners (see Figure 3-3 below).

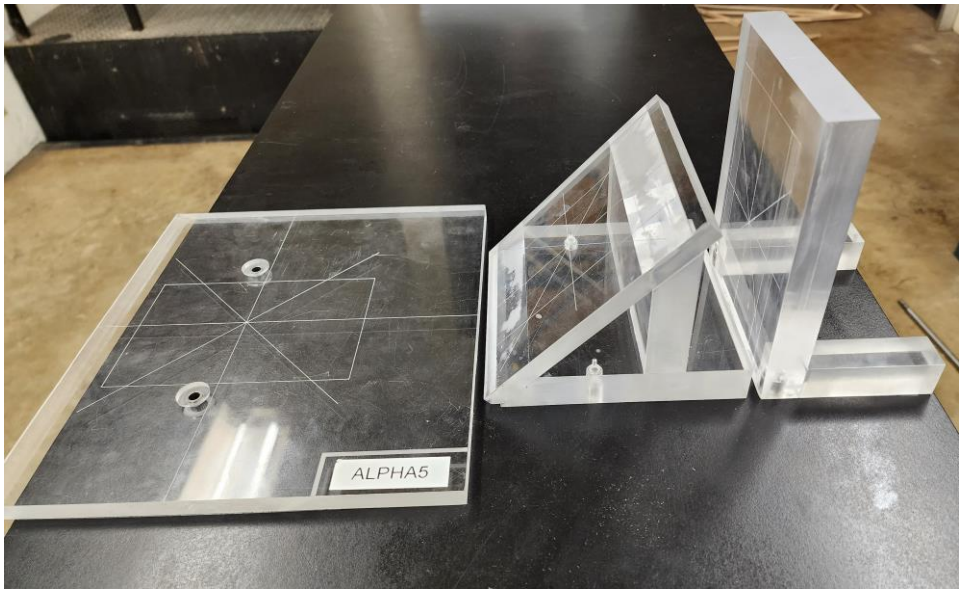

Figure 3-3 Robot positioning fixtures

3.3 Sample preparation

All test barcodes were mounted on fibreboard test cards. The Tier 3.2 test cards were based on the Tier 3.1 cards. Unique card identifiers were associated to each test card to allow for the definitive identification (ID) of the test cards themselves as well as ensuring the encoded data was unique for each card. Barcodes were verified to report their print quality, which was additional data used to correlate and analyse scan results (see A Annex: Tier 3.2 barcodes).

Figure 3-4 Example of Tier 3.2 test cards

The barcodes tested in Tier 3.2 were:

- Linear barcodes:
  - UPC-A (plain syntax) – EAN/UPC
  - EAN-13 (plain syntax) – EAN/UPC
- 2D barcodes:
  - GS1 DataMatrix (GS1 element string syntax) – GS1 DM
  - QR Code (GS1 Digital Link URI syntax) – QR Code
- For GS1-based encodings/syntaxes, data element combinations include:
  - GTIN, batch/lot number and expiration date
  - GTIN, batch/lot number, expiration date and domain name

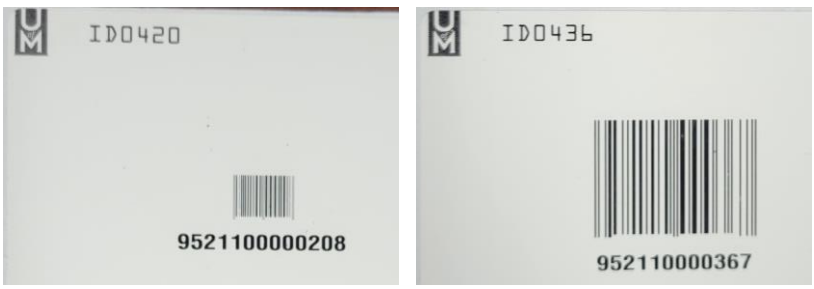

Figure 3-5 Example of size differences used in Tier 3.2 test cards

3.4 Testing process

Testing was conducted by a single robot that would pick up a single test card, present the unique test card identification (ID) number to an optical character recognition (OCR) scanner and then pass the test card with the barcode over each of the five bi-optic POS scanners.

Scanning speed was maintained by the robot and the scan path was repeatable to within about 0.01 mm at any given point. The robot ran at the defined speed required for each test profile. Every test card was run through the test profiles ten times to maximise our ability to analyse the resulting data and to ensure that we could identify any anomalous runs.

The programmed robot was responsible for managing the test profiles, including card pick-up, rotation and tilt angle. Optical photoeye sensors detected the card entering the scanner and triggered the data acquisition system timers.

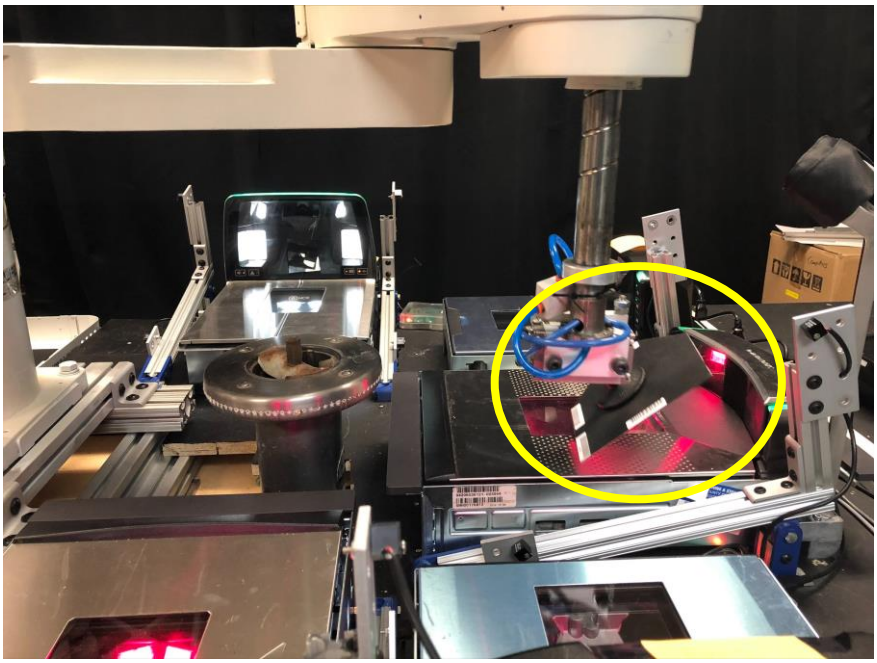

Figure 3-6 Bi-optic scanner with a card presented at 45° angle from horizontal

The scan count, scan time (time from trigger to data transmission time) and scanner decode data were all captured. Decoded data was compared to the expected data, based on the identification of the test card's carrier ID. All data was stored on local test lab servers.

3.5 Limitations

Tier 3.2 testing passed the test cards over each scanner within a consistent field of view (scan window) that was normalized across all scanners. These fields of view are optimised for single barcodes. Additionally, all samples were printed with a 600 dpi thermal transfer printer. It is understood that this may not be the ideal printing method for the smaller X-dimension barcodes.

- **Important:** This limitation may have impacted the Tier 3.2 data due to the nature of the tests and the fact that the cards were manually produced with a 0.5 mm variation in barcode positioning on the cards.

4 Test results and observations

A global solution provider community came together with GS1 to develop solutions to identify the X-dimension range to be tested. To answer key questions, a selection of targeted X-dimensions was specifically identified, along with the in-house printing capabilities available to the AutoID Lab. All scanner performance modifications were carried over from Tier 3.1. Analysis of 3.2 test results resulted in the following answers to industry's questions.

Question 1: Can the size of an EAN-13, UPC-A or a retail 2D barcode be reduced to fit within the dimensions of today's smallest allowable UPC-E or EAN-8 and will the barcodes be capable of retail scanning requirements?

With a linear barcode X-dimension of 0.264 millimetre (0.0104 inch), the nominal width of an EAN-8 is approximately 20.57 millimetres (0.81 inches) and an UPC-E is 17.02 millimetres (0.67 inches). The theoretical max X-dimension for a UPC-A barcode to fit within these envelopes would be between 0.150 millimetre (0.0059 inch) and 0.182 millimetre (0.0072 inch).

Tier 3.2 test cards (see A Annex: Tier 3.2 barcodes) were used to understand if the reduced X-dimensions could meet retail scanning expectations. Each test card went through all test profiles as described in section 3.1 (Test profile overview). The test data showed that while scannable to a degree, EAN-13 and UPC-A barcodes that are printed with an X-dimension of less than 0.226 millimetre (0.0089 inch) will result in unacceptable retail scan rates causing the items per minute (IPM) to be less than 40 IPM. If the bars were parallel with the direction of travel the scan rate was better than when at any perpendicular (90°) or 45° angle to the direction of travel. The results showed the scanners are not capable of the meeting retail scanning IPM when EAN-13 or UPC-A X-dimensions are reduced to fit within the area of an EAN-8 or UPC-E. The scan rate was as low as 60% for items crossing the POS scanner at 150 mm/min or 36 IPM.

With the nominal widths of an EAN-8 and UPC-E being established above, the next requirement is what size 2D barcode can fit within these envelopes. For a QR Code with GS1 Digital Link URI data including domain name, GTIN, batch/lot number, and expiration date (61 character) and GS1 DataMatrix data including GTIN, batch/lot number and expiration date (36 characters) the X-dimension would be between 0.457 millimetre (0.0180 inch) and 0.559 millimetre (0.0220 inch).Therefore both QR Code (GS1 Digital Link URI) and GS1 DataMatrix will fit within an EAN-8/UPC-E with the current GS1 specified X-dimension up to 0.457 millimetre (0.0180 inch) for the described data.

The test data showed that GS1 DataMatrix and QR Codes (GS1 Digital Link URI), both with encoded data sets that represent retail fresh food examples (36 and 61 characters) will not only be within the minimum UPC-E/EAN-8 envelopes, but also capable of retail POS requirement of 40 items per minute.

Figure 4-1[4]. From left to right, UPC-E symbol sized at 0.264 millimetre (0.0104 inch), followed by a GS1 DataMatrix sized at 0.457 millimetre (0.0180 inch), a QR Code (GS1 Digital Link URI) sized at 0.457 millimetre (0.0180 inch) and a UPC-A 0.150 millimetre (0.0059 inch). The dotted lines indicate the space a UPC-E requires, including Quiet Zones.

Table 4-1. Comparison of average read rates, by scanner, for the horizontal camera across all rotations, at 150 mm/s (36 IPM).

	Symbology	Scan Rate (%)				
		ALPHA2	ALPHA5	BETA3	DELTA0	DELTA1
X-dimension EAN-8/UPC-E envelope objective	Linear 0.14 mm (0.0056 inches)	85.5	72.2	73.8	75.8	72.8
	Linear 0.17 mm (0.0067 inches)	86.5	99.4	93.8	100.0	81.3
	QR Code 0.45 mm (0.018 inches)	100.0	100.0	96.7	100.0	100.0
	GS1 DataMatrix 0.45 mm (0.018 inches)	100.0	98.5	96.9	98.5	100.0
Gen Specs minimum X-dimension	Linear 0.25 mm (0.010 inches)	92.6	100.0	98.8	100.0	81.9
	QR Code 0.38 mm (0.015 inches)	100.0	100.0	96.5	100.0	100.0
	GS1 DataMatrix 0.38 mm (0.015 inches)	100.0	94.6	98.5	85.6	100.0

[4] Scale is approximate.

Table 4-2. Comparison of average scan rates, by scanner and tilt, for just the vertical camera and for both cameras, at 150 mm/s (36 IPM)

	Symbology	Scan Rate (%)				
		ALPHA2	ALPHA5	BETA3	DELTA0	DELTA1
90° tilt EAN-8/UPC-E envelope objective	Linear 0.14 mm (0.0056 inches)	71.9	81.7	60.0	75.8	71.7
	Linear 0.17 mm (0.0067 inches)	70.6	70.8	100.0	55.8	84.4
	QR Code 0.45 mm (0.018 inches)	100.0	98.3	88.8	85.0	100.0
	GS1 DataMatrix 0.45 mm (0.018 inches)	100.0	88.8	86.9	90.0	100.0
45° tilt EAN-8/UPC-E envelope objective	Linear 0.14 mm (0.0056 inches)	58.3	60.8	85.0	100.0	58.5
	Linear 0.17 mm (0.0067 inches)	75.4	57.5	80.0	100.0	86.7
	QR Code 0.45 mm (0.018 inches)	88.8	100.0	96.7	100.0	88.8
	GS1 DataMatrix 0.45 mm (0.018 inches)	94.0	96.7	88.3	100.0	100.0

Question 2: Will an EAN/UPC barcode and 2D barcode fit in the space of an EAN/UPC barcode printed at 0.25 mm (0.010 inches) and will barcodes be capable of retail scanning requirements?

For both the EAN-13/UPC-A and 2D barcodes to fit within the envelope of EAN-13 or UPC-A barcode printed with the minimum GS1 General Specifications X-dimension of 0.25 mm (10 mil), the resulting X-dimensions of both barcodes must be reduced below the allowed GS1 General Specification limits. A 0.25 mm (0.010 inches) EAN-13/UPC-A barcode with Quiet Zones results in a 29.85 mm (1.175 inches) wide by 18.29 mm (0.72 inches) tall envelope. Through mathematical calculation it was determined that a QR Code (GS1 Digital Link URI) that contains domain name, GTIN, batch/lot and expiration (61 characters) with 7% (L) error correction will require a X-dimension of 0.25 mm (0.10 inches) to be paired with an EAN-13/UPC-A of with X-dimension 0.181 mm (0.00713 inches) to fit within the envelope of the UPC-A including all Quiet Zones. This results in a theoretical maximum X-dimension for both the linear and 2D barcodes falling below of current GS1 General Specifications standards.

Figure 4-2[5]. UPC-A barcode with an X-dimension of 0.25 mm (0.010 inches) (left) versus a combination of a QR Code with GS1 Digital Link URI data sized at 0.25 mm (0.010 inches) and UPC-A symbol sized at 0.18 mm (0.007 inches) for placement within the same space (right). The dotted

[5] Scale is approximate.

line indicates the envelope of the UPC-A (including Quiet Zones 29.85 mm (1.4175 inches) X 18.29 mm (0.72 inches)).

The test data shows that the scanners will not reliably read individual barcodes with the reduced X-dimensions required to co-locate a linear and 2D barcode within the envelope of a 0.25 mm (0.010 inches) X-dimension EAN-13/UPC-A barcode.

Table 4-3 and 4-4, presents the scan rate for select barcodes X-dimensions. The test cards traversed the scanner at the minimum speed of retail (150 mm/min or 36 IPM) with all rotations, tilts and other movements itemised in the test profile. As can be seen, while the scanners will read the below minimum X-dimension (per the General Specification) barcodes, there is no reasonable consistency across the scanners. The X-dimensions required to achieve a linear and 2D barcode in the envelope of a UPC-A exposed the limits of many of the scanners' capabilities. The scan rate was as low as 56% for linear and 0% to 19% for 2D barcode items crossing the POS scanner at 150 mm/min or 36 IPM.

Table 4-3. Comparison of average scan rates, by scanner, for the horizontal camera across all rotations, at 150 mm/s (36 IPM)

	Symbology	Scan Rate (%)				
		ALPHA2	ALPHA5	BETA3	DELTA0	DELTA1
X-dimension UPC-A envelope objective	Linear 0.17 mm (0.0067 inches)	86.5	99.4	93.8	100.0	81.3
	QR Code 0.25 mm (0.010 inches)	99.8	98.3	82.8	99.8	82.3
	GS1 DataMatrix 0.25 mm (0.010 inches)	99.8	39.5	88.3	19.1	94.8
Gen Specs minimum X-dimension	Linear 0.25 mm (0.010 inches)	92.6	100.0	98.8	100.0	81.9
	QR Code 0.38 mm (0.015 inches)	100.0	100.0	96.5	100.0	100.0
	GS1 DataMatrix 0.38 mm (0.015 inches)	100.0	94.6	98.5	85.6	100.0

Table 4-4. Comparison of average scan rates, by scanner and tilt, for just the vertical camera and for both cameras, at 150 mm/s (36 IPM)

	Symbology	Scan Rate (%)				
		ALPHA2	ALPHA5	BETA3	DELTA0	DELTA1
90° tilt UPC-A envelope objective	Linear 0.17 mm (0.0067 inches)	70.6	70.8	100.0	55.8	84.4
	QR Code 0.25 mm (0.010 inches)	98.8	89.2	100.0	66.7	100.0
	GS1 DataMatrix 0.25 mm (0.010 inches)	96.7	0.0	100.0	42.5	100.0
45° tilt UPC-A envelope objective	Linear 0.17 mm (0.0067 inches)	75.4	57.5	80.0	100.0	86.7
	QR Code 0.25 mm (0.010 inches)	74.0	89.2	80.0	80.0	92.0
	GS1 DataMatrix 0.25 mm (0.010 inches)	75.4	0.0	58.3	95.0	91.7

Question 3: What is the smallest viable X-dimension size for the retail point-of-sale scanning environment?

The current minimum GS1 General Specifications X-dimension of 0.264 mm (0.0104 inches) for linear and 0.396 mm (0.0150 inches) for 2D barcodes are still the answer for todays of bi-optic scanners. Figure 4-3 shows that the barcode scan rate performance begin to drop at approximately the minimum X-dimension for both linear and 2D barcodes. Scan rate issues for linear and Data Matrix barcodes with X-dimensions below the minimum specification are clearly seen when the barcode bars are traversing at an angle (45°) to the direction of travel (see Figure 4-4). At retail speed some scanners can only achieve a 65% scan rate for barcodes traveling at an angle that are approximately 0.05 mm (0.002 inches) below the minimum. X-dimension approximately 0.05 mm (0.002 inches) above the minimum specifications have a greater than 95% scan rate when traveling at an angle (45°).

- **Note:** 2D X-dimension – Optical effects in the image capture process require that the GS1 DataMatrix and QR Code barcodes be printed at 1.5 times the equivalent X-dimension allowed for linear symbols.

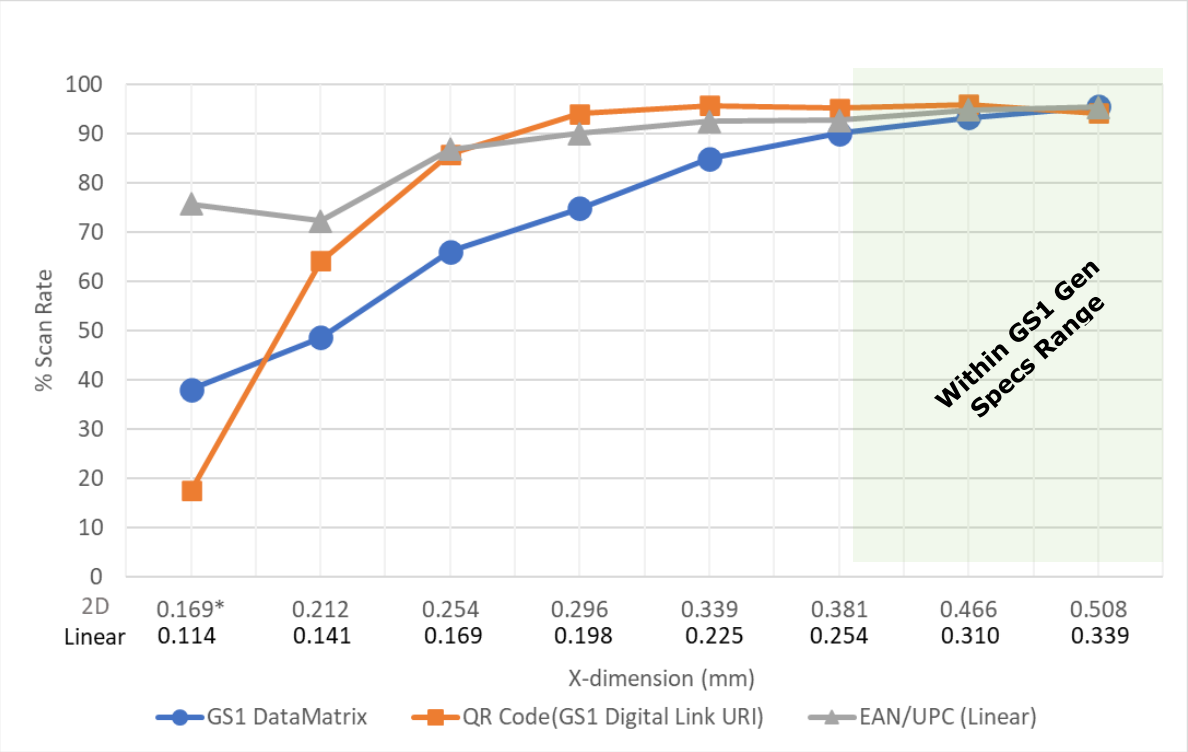

Figure 4-3. Linear and 2D barcode scan rate performance vs X-dimension for reasonably achievable retail POS speeds (150 and 300 mm/s) across all rotations and tilts at 25 mm from scanner surface. 2D symbols with an X-dimension of 0.169 mm (*) were not readable on all scanners.

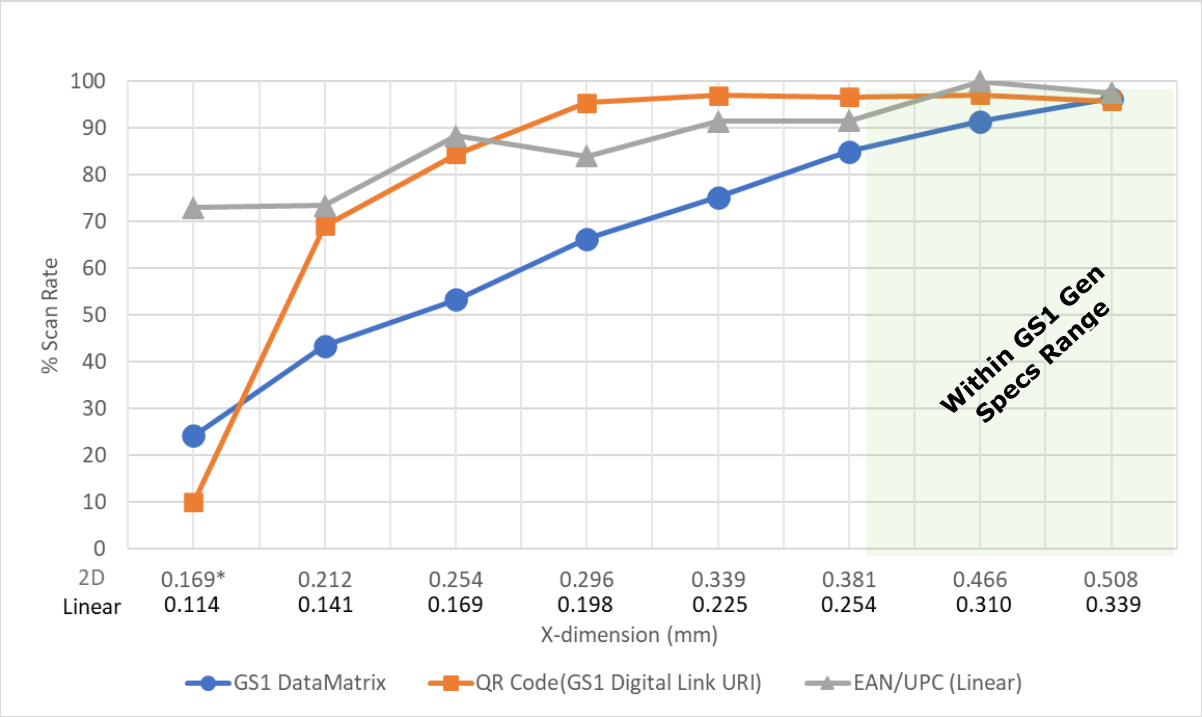

Figure 4-4. Linear and 2D barcode scan rate performance vs X-dimension for reasonably achievable retail POS speeds (150 and 300 mm/s) at a 45° rotation at 25 mm above the scanner surface. 2D symbols with an X-dimension of 0.169 mm (*) were not readable on all scanners.

Additional observations:

1. Scanning orientation matters for linear barcodes:

An observation of note was that the orientation of scanning for the linear barcodes made a significant difference. It is believed that this is due to the frame rates that the scanners were operating at. If the two scan orientations shown in Figure 4-6, are considered, the reader is invited to imagine a small amount of motion blur being introduced due to the scanning motion along the scan path.

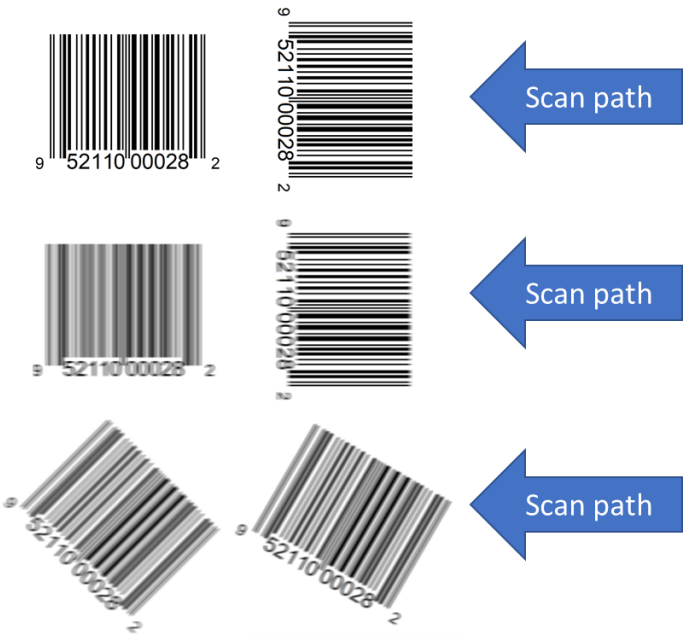

Figure 4-6. "Picket fence" (right) and "ladder" (left) scan orientations with exaggerated blurring[6] below each sample orientation. The bottom image set shows how the blur will also impact other arbitrary rotations (left – 45°, right – 30°).

As can be seen in the figure above, when the blurring occurs along the axis of the bars and spaces (middle right), the scanner may still be able to determine what is a bar and what is a space. However, when the blurring occurs perpendicular to the axis of the bars and spaces (middle left) the resulting image loses sufficient resolution rendering the smaller bars and spaces indistinguishable from each other. And when the symbol is passed at any other angle in between (e.g., 30°, 45°, etc.), the impact of the motion blur is progressively incurred, resulting in the same resultant decrease in performance.

The result of this blurring was that as the speed increased, the average scan rates for the linear symbols decreased. This effect was magnified as the X-dimension decreased since the number of pixels per bar or space was reduced, resulting in the scanner's inability to accurately distinguish between the two.

2. 2D barcode scan rate performance:

There was a noticeable difference in scan rate between QR Codes and Data Matrix (GS1 DataMatrix). QR Codes performed better than the equivalent size Data Matrix X-dimension. Data Matrix barcodes had scan rates issues when X-dimensions fell below 0.466 millimetre (0.0183 inch) to 0.381 millimetre (0.0149 inch). QR Codes began to have scan rates issues when X-dimensions fell below 0.340 millimetre (0.0134 inch). As can be seen in Figure 4-3, GS1 DataMatrix symbols experienced a steadily declining scan rate as the X-dimension decreased below 0.396 millimetre (0.0150 inch), whereas QR Codes did not see a reduction in scan rate until the X-dimension dropped below 0.340 millimetre (0.0134 inch). based on an aggregated average.

The most likely cause of this is that QR Code finder pattern is easier to isolate as the X-dimension decreases in size as compared to the "L" finder pattern of GS1 DataMatrix. All the "L" finder pattern can also be affected by the motion blur described earlier. In Figure 4.3 you see that the linear barcodes and the GS1 DataMatrix have a similar trend line. As the reader can imagine, it is significantly easier for the scanner to find the position detection pattern (Figure 4-7, left image) in the centre or right images of Figure 4-7 over finding an "L" in the patterns. The result of this decrease in time and effort is an increase in the available time to process additional pictures or to search larger areas within the existing pictures taken by the scanner.

Figure 4-7. Images of the QR Code unique detection pattern (left), a QR Code (GS1 Digital Link URI) (middle) and a GS1 DataMatrix (right).

3. Printing considerations:

   As mentioned previously, it is anticipated that graphic designers and brand owners will attempt to minimize the space that a 2D barcode is given. To this end, barcodes were generated that stressed both the scanners and the in-house printers. Linear barcodes were printed with X-dimensions down to 3.33 mil (0.09 mm) and 2D barcodes were printed with X-dimensions as low as 5.00 mil (0.13 mm). These minimal X-dimension values were selected based on the AutoID Lab's ability to print symbols using their 600 dpi thermal transfer printer.

   It was quickly determined that while the printer was technically capable of printing these small barcodes, the resulting labels were not verifiable, and were often not scannable despite considerable efforts to get the printer "tuned". As can be seen in A Annex: Tier 3.2 barcodes, five cards do not have verification reports. Despite an inability to verify the cards, all cards were initially tested to see if they scanned regardless of the missing verification reports. Four cards,

[6] 20% blur was artificially induced via Photoshop for these figures.

ID0401, ID0402, ID0419 and ID0428, ultimately were not scannable by the test equipment which correspond to the smallest X-dimensions (3.33 mil for linear and 5.0 mil for 2D) selected for the test plan.

5 Conclusions and recommendations

Conclusions

Tier 3.2 lab testing demonstrated that current bi-optic scanning hardware are unable to scan both linear and 2D barcodes with reduced X-dimensions without a moderate impact to scan rates. The results of this testing show that the current minimum X-dimensions in the GS1 General Specifications need to remain the same. Decreasing the existing X-dimensions to allow for smaller barcodes would result in slowing down retail point-of-sale (POS) and have some barcode scans fail.

These results will **not** prevent industry from progressing real-world pilot projects using the existing, minimum X-dimension sizes outlined in the GS1 General Specifications.

While standards cannot be lowered to make the X-dimension smaller at this time, other avenues can be explored to support the use of both a linear and 2D barcode during a transition period, such as optimising the encoded data and minimising the space between the barcodes when used for the same application. These topics are being discussed at the time of this publication in global GS1 standards development work in conjunction with learnings coming in from real-world pilots and implementations.

The conclusions of this Tier 3.2 testing reinforce the need for industry to expedite enabling 2D barcode capabilities at retail point-of-sale so that linear barcodes will not be required and the smaller 2D barcodes can exist on packaging independently.

Recommendation for additional testing

While the X-dimension sizes permitted in the GS1 General Specifications at this time cannot be lowered, the use of image-based scanners may allow for linear barcodes to have their height reduced, known as truncated, to reduce the amount of space required. Testing would be required to determine if truncated linear barcodes can perform successfully at retail POS and, if so, how much the height can be reduced.

The test samples used in Tier 3.2 were printed on a 600 dpi thermal transfer printer. It is understood that this is not how most retail labels on pre-packaged goods are generated and so it is recommended that testing be performed using production printing techniques for a similar X-dimension range to confirm the findings of this test and that 4.0 (A-grade) barcodes can be reliably produced at the smaller X-dimensions.

This Tier 3.2 report does not include any additional optical disturbances surrounding the barcodes (e.g., label graphics, reflective surfaces, curved surfaces, etc) or retail scanner types beyond bi-optic hardware.

Therefore, the University of Memphis and GS1 have planned a next phase of testing to:

- Expand the co-located barcode testing to include "real-world analogue" challenges (e.g., label graphics, curved surfaces, varying X-dimension combinations, reflective surfaces, etc.)
- Expand the testing to other retail scanning solutions (e.g., presentation and hand-held scanners – see Figure 5-1)

Lastly, these tests should be reconducted in the future once noteworthy advancements are made to in-market scanning equipment.

Future tests beyond the above are required to understand how earlier generations and other manufacturers' bi-optic scanner solutions decode the Tier 3.1 and Tier 3.2 barcode test cards. GS1 is hopeful that those scanner manufacturers who have been involved with the testing in this report will be able to accurately extrapolate the data from this Tier 3.2 testing to their own prior-generation scanners, as such extrapolation will allow the existing install base of scanners to be more accurately evaluated for updateability.

A Annex: Tier 3.2 barcodes

During the Tier 3.2 test, 32 cards were tested. The barcodes varied in:

- 1D barcodes
  - UPC-A (plain syntax)
  - EAN-13 (plain syntax)
- 2D barcodes:
  - GS1 DataMatrix (GS1 element string syntax)
  - QR Code (GS1 Digital Link URI syntax)
- 2D encoded data element combinations include:
  - GTIN, batch/lot number and expiration date
  - GTIN, batch/lot number, expiration date and domain name (GS1 Digital Link URI only)

Below image show a sample of the barcodes created for the test on the test card carriers.

Figure A-1 Barcode test cards

The table below shows the test cards, their X-dimensions and verification grade of the barcodes. All barcodes used in the testing were validated on a barcode verifier to discover the barcodes quality based on the GS1 General Specifications Section 5.12 Barcode production and quality assessment.

Table A-1 Tier 3.2 test card barcodes

CardID	Symbology	X-dim	Encoded Data	Grade
ID0401	QR Code (DL)	5.00 (0.13)	https://id.gs1.org/01/09521520000017/10/10ABC?17=271201	N/A
ID0402	GS1 DM	5.00 (0.13)	(01)09521610000026(10)11ABC(17)271202	N/A
ID0403	QR Code (DL)	6.67 (0.17)	https://id.gs1.org/01/09521520000031/10/12ABC?17=271203	N/A
ID0404	GS1 DM	6.67 (0.17)	(01)09521610000040(10)13ABC(17)271204	4.0/3.5/660
ID0405	QR Code (DL)	8.34 (0.21)	https://id.gs1.org/01/09521520000055/10/14ABC?17=271205	3.0/4.2/660
ID0406	GS1 DM	8.34 (0.21)	(01)09521610000064(10)15ABC(17)271206	4.0/4.2/660
ID0407	QR Code (DL)	10.00 (0.25)	https://id.gs1.org/01/09521520000079/10/16ABC?17=271207	4.0/5/660
ID0408	GS1 DM	10.00 (0.25)	(01)09521610000088(10)17ABC(17)271208	4.0/5/660
ID0409	QR Code (DL)	11.67 (0.30)	https://id.gs1.org/01/09521520000093/10/18ABC?17=271209	4.0/6/660
ID0410	GS1 DM	11.67 (0.30)	(01)09521610000102(10)19ABC(17)271210	4.0/6/660
ID0411	QR Code (DL)	13.34 (0.34)	https://id.gs1.org/01/09521520000117/10/20ABC?17=271211	4.0/7/660
ID0412	GS1 DM	13.34 (0.34)	(01)09521610000126(10)21ABC(17)271212	4.0/7/660
ID0413	QR Code (DL)	15.00 (0.38)	https://id.gs1.org/01/09521520000131/10/22ABC?17=271213	4.0/8/660
ID0414	GS1 DM	15.00 (0.38)	(01)09521610000140(10)23ABC(17)271214	4.0/8/660
ID0415	QR Code (DL)	18.34 (0.47)	https://id.gs1.org/01/09521520000155/10/24ABC(17)271215	4.0/9/660
ID0416	GS1 DM	18.34 (0.47)	(01)09521610000164(10)25ABC(17)271216	4.0/9/660
ID0417	QR Code (DL)	20.00 (0.51)	https://id.gs1.org/01/09521520000179/10/26ABC?17=271217	4.0/10/660
ID0418	GS1 DM	20.00 (0.51)	(01)09521610000188(10)27ABC(17)271218	4.0/10/660
ID0419	EAN -13	3.33(0.09)	9521100000192	N/A
ID0420	EAN -13	4.45(0.11)	9521100000208	1.5/3/660
ID0421	EAN -13	5.56(0.14)	9521100000215	1.6/3/660
ID0422	EAN -13	6.67(0.17)	9521100000222	4.0/3/660
ID0423	EAN -13	7.78(0.20)	9521100000239	4.0/5/660
ID0424	EAN -13	8.89(0.23)	9521100000246	4.0/5/660
ID0425	EAN -13	10.00(0.25)	9521100000253	4.0/5/660
ID0426	EAN -13	12.223(0.31)	9521100000260	4.0/5/660
ID0427	EAN -13	13.33(0.34)	9521100000277	4.0/10/660
ID0428	UPC-A	3.33(0.09)	952110000282	N/A
ID0429	UPC-A	4.45(0.11)	952110000299	1.4/3/660
ID0430	UPC-A	5.56(0.14)	952110000305	1.5/3/660
ID0431	UPC-A	6.67(0.17)	952110000312	4.0/3/660
ID0432	UPC-A	7.78(0.20)	952110000329	4.0/5/660
ID0433	UPC-A	8.89(0.23)	952110000336	4.0/5/660
ID0434	UPC-A	10.00(0.25)	952110000343	4.0/4/660

CardID	Symbology	X-dim	Encoded Data	Grade
ID0435	UPC-A	12.223(0.31)	952110000350	4.0/10/660
ID0436	UPC-A	13.33(0.34)	952110000367	4.0/10/660

Note: Grades of "N/A" indicate that the barcode could not be verified.

B Annex: Test profiles

Thirty-eight different test profiles, summarised in the table below, were run to analyse and understand the scan rates of different barcodes. The parameters that were adjusted are explained as follows:

1. The number of enabled barcode decode algorithms varied from a limited selection, only looking for expected barcodes (Config1), to the full suite of test, which included the enabling of all decoding algorithms for all barcodes turned on within the scanner. The following symbologies were enabled as the full suite of test (Config2) in all scanners: Data Matrix, QR Code, GS1 DataBar Expanded Stacked, GS1 DataBar Omnidirectional, EAN/UPC, ITF-14, PDF417, Code 128, Code 39, ISBN, digital watermark.
2. When the barcode was passed in front of the scan window, the height or distance from the scan window was tested at 12.5, 55 mm.
3. Horizontal offsets (scanner optimal scan location, optimal +25 mm, optimal -25 mm)
4. The barcodes were passed in front of the scan window at the following speeds: 150 mm/s, 300 mm/s, 400 mm/s, 600 mm/s, 800 mm/s, 1200 mm/s and at 1500 mm/s + a 250ms pause.
5. The barcodes were presented at different tilt angles from parallel to the scan window: 0°, 45°, and 90°.
6. Within the parallel presentation to the scan window, the barcodes were rotated clockwise: 0°, 45°, 90°, and 180°.

The full test matrix is shown in Table B-1, below.

Table B-1. Test matrix

Auto Discriminate	Horizontal Offset (mm)	Vertical Offset (mm)	speed mm/s	Tilt Angle from Horizontal	CW Rotation in Plane	Test ID
Config 1	0	12.5mm & 55mm	all (150, 300, 400, 600,1200 & 1500 1/4 pause)	0	0	test8
					45	test9
					90	test10
					180	test11
				45	0	test13
				90	0	test15
Config 1	Nominal + 25	12.5mm & 55mm	all	0	0	test24 (8)
					45	test25 (9)
					90	test26 (10)
					180	test27 (11)
				45	0	test28 (13)
				90	0	test29 (15)
Config 1	Nominal - 18 (towards hood)	12.5mm & 55mm	all	0	0	test30
					45	test31
					90	test32
					180	test33
				45	0	test34
				90	0	test35
				90	horizontal	test48
Config 2 (full monty)	0	12.5mm & 55mm	all	0	0	test16 (8)
					45	test17 (9)
					90	test18 (10)
					180	test19 (11)
				45	0	test21 (13)
				90	0	test23 (15)
Config 2 (full monty)	Nominal + 25	12.5mm & 55mm	all	0	0	Test36 (24)
					45	Test37 (25)
					90	Test38 (26)
					180	Test39 (27)
				45	0	Test40 (28)
				90	0	Test41 (29)
Config 2 (full monty)	Nominal - 18 (towards hood)	12.5mm & 55mm	all	0	0	Test42 (30)
					45	Test43 (31)
					90	Test44 (32)
					180	Test45 (33)
				45	0	Test46 (34)
				90	0	Test47 (35)
				90	horizontal	Test49(48)