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2D in Retail – Tier 3.3 Test Report

2D Barcode Scanning: Co-Located 2D and Truncated Linear Barcodes

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1 Introduction

Globally, stakeholders are adopting 2D barcodes that contain more data encoded in different data structures (syntaxes). At the same time, retail environments have deployed high-volume point-of-sale (POS) solutions capable of scanning 2D barcodes. The retail environment is poised to enable 2D on retail packaging for POS processes. However, during the 2D transition period, co-located linear (EAN/UPC) and 2D (Data Matrix/QR Code) barcodes can be present on brand packaging. This can create placement challenges due to available space on the packaging or product. Today's linear barcode dimensions for retail are based on laser scanner technologies. Laser barcode scanners are not capable of reading 2D barcodes and have been steadily replaced in the retail ecosystem by imaging-based scanners. These tests have been designed to supply unbiased, independent data required to support:

- Answers to key retail sector questions
- Scalable, interoperable solutions that leverage the data carrying capacity of 2D barcodes
- Potential standards updates

GS1 works with retail scanner manufacturers and has conducted tests to quantify the performance of linear and 2D barcodes in retail POS scanning scenarios. This report covers the fourth iteration of this testing and focuses on truncated (i.e., shortened) barcodes.

The University of Memphis Automatic Identification Lab was engaged to conduct this unbiased, independent testing using robotic equipment and representative high-volume, bi-optic POS scanners. To establish common baselines of performance and unbiased test data, a series of tests were performed on a variety of barcodes to understand their scanning performance.

The first tier of testing, Tier 1, focused on linear and 2D barcodes with only a Global Trade Item Number (GTIN) encoded. This test determined the baseline scanning performance of 2D barcodes to compare against current EAN/UPCs on-pack.

Tier 2 and Tier 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 retail POS systems could process GS1 Digital Link URI syntax without requiring out-of-cycle system upgrades. The scanner manufacturers' syntax conversion capability was included in the Tier 3 software update. The BETA3 scanner did not receive any update to the software to optimise reading of 2D barcodes.

At the conclusion of Tier 3.1 testing, testing still needed to be completed to understand how updated software from the scanner manufacturers would handle smaller X-dimensions that fall below the current GS1 General Specifications Standard as contained in Figure 5.12.2.6-1. The existing testing setup from the Tier 3.1 testing was used with a new set of test cards that isolated the X-dimension of the barcodes. This testing was referred to as Tier 3.2 testing. In Tier 3.3 testing (the subject of this report), variation of the height of the linear barcode was isolated as the only variable.

For those transitioning to 2D barcodes, items will need to be marked with both an EAN/UPC or GS1 DataBar retail family barcode AND a 2D barcode, since 2D readiness will vary at POS and in other scanning environments. However, the space for both barcodes on the packages may not be able to be increased 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, there are ongoing requests to reduce the size of linear and 2D barcodes overall.

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. The Tier 3.2 report was published in May 2023. All reports can be found, alongside other 2D solution provider barcode resources, at https://www.gs1.org/industries/retail/solution-provider-2d-readiness.

The Tier 3.3 testing outlined in this report determines the impacts of linear barcode truncation (height reduction) on performance in POS retail scanning environments and answers these important questions:

1. Can POS scanners identify (i.e., recognise) truncated linear barcodes along with compliant 2D barcodes encoded with GS1 data structures?

2. Do truncated linear barcodes adversely affect the decode time between multiple barcodes on a single product?
3. How much can the height of linear barcodes be reduced for retail imaging scanners and still meet the minimum 40 items per minute scanning benchmark for retail POS.

Figure 1-1 Full height and truncated co-located barcode test card examples

The Tier 3.3 tests were designed to evaluate if recent scanner manufacturer software updates made to bi-optic scanners from major manufacturers can sufficiently decode truncated linear barcodes and compliant 2D barcodes at typical retail throughput. One of the five scanners (BETA 3) under test had no software updates (to enhance retail 2D barcode capability) 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 (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 was also included.
- Varying linear barcode with truncated sizes from full height to 10% of full height (90% truncated).

The EAN/UPC family of retail barcodes was originally designed for omnidirectional laser scanners. For this type of scanner, the specifications define a fixed relationship between the symbol's width and height. The term "fixed aspect ratio" is used to refer to this fixed proportion. For example, an EAN-13 symbol with an X-dimension of 0.330 mm (0.0130 inch), its nominal dimension, has a width of 37.29 mm (1.468 inch) and a bar height of 22.85 mm (0.900 inch). The symbol specification tables (SSTs) list the target, minimum and maximum values for the barcode's X-dimension and height.

Note: The height of an EAN/UPC barcode does not includes the human readable interpretation and is the height of the bars. Additionally, the height of an EAN/UPC barcode does not include the extended height of either the guard patterns or the first and last symbol characters of a UPC-A barcode.

Figure 1-2 EAN-13 bar height

Figure 1-3 EAN-13 60% truncated barcode

2 Executive summary

As industry continues to migrate to 2D barcodes at retail point-of-sale (POS), the area needed on some packages for barcode placement has voiced as 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 major manufacturers to capture data.

In prior testing (Tier 3.2), the smallest viable X-dimension size for the retail point-of-sale scanning environment was investigated. The results determined that the **current minimum GS1 General Specifications Standard X-dimensions** of 0.264 mm (0.0104 inches) for linear and 0.396 mm (0.0150 inches) for 2D barcodes are **still appropriate for today's bi-optic scanners**. The Tier 3.3 test was designed to evaluate the scan performance of barcodes with heights less than the required heights (truncated barcodes). According to the GS1 General Specifications Standard, a truncated barcode (normal length, but reduced in height) may only be used if there is absolutely no possibility of printing a full size barcode since truncation reduces the omnidirectional laser scanning capability.

The Tier 3.3 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.

Tier 3.3 truncated barcode testing resulted in the following insights to key industry questions:

1. Truncated EAN/UPC barcodes can be decoded by imager based scanners to varying degrees of success.
2. Test results suggest that barcodes at 60% truncation could without affecting the 40 items per minute (IPM) throughput benchmark for POS scanning.
3. The test showed that truncated EAN/UPC barcodes had no significant impact on decode times or scan rates for co-located barcodes in comparison to previous Tier 3.1 testing.

Note: All truncated EAN/UPC co-located with the 2D barcode used in the Tier 3.3 test respected the 50mm (~2 inch) radius envelope defined in the GS1 General Specifications Standard.

Additional, noteworthy observations from the Tier 3.3 testing include:

The orientation of linear barcodes as they move over the scanner's mirrors can significantly impact the performance of truncated EAN/UPC barcodes. This effect is attributed to several factors:

- **Motion Blur:** As a barcode moves across the scanner, image blurring can occur. While motion blur affects all linear or 2D barcodes, its negative impact is exacerbated with truncation, where shorter bars and reduced X-dimension increase the likelihood of unreadable data.
- **Reduced Redundancy:** Decreasing the height of a linear barcode reduces the number of decodable segments available. Any damage or distortion to the shorter barcode further diminishes the chances of a successful read, as fewer redundant scanning paths exist.
- **Image Stitching Challenges:** High-speed point-of-sale scanners employ multiple mirrors to reflect the barcode image onto an imager, where image stitching techniques reconstruct the barcode for decoding. When barcodes are truncated, the reduced height limits the scanner's ability to capture and accurately assemble the full barcode, impacting readability.
- **Spectral Reflection Artifacts:** Camera sensors detect and record light reflected from barcode surfaces across different wavelengths. Factors such as material properties, angle of incidence, and sensor spectral sensitivity influence this reflection. Spectral reflection can introduce bright spots in the barcode image, reducing decodability. With truncated barcodes lacking sufficient height to provide redundant data, spectral reflection artifacts further decrease the probability of a successful scan.

- **Important**: Point-of-sale scanners with slower processors or lower resolution cameras may not have similar results. Lower print quality of truncated linear and 2D barcodes may also impact the results found in Tier 3.3 testing. In addition, real-world environmental factors such as lighting and human movement may result in lower scan performance than what was captured in the lab environment.

3 The Methodology

Like the previous tests, Tier 3 series 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., Truncate linear barcodes, 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 symbology (barcode) and syntax.
- The EAN/UPC only contain GTINs, no restricted circulation numbers.
- 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 and applied to the test cards.
- The use of the current-generation retail scanners listed below. All scanners were reset to factory default settings and then had Tier 3.1 software updates and specific configurations applied (i.e., data formatting, communications ports, etc.).
  - Datalogic (9400i and 9800i)
  - NCR (RealScan 7879)
  - Zebra (MP7000 and 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 test series reports.

3.1 Test profile overview

Tier 3.3 testing, similar to the previous Tiers, a variety of testing scenarios were used, called "test profiles", that were determined through a series of beta tests, historic tests and the use of rules and standards outlined in the GS1 General Specifications Standard. Test profiles are detailed below. (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 3.3 testing. A detailed spreadsheet of the barcodes is available as an appendix to this report. See Annex: Tier 3.3 barcodes.

The nineteen **test profiles varied by**:

1. Distance (~12.5 mm (~0.5 inch) and 55 mm (~2 inch) from the scanner horizontal and vertical surfaces)
2. Horizontal offsets (optimal scan location for the scanner, optimal +25 mm (~1 inch), optimal -25 mm (~-1 inch))
3. Speed (from 150 mm/s (~0.5 ft/s) to 1,200 mm/s (~4 ft/s))
4. Pause (travel @ 1200 mm/s (~4 ft/s) with 0.25 second stop at scanner)
5. Tilt angle from horizontal (0º, 45º, 90º)
6. Clockwise rotation in plane (0º, 45º, 90º, 180º)
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

Co-located barcode **test cards varied by**:

8. Symbology combinations
9. Percent of linear barcode truncation
    a. 0% (full height) to 90% truncation
10. X-dimension
    a. EAN and UPC family
        i. Minimum: 0.264 mm (0.0104")
        ii. Target: 0.330 mm (0.0130")
        iii. Maximum: 0.660 mm (0.0260")
    b. GS1 DataMatrix and QR Code
        i. Minimum: 0.396 mm (0.0150")
        ii. Target: 0.495 mm (0.0195")
        iii. Maximum: 0.990 mm (0.0390")

11. Data encoded

3.2 Test rig design

Tier 3.3 used the same test rig (see Figure 3-1) that was used in Tier 2. 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 had 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.

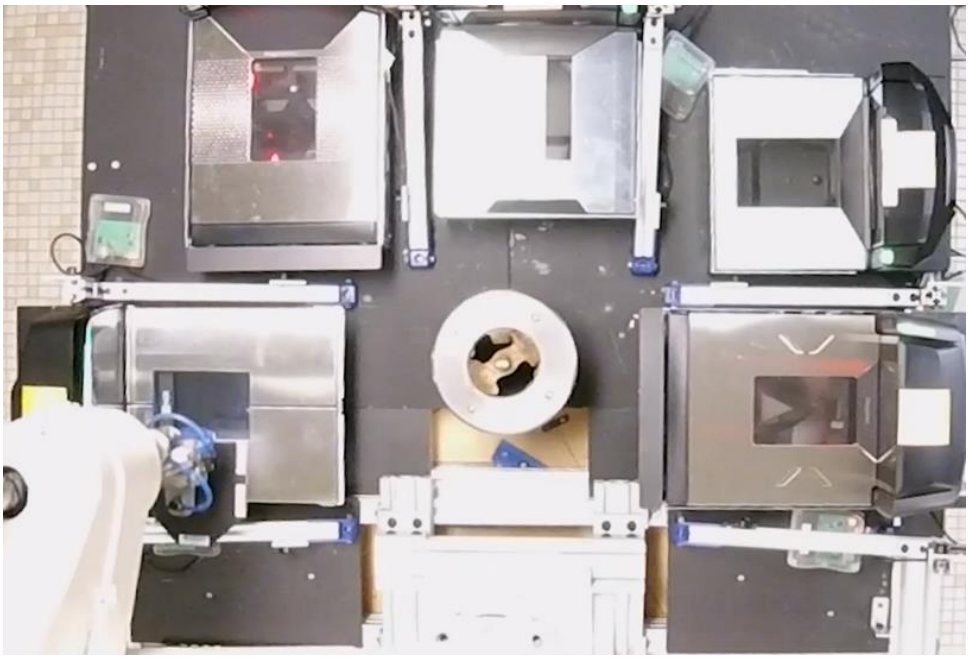

Figure 3-1 Scanning setup with robotic arm and POS scanners

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). That is to say that the reading zone used for ALL scanners was only that zone which was common to ALL of the specifications for ALL of the scanners tested.

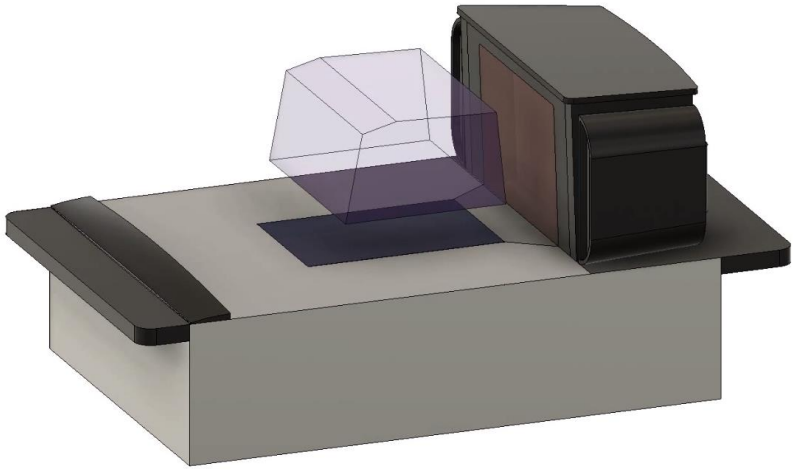

Figure 3-2 Optimal common 2D scanning envelope (transparent shape)

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

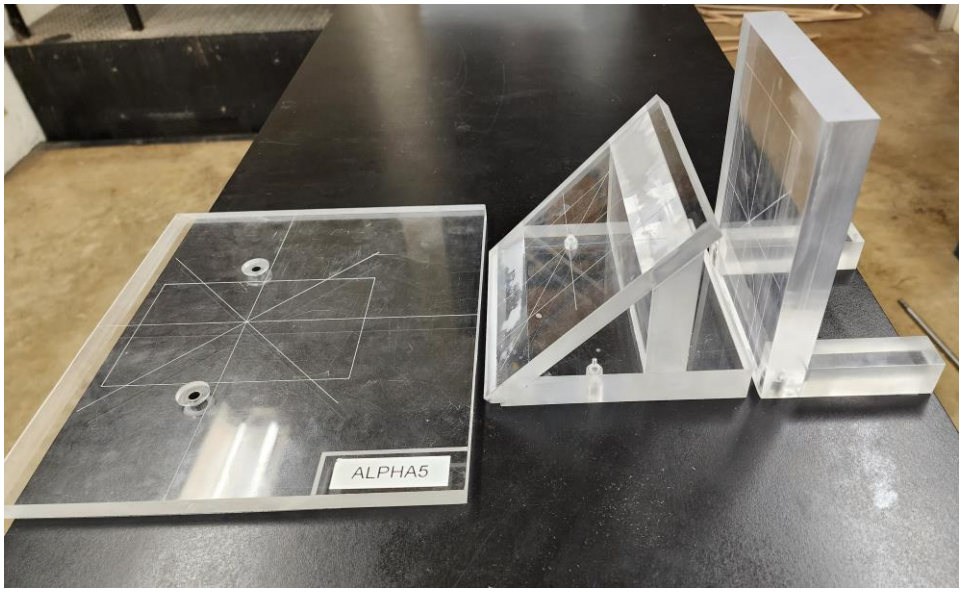

Figure 3-3 Robot positioning fixtures

3.3 Sample preparation

All test barcodes were mounted on fibreboard test cards. The Tier 3.3 test cards were based on the Tier 1 and Tier 2 cards. Unique card identifiers were associated to each test card to allow for the definitive identification (ID) of the test cards themselves as the test was being run. Test barcodes were verified to report their print quality, which was additional data used to correlate and analyse scan results (see C Annex: Barcode verification data).

Figure 3-4 Example of Tier 3.3 test cards

The barcodes tested in Tier 3.3 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 3.3 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 barcodes 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 field and triggered the data acquisition system timers.

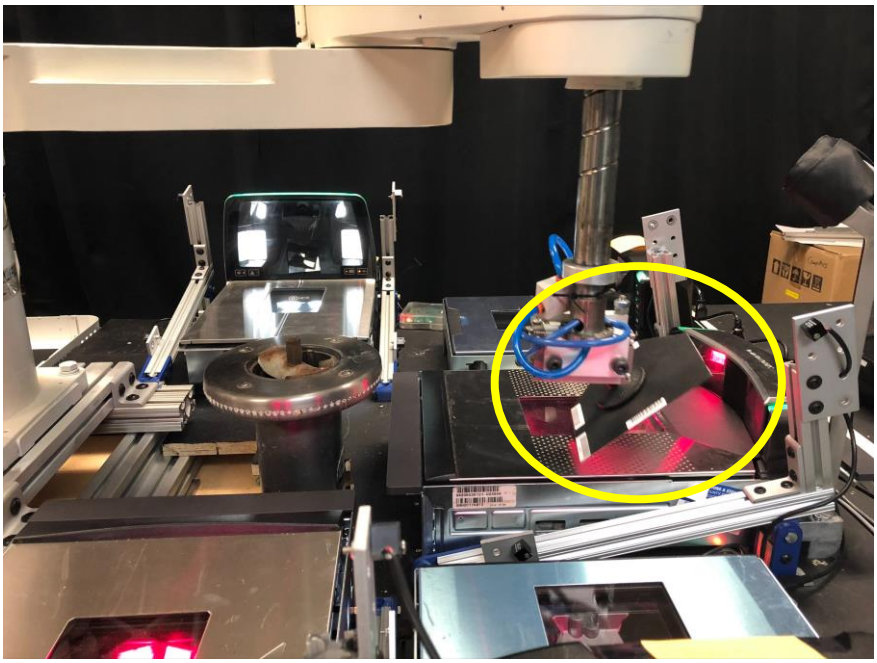

Figure 3-5 Bi-optic scanner with a card presented at 45° angle from horizontal

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 3.3 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 barcode and therefore not optimised for co-located barcodes. Additionally, all samples were printed with a 600 dpi thermal transfer printer.

Important: This limitation may have impacted the Tier 3.3 data due to the nature of the tests and the fact that the cards were manually produced with a 0.5 mm (~0.02 inch) 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 truncated linear range to be tested. To answer key questions, a selection of targeted truncated barcode heights were 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 3.3 test results resulted in the following answers to industry's questions.

4.1 Question 1: Can high speed bi-optic imager (camera) based POS scanners identify truncated EAN/UPC linear and 2D barcodes encoded with GS1 data structures?

With the truncated linear barcode and a 2D barcode both placed within a 50 millimetre (2 inch) radius from the centre of the linear barcode, the Tier 3.3 results proved that truncated EAN/UPC barcodes can be decoded by imager based scanners to varying degrees of success. The average

high speed bi-optic scanner decode rate was over 90% for all scanners for truncated barcodes greater than 70% (30% of GS1 General Specification full bar height). A significant drop in scanner decode ability was noticed for all barcodes truncated by 90% (10% of GS1 General Specification full bar height), see table 4-1 and Figure 4-1.

Note: In the GS1 General Specifications Standard, a truncated barcode (normal length, but reduced in height) may only be used if there is absolutely no possibility of printing a full size barcode. Truncation reduces the omnidirectional laser scanning capability. Tier 3.3 exclusively uses imager (camera) based scanners

Table 4-1 Average EAN/UPC scan decode rate (%) all test cards

Truncation (%)	Test card velocity (mm/sec)						
	150	300	400	600	800	1200	1200 + pause
Full Height	89	93	96	98	97	96	97
10	92	96	97	98	98	97	95
20	87	93	93	95	94	94	94
30	82	90	92	94	94	93	92
40	89	93	95	95	94	94	95
50	87	93	94	97	95	93	95
60	82	89	91	93	92	91	92
70	86	89	93	94	94	93	90
80	84	88	90	91	89	85	89
90	58	60	56	57	49	48	59

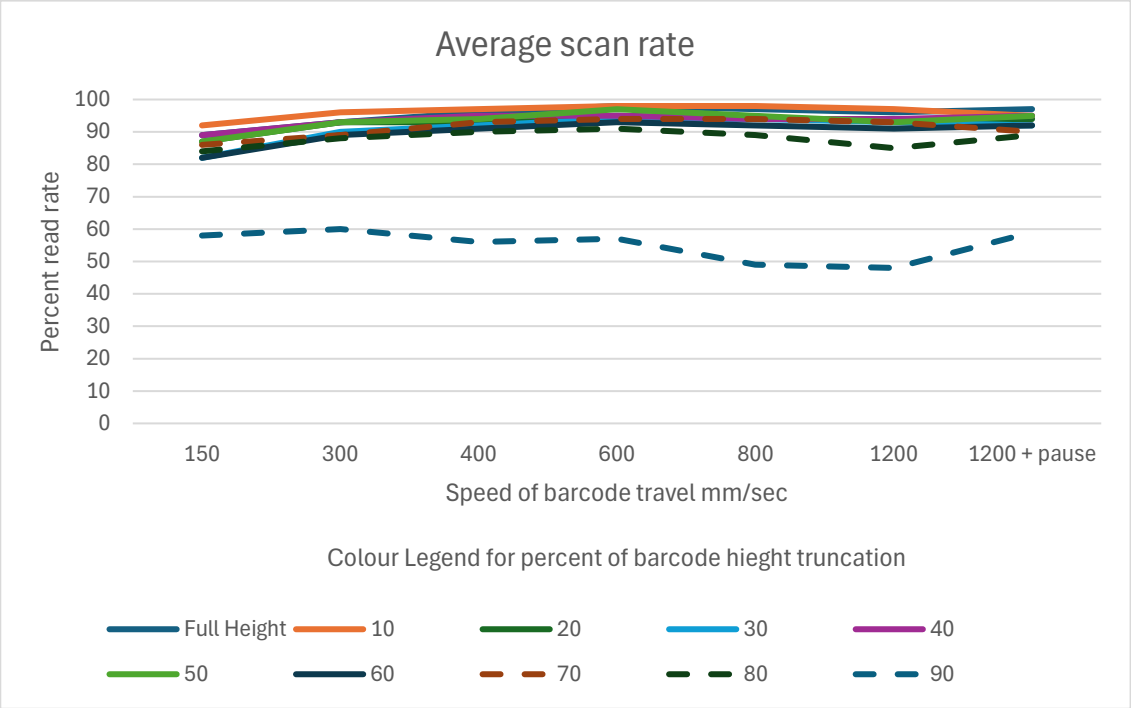

Figure 4-1 Linear barcode scan rate (%) by height for example 90 = 90% truncated = 10% of bar height remaining.

Based on retail stakeholder feedback collected during the Tier 2 study, GS1 estimates that a range of 40 IPM to 70 IPM is a realistic estimate of practical scanning throughput in retail stores. Using 70 IPM and assuming the average item size plus a practical scanning gap of 250 mm (~9.8 inch), the resulting barcode/package velocity is ~315 mm/s (~1 ft/s). At the low end of the range (40 IPM), the resulting barcode/package velocity is ~167 mm/s (~0.55 ft/s).

Within these speed ranges, the scanners all performed well on both truncated linear and 2D barcodes, with only a decrease in scan rates when presented with higher truncations. (the robotic cell manages the barcode test card velocity as it moves/travels across the bi-optic scanners.)

Test results suggest up to 60% truncation could be capable of the 40 IPM high speed POS requirement, when the current minimum, target and maximum GS1 General Specifications Standard X-dimension are used.

Table 4-2 displays the linear barcode's calculated items per minute scan rate from full height to 90% truncation across four test card traversing velocities.

Table 4-2 Average throughput (IPM) for co-located linear and 2D barcodes by precent truncation for listed velocities

Truncation (%)	Test card items per minute (IPM)				
		36 IPM 150 mm/s	72 IPM 300 mm/s	96 IPM 400 mm/s	~160 IPM 1200 mm/s + 0.25 sec pause
	Full Height	33	58	74	141
	10	30	52	66	126
	20	31	54	68	131
	30	31	52	70	131
	40	30	53	68	129
	50	31	53	67	123
	60	29	55	70	148
	70	31	54	68	133
	80	31	55	70	136
	90	28	44	51	115

4.1.1 Question 1.1: Will imager-based handheld and presentation POS scanners identify truncated EAN/UPC linear and 2D barcodes encoded with GS1 data structures?

The answer can be extrapolated by pausing the test cards in front of the bi-optic vertical imager (see Figure 4-2). The bi-optic vertical imager's optic configuration often has either direct line of sight or a single reflecting mirror, the same configuration found in presentation scanners. The direct line of sight is the same as handheld scanner. Both handheld and presentation scanners require the barcode to be stationary for the identification and decoding process. The Tier 3.3 test profile included one profile with a 0.25 second pause with the focal range of the bi-optic scanners vertical axis, thereby simulating the handheld and presentation scanner process with similar imager configurations. The scanner decode rate was above 95% for all truncations except the maximum (10% of full height) tested. Handhelds and presentation scanners additionally take multiple images within a specific trigger cycle and the pause will likely even further increase the performance of these kinds of devices. Therefore, this suggests that imaged based handheld and presentation would also be capable of decoding EAN/UPC barcodes truncated below 80% (above 20% of full height).

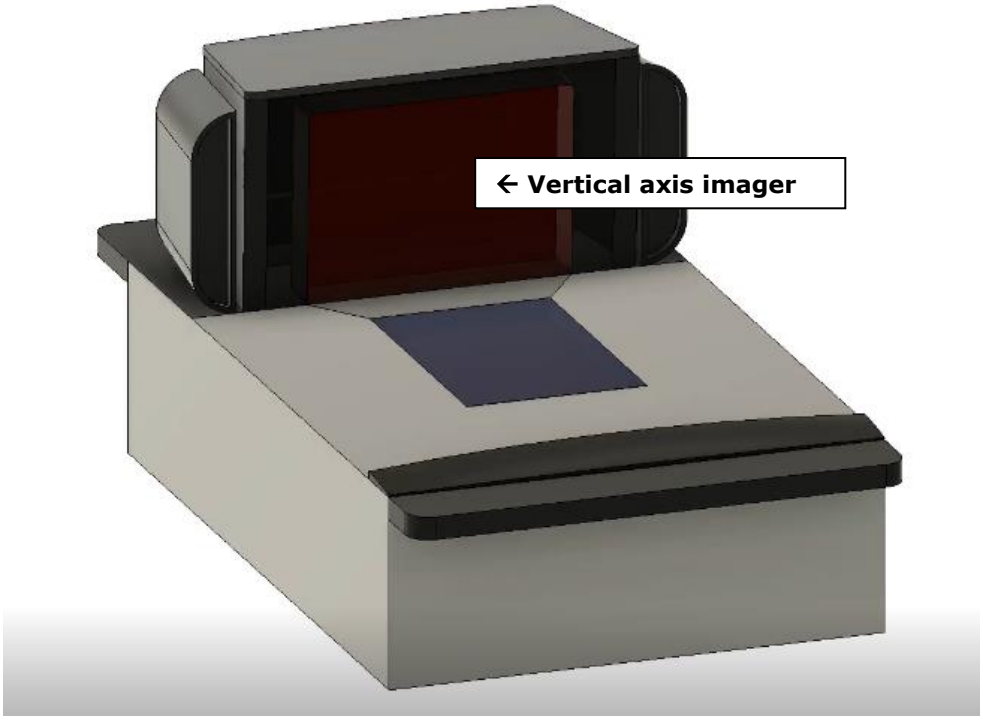

Figure 4-2 Bi-optic vertical imager

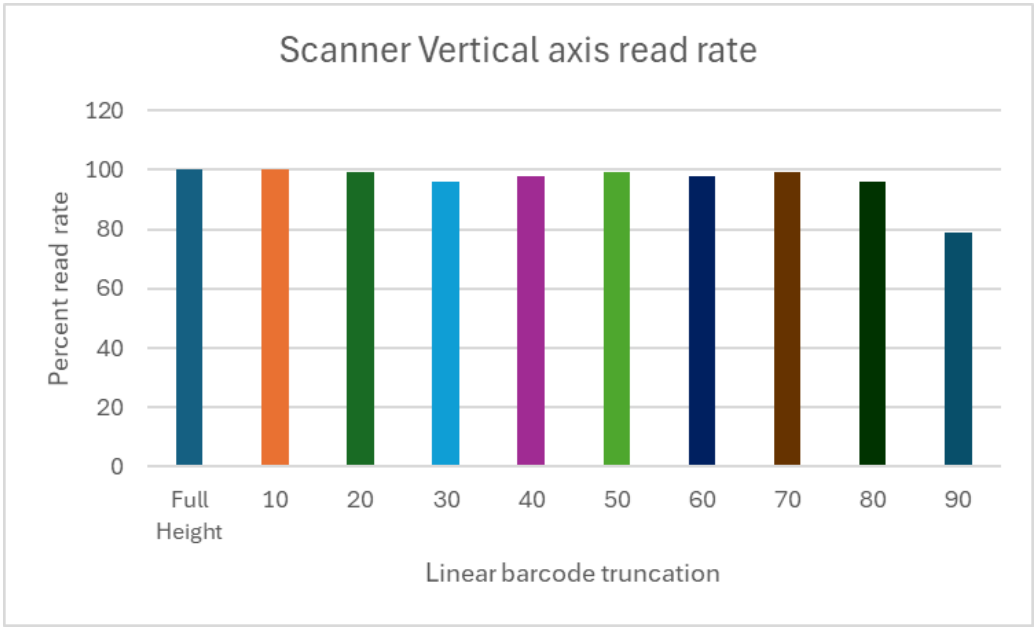

Figure 4-3 Linear barcode scan rate for vertical scanner imager with 0.25 millisecond pause versus linear truncation (90 = 90% truncated = 10% of bar height remaining).

4.2 Question 2: Will truncated linear barcodes adversely affect the decode time between multiple barcodes on a single product?

With the truncated EAN/UPC barcode and a 2D barcode both being placed within a 50 millimetre (2 inch) radius from the centre of the linear barcode, the Tier 3.3 results proved that truncated EAN/UPC barcodes had no significant impact on decode times or scan rates for co-located barcodes when compared to previous Tier 3.1 testing.

Table 4-3 show the scan time to the second barcode transmitted, for all tested speeds. It should be noted that at the slower speeds(e.g., 36 IPM), the time between when the system sees the test card and the time that the first barcode is in the read zone is a significant component of the times recorded. Additionally, all times are only relative to a specific scanner as efforts were not made to normalize the exact timing between the sensor and the beginning of the scan envelope of the scanners. The green zone in Figure 4-2 highlights when the travel time influence is minimal and reveals the actual additional scan time to deliver the second barcode. Note that BETA3 has longer scan read times. The BETA3 scanner did not receive any update to the software to optimise reading of 2D barcodes. If the currently installed bi-optic configurations are not updated, performance similar to BETA3 can be anticipated once co-located barcodes are introduced and reading of 2D symbols is enabled at these POS terminals.

Table 4-3 Additional time to deliver second barcode results, by speed and scanner (milliseconds)

Scanner	36 IPM 150 mm/s	72 IPM 300 mm/s	96 IPM 400 mm/s	144 IPM 600 mm/s	192 IPM 800 mm/s	288 IPM 1200 mm/s	~160 IPM 1200 mm/s + pause
ALPHA2	441	208	204	139	152	132.5	163
ALPHA5	251	182.5	151	147	130	113	190
BETA3	464	309	252	202	176	154	263
DELTA0	403	199	172	152	144	144	220
DELTA1	298	185	160	131	120	110	136

4.3 Question 3: How much can the height of linear barcodes be reduced for retail imaging scanners and meet the minimum 40 items per minute (IPM) scanning rate of retail.

The data show that, when barcodes are presented to the scanner within the scanning window and when the co-located linear truncated and compliant 2D barcodes are within 50 mm (~2 inch) from each other, both barcodes can be scanned and delivered to the host POS system. Test results suggest 60% truncation could be capable of the 40 IPM throughput expectation for POS, when the current minimum, target and maximum GS1 General Specifications Standard X-dimension are used.

Tier 3.3 testing noted that the orientation of the small X-dimension barcode to the scan path can negatively affected the POS scan rate. It is believed that this is due to the frame rates that the scanners were operating at and image stitching. If the two scan orientations shown in Figure 4-4, are considered, a small amount of motion blur being introduced due to the scanning motion along the scan path is reasonable to expect.

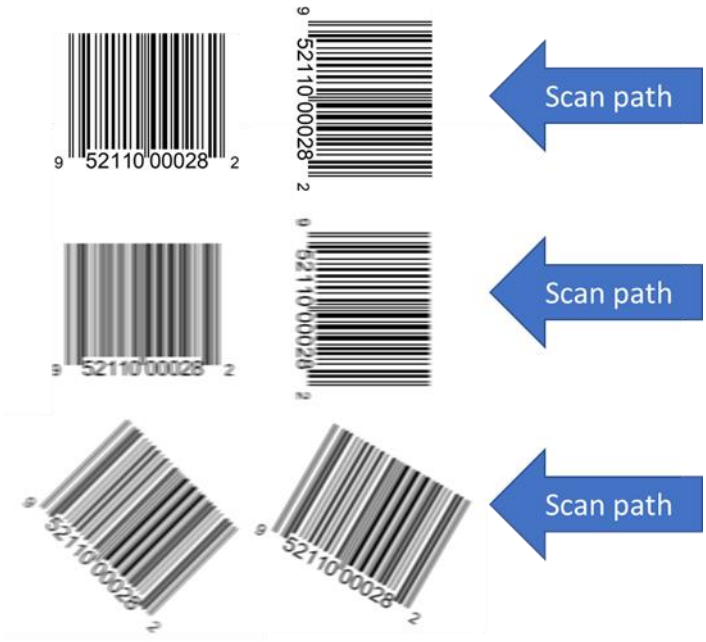

Figure 4-4 "Picket fence" (top left) and "ladder" (top right) scan orientations with exaggerated blurring below each sample orientation. The bottom image set shows how the blur will also impact other arbitrary rotations (left – 45°, right – 30°).

As 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. When the symbol is passed at any other angle in between (e.g., 30°, 45°, etc.), the impact of the motion blur can be expected, resulting in a similar decrease in read performance.

Beyond the motion blur there are several other factors that can significantly impact the performance of truncated EAN/UPC barcodes. In summary the reduced decoding results can be attributed to several factors:

- Motion Blur: As a barcode moves across the scanner, image blurring can occur. While motion blur affects all linear or 2D barcodes, its negative impact is exacerbated with truncation, where shorter bars and reduced X-dimension increase the likelihood of unreadable data.
- Reduced Redundancy: Decreasing the height of a linear barcode reduces the number of decodable segments available. Any damage or distortion to the barcode further diminishes the chances of a successful read, as fewer redundant scanning paths exist.
- Image Stitching Challenges: High-speed point-of-sale scanners employ multiple mirrors to reflect the barcode image onto an imager, where image stitching techniques reconstruct the barcode for decoding. When barcodes are truncated, the reduced height limits the scanner's ability to capture and accurately assemble the full barcode, impacting readability.
- Spectral Reflection Artifacts: Camera sensors detect and record light reflected from barcode surfaces across different wavelengths. Factors such as material properties, angle of incidence, and sensor spectral sensitivity influence this reflection. Spectral reflection can introduce bright spots in the barcode image, reducing decodability. With truncated barcodes lacking sufficient height to provide redundant data, spectral reflection artifacts further decrease the probability of a successful scan.

Table 4-4 Average scan decode rate (%) for 45˚scan path and minimum X-dimension test cards

Truncation (%)	Traversing Speed (mm/sec)						
	150	300	400	600	800	1200	1200 + pause
Full Height	83	95	96	97	95	98	97
10	99	99	100	99	100	100	100
20	86	92	92	93	98	97	96
30	86	94	94	98	98	97	98
40	99	99	98	99	97	98	99
50	98	98	97	97	92	86	97
60	83	91	91	96	92	92	93
70	75	76	76	77	72	68	79
80	75	76	78	77	76	59	82
90	36	33	34	23	26	16	28

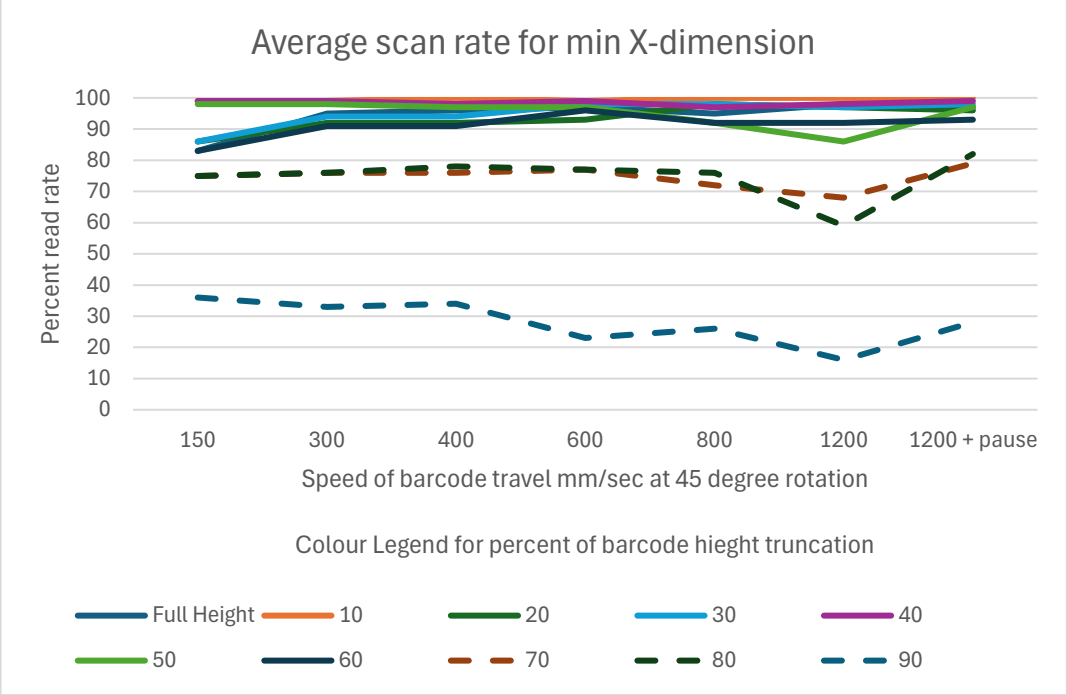

Figure 4-5 Average scan decode rate 45˚scan path minimum X-dimension test cards

5 Conclusions and recommendations

Conclusions

Tier 3.3 lab testing suggests 60% truncation of EAN/UPC linear barcodes could be capable of the 40 IPM throughput benchmark for retail POS, when the current minimum, target and maximum GS1 General Specifications Standard X-dimension are used. The 60% truncation of EAN/UPC linear barcodes would reduce the overall space required for co-located linear and 2D barcodes.

Recommendation for additional testing

It is important to note that the data in this Tier 3.3 report does not include curved surfaces or other retail scanner types.

GS1's next phase of testing may include:

- Further truncated linear lab and in field testing
- Expand the testing to include other retail scanning solutions (e.g., presentation and handheld scanners – see Figure 5-1) through pilot programs in real-world environments. This would look to validate Tier 3.3's assumptions regarding the test profile's 0.25-second test card pause in front of the bi-optic scanner's vertical axis, simulating the processes used by handheld and presentation scanners.
- Determine the optimal 2D barcode size for curved packaging and products to enable retail scanning.

It is important to note that a lab robot cannot truly simulate human motions, and we expect that retail pilots will better reflect operational conditions and other factors present in a live environment. Scanner manufacturers, the University of Memphis and GS1 recommend that **retail store pilots are now needed to continue the learning and vetting of POS scanner improvements**, and that such pilots should begin with earnest around the world.

Figure 5-1 An example of a presentation (left) and handheld (right) scanner

A Annex: Tier 3.3 barcodes

During the Tier 3.3 test, 32 cards were tested. The barcodes varied in:

- 1D barcodes
  - UPC-A & UPC-E (plain syntax)
  - EAN-13 & EAN-8 (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 different barcodes and the characteristics of the barcodes.

Table A-1 Tier 3.3 test card barcodes

CardID	X-dimension (mm)	Symbologies	Truncation	Truncation2
ID0550	0.25 & 0.38	UPC-A & QR Code	10	90
ID0551	0.33 & 0.50	UPC-A & QR Code	20	80
ID0552	0.25 & 0.38	UPC-E & QR Code	40	60
ID0554	0.33 & 0.50	UPC-A & GS1 DM	80	20
ID0555	0.67 & 0.96	UPC-A & QR Code	70	30
ID0556	0.67 & 0.96	UPC-E & GS1 DM	20	80
ID0558	0.67 & 0.96	UPC-E & QR Code	60	40
ID0559	0.25 & 0.38	UPC-E & QR Code	70	30
ID0561	0.33 & 0.50	UPC-E & QR Code	30	70
ID0562	0.67 & 0.96	EAN-13 & QR Code	80	20
ID0563	0.25 & 0.38	EAN-8 & GS1 DM	50	50
ID0564	0.33 & 0.50	EAN-8 & QR Code	40	60
ID0565	0.67 & 0.96	EAN-8 & QR Code	10	90
ID0566	0.67 & 0.96	UPC-A & GS1 DM	40	60
ID0567	0.25 & 0.38	UPC-A & QR Code	40	60
ID0568	0.25 & 0.38	UPC-A & GS1 DM	60	40
ID0569	0.33 & 0.50	UPC-A & QR Code	50	50
ID0570	0.33 & 0.50	EAN-8 & QR Code	60	40
ID0571	0.25 & 0.38	EAN-8 & QR Code	80	20
ID0572	0.67 & 0.96	EAN-8 & GS1 DM	100	0
ID0573	0.67 & 0.96	EAN-13 & QR Code	10	90
ID0574	0.25 & 0.38	EAN-13 & QR Code	20	80
ID0575	0.67 & 0.96	EAN-13 & QR Code	30	70
ID0576	0.33 & 0.50	EAN-13 & QR Code	40	60
ID0577	0.67 & 0.96	EAN-13 & QR Code	50	50
ID0578	0.67 & 0.96	EAN-13 & GS1 DM	60	40
ID0579	0.33 & 0.50	EAN-13 & QR Code	70	30
ID0580	0.25 & 0.38	EAN-13 & GS1 DM	90	10
ID0581	0.33 & 0.50	EAN-13 & QR Code	100	0
ID0583	0.67 & 0.96	UPC-A & QR Code	90	10
ID0584	0.25 & 0.38	UPC-A & QR Code	100	0
ID0585	0.33 & 0.50	UPC-E & GS1 DM	90	10

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 symbol was passed in front of the scan window, the height or distance from the scan window was tested at 12.5 and 55 mm (~0.5 and 2 inch).
3. Horizontal offsets (scanner optimal scan location, optimal +25 mm (~1 inch), optimal -25 mm (~-1 inch))
4. The barcodes were passed in front of the scan window at the following speeds: 150 mm/s (~0.5 ft/s), 300 mm/s (~1 ft/s), 400 mm/s (~1.3 ft/s), 600 mm/s (~2 ft/s), 800 mm/s (~2.6 ft/s), 1200 mm/s (~4 ft/s) and at 1200mm/s (~4 ft/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 profile matrix

Auto Discriminate	Horizontal Offset (mm)	Vertical Offset (mm)	speed mm/s	Tilt Angle from Horizontal	CW Rotation in Plane
Config 1	0	12.5mm & 55mm	all (150, 300, 400, 600,1200 & 1500 1/4 pause)	0	0
					45
					90
					180
				45	0
				90	0
Config 1	Nominal + 25	12.5mm & 55mm	all	0	0
					45
					90
					180
				45	0
				90	0
Config 1	Nominal - 18 (towards hood)	12.5mm & 55mm	all	0	0
					45
					90
					180
				45	0
				90	0
				90	horizontal
Config 2 (full monty)	0	12.5mm & 55mm	all	0	0
					45
					90
					180
				45	0
				90	0
Config 2 (full monty)	Nominal + 25	12.5mm & 55mm	all	0	0
					45
					90
					180
				45	0
				90	0
Config 2 (full monty)	Nominal - 18 (towards hood)	12.5mm & 55mm	all	0	0
					45
					90
					180
				45	0
				90	0
				90	horizontal

C Annex: Barcode verification data

All barcodes used in the testing were validated on a barcode verifier to discover the barcodes quality based on the GS1 General Specifications Standard Section 5.12 Barcode production and quality assessment. Only barcodes that received a 1.5 (C) and above were acceptable for testing.

Table C-1. Verification data for all cards and barcodes

card ID	2D data	Linear data	2D Xdim (mm)	Linear Xdim (mm)	Linear Barcode	2D Barcode	Truncation	Linear grade	2D grade	Linear Xdim (mils)	2D Xdim (mils)
ID0550	https://id.example.com/01/00952101072304/10/ABC123/21/123456789ABCE?17=271231	0952101072304	0.38	0.25	UPC-A	QR Code	90	4.0	3.0	10.0	15.0
ID0551	https://id.example.com/01/00952201072310/10/ABC123/21/123456789ABCE?17=271231	0952201072310	0.50	0.33	UPC-A	QR Code	80	4.0	2.6	13.3	20.0
ID0552	https://id.example.com/01/00001000004074/10/ABC123/21/123456789ABCE?17=271231	00140704	0.38	0.25	UPC-E	QR Code	60	3.4	2.0	10.0	15.0
ID0554	0100952801051319	0952801051319	0.50	0.33	UPC-A	GS1 DM	20	4.0	4.0	13.3	20.1
ID0555	https://id.example.com/01/00952701072322/10/ABC123/21/123456789ABCE?17=271231	0952701072322	0.96	0.67	UPC-A	QR Code	30	2.5	4.0	26.5	38.2
ID0556	0100001000002056	00120506	0.96	0.67	UPC-E	GS1 DM	80	4.0	4.0	26.7	38.4
ID0558	https://id.example.com/01/00001000006078/10/ABC123/21/123456789ABCE?17=271231	00160708	0.96	0.67	UPC-E	QR Code	40	3.8	4.0	10.0	15.0
ID0559	https://id.example.com/01/00001000007068	00170608	0.38	0.25	UPC-E	QR Code	30	4.0	4.0	26.6	38.2
ID0561	https://id.example.com/01/00001000003060	00130600	0.50	0.33	UPC-E	QR Code	70	3.1	4.0	10.0	15.0
ID0562	https://id.example.com/01/09528020723200/10/ABC123/21/123456789ABCE?17=271231	9528020723200	0.96	0.67	EAN-13	QR Code	20	4.0	3.0	13.3	20.0
ID0563	0100000050405107	50405107	0.38	0.25	EAN-8	GS1 DM	50	3.4	4.0	10.1	15.1
ID0564	https://id.example.com/01/00000040407210/10/ABC123/21/123456789ABCE?17=271231	40407210	0.50	0.33	EAN-8	QR Code	60	4.0	4.0	13.4	20.1
ID0565	https://id.example.com/01/00000010406229	10406229	0.96	0.67	EAN-8	QR Code	90	4.0	4.0	26.9	38.6
ID0566	0100952401051320	0952401051320	0.96	0.67	UPC-A	GS1 DM	60	0.0	4.0	26.8	38.6
ID0567	https://id.example.com/01/00952301062303	0952301062303	0.38	0.25	UPC-A	QR Code	60	3.4	4.0	10.0	15.0
ID0568	0100952601051304	0952601051304	0.38	0.25	UPC-A	GS1 DM	40	3.2	4.0	10.1	15.0
ID0569	https://id.example.com/01/00952501062318	0952501062318	0.50	0.33	UPC-A	QR Code	50	4.0	4.0	13.4	20.2
ID0570	https://id.example.com/01/00000060406217	60406217	0.50	0.33	EAN-8	QR Code	40	4.0	4.0	13.4	20.0
ID0571	https://id.example.com/01/00000080406211	80406211	0.38	0.25	EAN-8	QR Code	20	4.0	4.0	10.1	15.1
ID0572	0100000011405122	11405122	0.96	0.67	EAN-8	GS1 DM	0	4.0	4.0	26.9	38.5
ID0573	https://id.example.com/01/09521020623006	9521020623006	0.50	0.25	EAN-13	QR Code	90	3.7	4.0	10.1	20.2
ID0574	https://id.example.com/01/09522020723000/10/ABC123/21/123456789ABCE?17=271231	9522020723000	0.38	0.25	EAN-13	QR Code	80	3.7	4.0	10.1	15.2
ID0575	https://id.example.com/01/09523020723205/10/ABC123/21/123456789ABCE?17=271231	9523020723205	0.96	0.67	EAN-13	QR Code	70	4.0	4.0	26.8	38.5
ID0576	https://id.example.com/01/09524020723103/10/ABC123/21/123456789ABCE?17=271231	9524020723103	0.50	0.33	EAN-13	QR Code	60	3.9	4.0	13.4	20.0
ID0577	https://id.example.com/01/09525020623004	9525020623004	0.50	0.25	EAN-13	QR Code	50	2.9	4.0	10.0	20.0

ID0578	0109526020513203	9526020513203	0.96	0.67	EAN-13	GS1 DM	40	1.3	4.0	26.8	38.6
ID0579	https://id.example.com/01/09527020623107	9527020623107	0.50	0.33	EAN-13	QR Code	30	4.0	3.0	13.4	20.1
ID0580	09521120623104	9529020513006	0.38	0.25	EAN-13	GS1 DM	10	3.6	4.0	10.1	15.0
ID0581	09521120623104	9521120623104	0.50	0.33	EAN-13	QR Code	0	4.0	4.0	13.4	20.1
ID0583	https://id.example.com/01/00952901062321	0952901062321	0.96	0.67	UPC-A	QR Code	10	4.0	4.0	26.8	38.3
ID0584	https://id.example.com/01/00952111072301/10/ABC123/21/123456789ABCE?17=271231	0952111072301	0.38	0.25	UPC-A	QR Code	0	3.5	4.0	10.0	15.0
ID0585	0100001000009055	00190505	0.50	0.33	UPC-E	GS1 DM	10	4.0	4.0	13.4	20.2