The Global Language of Business

2D in Retail – Tier 2 Test Report

2D Barcode Scanning: GTIN + additional data

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1 Introduction

Globally, stakeholders are quickly transitioning to 2D barcodes that contain more data encoded in different syntaxes. Details on scanning system capabilities and best practices are currently unclear. Unbiased, independent data is required to support improving this understanding and answer key questions that are critical to users looking to implement scaled, interoperable solutions to leverage 2D barcodes.

GS1 is conducting tests to quantify the performance of 2D barcodes in retail point-of-sale (POS) scenarios, using both GS1 syntaxes (i.e., plain, GS1 element string, GS1 Digital Link URI) and non-GS1 encodings (e.g., unformatted data, generic marketing QR Code with a URI, etc).

The University of Memphis Automatic Identification Lab has been engaged to conduct this unbiased, independent testing using robotic equipment and representative 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 how they scan. The first tier of testing focused on barcodes with only a Global Trade Item Number (GTIN) contained within them, to compare against current EAN/UPC scanning. The full Tier 1 report was published in May 2022 and can be found alongside other 2D barcode resources at https://www.gs1.org/industries/retail/2D-barcodes.

Barcodes containing GTIN with additional data elements were the focus of the testing in Tier 2. These tests assess the impact of including additional data that will unlock many of the use cases enabled by 2D barcodes. All tiers of testing analyse variables including barcode orientation, barcode print technology, speed, angle and distance from the scanner. This report is the full Tier 2 test results.

2 Executive summary

This 2D in Retail - Tier 2 Report is the result of the collaborative efforts of printing and scanning solution providers, the University of Memphis and GS1. These scanner tests are designed to support solution providers preparations for retailers welcoming multiple types of barcodes through the POS. Additionally, this report will help other stakeholders make more informed decisions as they pilot and implement 2D barcodes.

Both Tier 1 and Tier 2 testing were executed in a lab environment. This testing was performed on five commercial retail point-of-sale (POS) systems from four different manufacturers. Tier 1 testing laid the groundwork for initial scanner improvements and created a baseline while Tier 2 focused on answering the following:

- Can 2D barcodes (e.g., QR Code and Data Matrix) encoded with GTIN **and additional data** be scanned at retail speeds between 40 and 70 items per minute (IPM)?
  - The results show that, in a controlled environment, 2D barcodes encoded with GTIN and additional attributes can meet today's retail speeds.
    - Various combinations of data were tested. Even the barcode containing the most data elements processed consistently at over 40 IPM. These 2D barcodes had up to 78 characters to included domain name, GTIN, batch/lot number, expiration date, serial number, and packaging component.
  - Average scan times marginally increased for barcodes with additional data compared to the GTIN-only control.
    - The scan speeds are captured in milliseconds. The overall difference between UPC-A with GTIN-only and 2D barcodes with additional data is not significant.
- What are the performance differences between barcode types and syntaxes encoded with GTIN and additional data?
  - All 2D barcodes can be scanned with accuracy. However, as the barcode traversing speed increases, the scan rate for 2D is lower than the scan rate for the control barcode (UPC-A). It is important to note that 2D barcodes performed better than GS1 DataBar Expanded Stacked containing the same data elements. (See Table 4-7 Barcode scan rate with full suite of tests (%))
  - We are starting to see some difference in scan speed between 2D symbologies (as measured by overall time to delivery of the scanned data to host system). QR Codes (GS1

Digital Link URI syntax) are scanning faster than GS1 DataMatrix (GS1 element string syntax) and Data Matrix (GS1 Digital Link URI syntax).

- Solution provider software refinement and scanner setting updates are resulting in a significant performance optimisation. This is promising, as future updates will continue to improve 2D performance and bring scan speeds closer to 1D levels. (See Table 4-4 Data conversion in milliseconds).

- How does the number of barcode decode algorithms that are switched on (barcode types turned on in a scan engine) impact relative scanning performance?
  - Testing showed that barcode direction and the number of barcode types (decode algorithms) enabled does not negatively impact scanner throughput on the tested barcodes. The average decode time per scanner readings having no significant increase in time.
- Is GS1 guidance for 2D barcode quality and size appropriate for imaged-based bi-optic POS scanners? See GS1 General Specification Section 5.12 Barcode production and quality assessment
  - The testing confirmed that the current GS1 standards for barcode dimensions work with a representative sample of today's most popular scanning systems.

Tier 3 testing will answer these additional questions:

- If there are multiple barcodes on a pack (such as an EAN/UPC AND a QR Code), how well do scanning systems find the needed information?
- How should barcodes be placed in relation to each other for optimised scan results?
- Is the decode time between multiple barcodes on a single product acceptable for retailer host systems?

- **Important**: The solution providers, the University of Memphis and GS1 all agree that retail store pilots are needed to continue the learning and vetting of POS scanner improvements.

3 Methodology

This section outlines the process followed in the development and execution of the testing.

The primary considerations made during the test design include:

1. The Tier 2 group of barcodes encode GTIN plus additional attributes (GTIN+) in the format required by the symbology and syntax. Barcodes were printed on standard width 4X3 inch labels using known major production printing technologies
   a. Next Generation Continuous ink jet (CIJ/SPI)
   b. CO^2 laser
   c. Thermal ink jet (TIJ)
   d. Thermal transfer (TT)
   e. High resolution laser jet
2. Use of current generation retail scanners. All scanners were set to factory defaults settings
   a. Datalogic
   b. Honeywell
   c. NCR Realscan 7879
   d. Zebra

- **Note**: In this report the scanners are given aliases (Alpha#. Beta#, Delta#, …) The aliases are the same as in the Tier 1 report (i.e., the Alpha1 scanner in this report is the same as the Alpha1 scanner in the Tier 1 report).

3. Data must be as statistically robust as previous tests.

3.1 Test profile overview

Tier 1 & 2 test scenarios (called 'profiles' within this document) were determined using a series of beta tests, historic tests and GS1 specifications (including barcode size, quality, test velocity, distance from the scanner surface, rotational and angular distances and other parameters). Twenty-three test profiles were designed to understand how barcodes would be read when the parameters were altered for Tier 1. The number of profiles for the Tier 2 testing was optimised to 16.

The variation of parameters in the test setup and the variation of barcode characteristics are both important to evaluate 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 2 testing. A detailed spreadsheet of the barcodes is available as an appendix to this report. (see section 5).

Test profiles were varied in:

4. Distance (~25, 55 mm from scan horizontal and vertical surfaces)
5. Speed (from 150 mm/s to 1,200 mm/s)
6. Pause (traverse @ 1500 mm/s with 0.250 second stop)
7. Tilt angle from horizontal (0, 30, 45, 75, 90)
8. Clockwise rotation in plane (0, 45, 90, 180)
9. Symbologies activated/enabled in the scanners
    a. 1D and 2D barcodes (UPC-A, GS1 DataBar Expanded Stacked, GS1 DataMatrix, Data Matrix (GS1 DL URI) QR Code (GS1 DL URI))
        i. Test 1: EAN/UPC, GS1 DataBar Expanded Stacked, GS1 DataBar Omnidirectional, Data Matrix and QR Code
        ii. Test 2: EAN/UPC, GS1 DataBar Expanded Stacked, GS1 DataBar Omnidirectional, Data Matrix, QR Code, ITF-14, PDF417, Code 128, ISBN, watermark

Barcodes varied by:

1. Symbology
2. Data encoded
3. X-dimension
4. Print technology used to produce
5. Print quality (various levels of contrast)
6. Error correction level (for QR Code only)

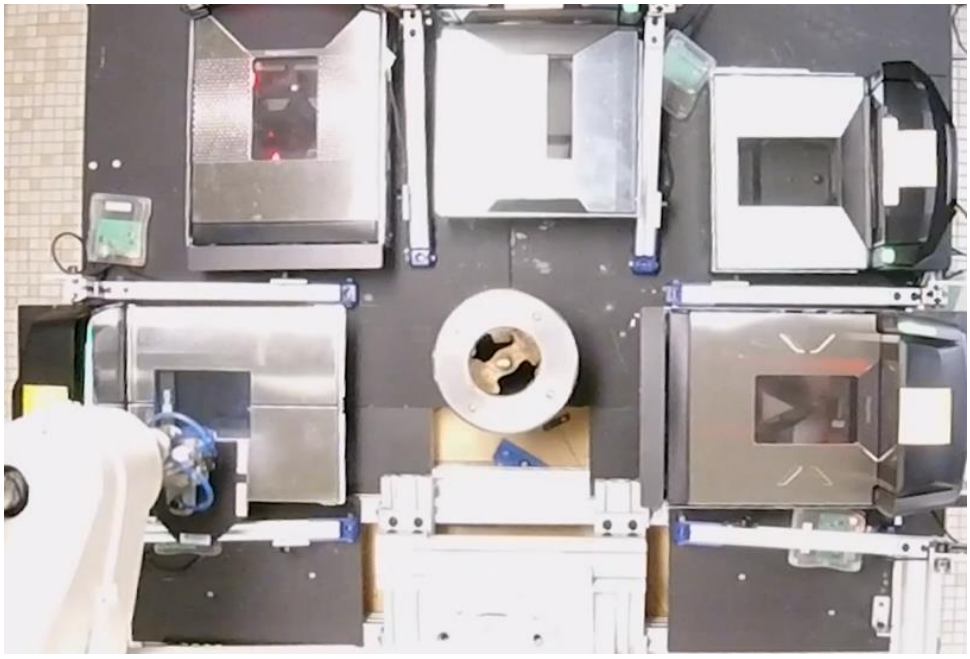
3.2 Test rig design

A test rig was constructed with a robotic arm. Five tabletop 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 connections and a computer with multiple serial ports.

To address timing requirements, photoeye sensors were tied to a programmable logic controller and the custom software was configured to capture the photoeye events. The leading edges of the scan windows and sensors were optimised for 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

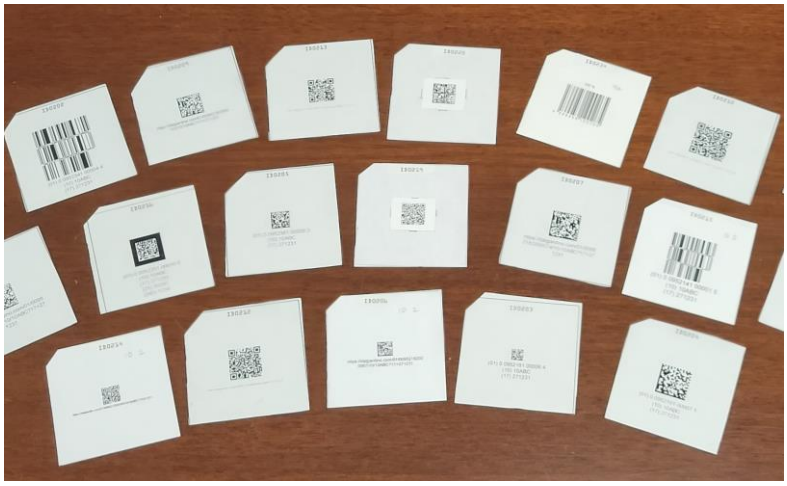


3.3 Sample preparation

All test barcodes were mounted on fibre-board test cards. The Tier 2 test cards were made smaller than what was used in Tier 1 testing to support consistent scan path within the scanner's camera view angle. Unique card identifiers were associated to each test card to allow for the definitive identification (ID) of the test cards themselves. Barcodes were verified to report their print quality of the for correlation with scan results (see section 5).

Figure 3-2 Example of Tier 1 vs Tier 2 test cards

Figure 3-3 Example of Tier 2 barcodes on test cards

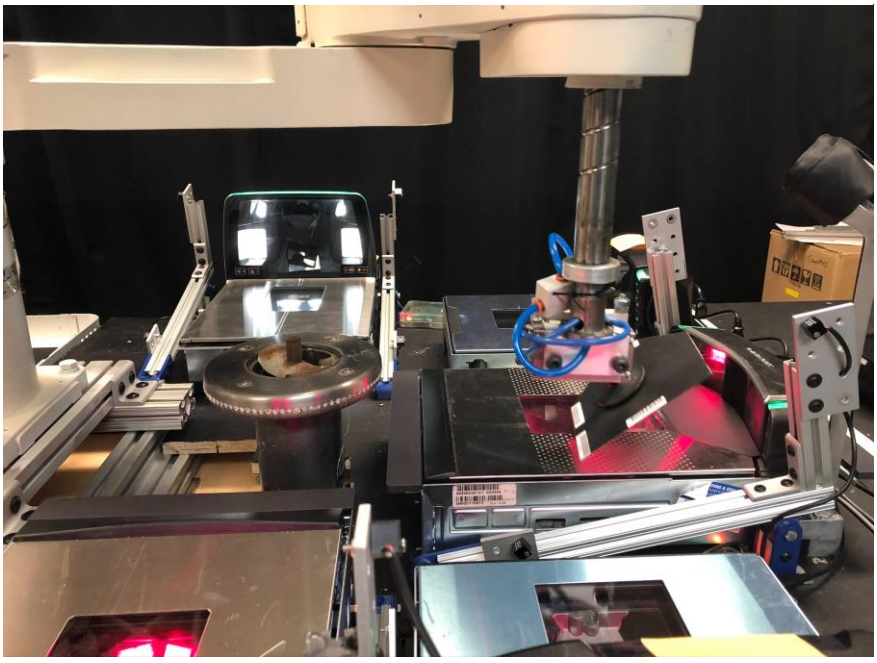


3.4 Testing process

Testing was conducted by a single robot that would pick up each single test card, scan the unique test card identification number, and then pass the symbol 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 cards was used between ten and fifty times for each test scenario, to maximise our ability to analyse the resulting data and to ensure that we could identify any anomalous runs.

Figure 3-4 Presentation scanner with card presented at 45° angle from horizontal



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 timer.

The scan count, scan time (time from trigger to data transmission time) and scanner decode data was 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 test lab local servers.

3.5 Limitations

Tier 2 testing passed the test cards over each scanner within a field of view (scan window) that was defined (by the scanner manufacturers) for 1D barcode reading. These fields of view are not necessarily optimised for 2D barcodes.

Tier 3 tests will leverage an optimised scan window that is designed for multiple barcode scenarios.

- **Important**: This limitation did not impact the output of Tier 2 and the results maintain integrity and statistical relevance.

4 Test results and observations

The 2D barcodes tested in Tier 2 were:

- 1D barcodes
  - UPC-A (control, plain syntax)
  - GS1 DataBar Expanded Stacked (GS1 element string syntax)
- 2D barcodes:
  - GS1 DataMatrix (GS1 element string syntax)
  - Data Matrix (GS1 Digital Link URI syntax)
  - QR Code (GS1 Digital Link URI syntax)
- Encoded data element combinations include:
  - GTIN, batch/lot number and expiration date
  - GTIN, batch/lot number, expiration date and domain name
  - GTIN, batch/lot number, expiration date and packaging component number
  - GTIN, batch/lot number, expiration date, packaging component number and domain name
  - GTIN, batch/lot number, expiration date, packaging component number and serial number
  - GTIN, batch/lot number, expiration date, packaging component number, serial number and domain name

In addition to analysing read rates, the tests were designed to understand whether translation between data syntaxes (e.g., GS1 Digital Link URI data structures to GS1 element string syntax) adversely affected the total scan time. Two scanner manufacturers provided an updated version of their GS1 Digital Link URI parser/translator software.

For the systems of these two scanner manufacturers, 2D barcodes were translated correctly on all tests whenever the barcodes were successfully decoded, regardless of translation between syntaxes being part of the process or not. This indicates that syntax translation is not a material contributor to total scan time.

Both 1D and 2D scan rates dropped as speeds beyond 400 mm/s-600 mm/s (which are speed that exceed even the fastest POS checkout speeds ever recorded). At 1200 mm/s, the control UPC-A was in the 90%-range, while GS1 DataBar Expanded Stacked scan rates were at 60% and 2D scan rates were in the 55-65% range.

If the 1D or 2D barcode tests are limited to those speeds that are considered normal (or best-in-class) retail scan speeds, the scan rates for all Tier 2 barcodes are between 95%-100%, except for GS1 DataBar Expanded Stacked (which was 80%-86%).

GS1 DataBar Expanded Stacked (265 ms) decoded marginally faster than the 2D barcodes (312 ms for QR Code with GS1 Digital Link URI). The processing speed for decoding is expected to be faster for 1D barcodes than for 2D barcodes, as the processing times are closely tied to the level of scanner decoding algorithm optimisation (scanner manufacturers have spent many more years optimising 1D algorithms).

It should be noted that QR Codes decode times were only ~50 milliseconds (ms) slower than the decode times of a 1D barcode with equivalent data, which is likely attributed to the ease of locating this barcode symbology's prominent finder pattern. In contrast, the decode times for Data Matrix symbologies were ~100 ms slower than the decode time for data equivalent 1D barcodes. In the most fast-paced environments, these decode processing times for Data Matrix codes may create throughput challenges. Over time, decoding algorithm optimisations are expected to reduce the decode processing times required for all 2D barcodes, but it is possible that the differential between QR code and Data Matrix codes may persist (due to their designs).

We have heard a concern expressed by some constituents that an increase in the number of barcode decoding algorithms that are enabled on a scanner could slow down processing speeds of the POS scanner. In Tier 1 and Tier 2 tests, we did not find a correlation between the number of decoding algorithms that were enabled and the decode time of the barcodes under test, even with fourteen barcode decoding algorithms enabled at the same time. However, this testing will be repeated again for Tier 3 testing, which adds the complexity of multiple symbols side-by-side. It is essential to note that the systems under test in the lab are NOT using the same decoding algorithms as are currently deployed in existing installations around the world. As such, impacts on decode time may be significantly more pronounced in pilot tests that attempt to repeat these lab tests. It is essential that all retailer pilots ensure that your testing is taking advantage of the algorithms that have already been significantly optimised. Please contact GS1 to get connected to the right people within your scanner manufacturer.

As noted earlier, two scanner manufactures delivered a GS1 Digital Link URI ←→ GS1 element string translation solution that works for all tested barcodes. The ability for the scanning system to do this translation "on the fly" is important to retailers, as it removes the requirement to make any changes to the POS backend systems within a particular retail environment. The GS1 Digital Link URI ←→ GS1 element string conversions has three steps:

1. GTIN-only conversion
2. GTIN plus attribute data
3. Co-located barcodes

No appreciable delay was identified between units with the GS1 Digital Link URI parser/translator and those without, which indicates that the scanners execute the parser/translator conversion quickly.

All barcodes were created to meet the GS1 General Specifications barcode quality standards. The X-dimension (i.e., bar or module size) was varied within the tolerances of the standard. Both 1D and 2D barcodes from minimum to maximum X-dimension as prescribed in the GS1 General Specifications decoded correctly on all tests. This is an important milestone in 2D scanning on bi-optic POS scanners: Current GS1 barcode specifications do not need to change.

Figure 4-1 Example of reverse reflectance test cards

Printing technologies were varied across the tests, to produce a representative population of the types of print technologies that are currently scanned in retail environments. All printing technologies could produce a code that could be decoded by bi-optic scanners.

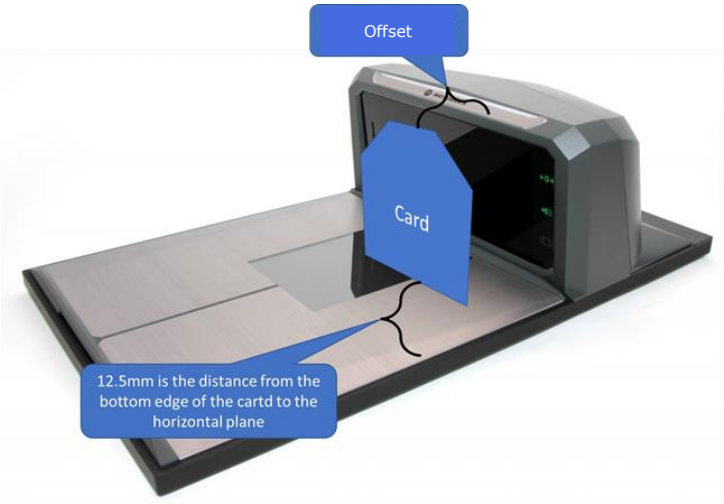
One scanner had issues decoding the reverse reflectance test symbols (i.e., white on black) that were generated by laser printing. In the past, similar limitations on reverse printed symbologies were rectified by scanner manufacturers with algorithm adjustments.

Laser printed symbologies performed marginally lower than Continuous Ink Jet printed symbols (we used a new generation printer called Super Piezo Inkjet (SPI) that significantly improve the printing performance).

The minimum and maximum horizontal and vertical offset did affect scan rates for all barcodes containing additional data beyond GTIN. This impact was most prevalent when combined with scan speed increases, as the barcode was in the available scan view for a shorter amount of time. It is normal for scanning systems to be challenged with barcodes at the outer limit of their focal distance, particularly at very high speeds.

Scan rates were affected by the card velocity, offset distance and tilt angle (e.g., there were maximum speeds, distances and tilt angles that resulted in performance drop-offs). The minimum and maximum horizontal and vertical distance did affect scan rates for most barcodes.

Figure 4-2 Vertical offset reference



Scan rates were NOT affected by barcode direction or the barcode test card rotation in plane. Barcode test card tilt angle was determined to impact scan rates, with larger angles reducing the scan rate for all the bi-optic scanners under test. Interestingly a 30-degree tilted barcode caused the largest reduction in scan rates for most scanners. This detail (along with all other data) is being shared with the scanner manufacturers for continuous algorithm and scanning developments.

4.1 Items per minute (IPM) results (across all possible real-world retailer speeds)

Based on a scan of available data, GS1 estimates that a range of 40 IPM to a maximum of 60-70 IPM is a very robust estimate of practical scanning speeds in retail stores. Using 70 IPM and assuming the average item size + a practical scanning gap of 250 mm, the resulting barcode/package velocity is ~315 mm/s. At the low end of the range (40 IPM), the resulting barcode/package velocity is ~167 mm/s.

Within these speed ranges, the scanners all performed extremely well on both 1D and 2D barcodes. The robotic cell manages the barcode test card velocity as it traverses across the bi-optic scanners.

The IPM calculation assumes the barcode test cards are presented in a back-to-back manner, as could happen in a typical retail environment. All tests assume a minimum gap between products of 250 mm (average distance to scan window + barcode location on product), which is seen as a very robust and aggressive estimate of throughput.

Relating speed of the robot (mm/s) to IPM calculations (IPM), the following reference table is established:

- 150 mm/s → 36 IPM
- 300 mm/s → 72 IPM
- 400 mm/s → 96 IPM
- 600 mm/s → 144 IPM
- 800 mm/s → 192 IPM
- 1200 mm/s → 288 IPM
- 1500 mm/s + 250 ms (0.25 seconds) pause between products → 240 IPM

Within normal retail speeds and when barcodes pass directly in front of the scanner's camera surfaces, the result shows acceptable scanner performance for both 1D and 2D barcodes, as shown in Table 4-1 below. There is an observed marginal improvement of scanning performance across the

vertical camera surface, which now appears to be more efficient at decoding 2D barcodes in comparison the baseline test. This could be a result of the scanner settings update and/or the smaller test card paths being relatively lower and more in the field of view.

Table 4-1 Average retail IPM scan rate in percentage.

Bi-Optic Scanner	Horizontal plane			Vertical plane		
Barcode type	36 IPM 150mm/s	72 IPM 300mm/s	96 IPM 400mm/s	36 IPM 150mm/s	72 IPM 300mm/s	96 IPM 400mm/s
UPC-A	99	97	99	99	100	99
GS1 DataBar Expanded Stacked	86	78	75	84	80	78
GS1 DataMatrix	99	91	85	100	98	94
Data Matrix (GS1 DL URI)	99	86	82	100	98	94
QR Code (GS1 DL URI)	99	91	86	100	97	94

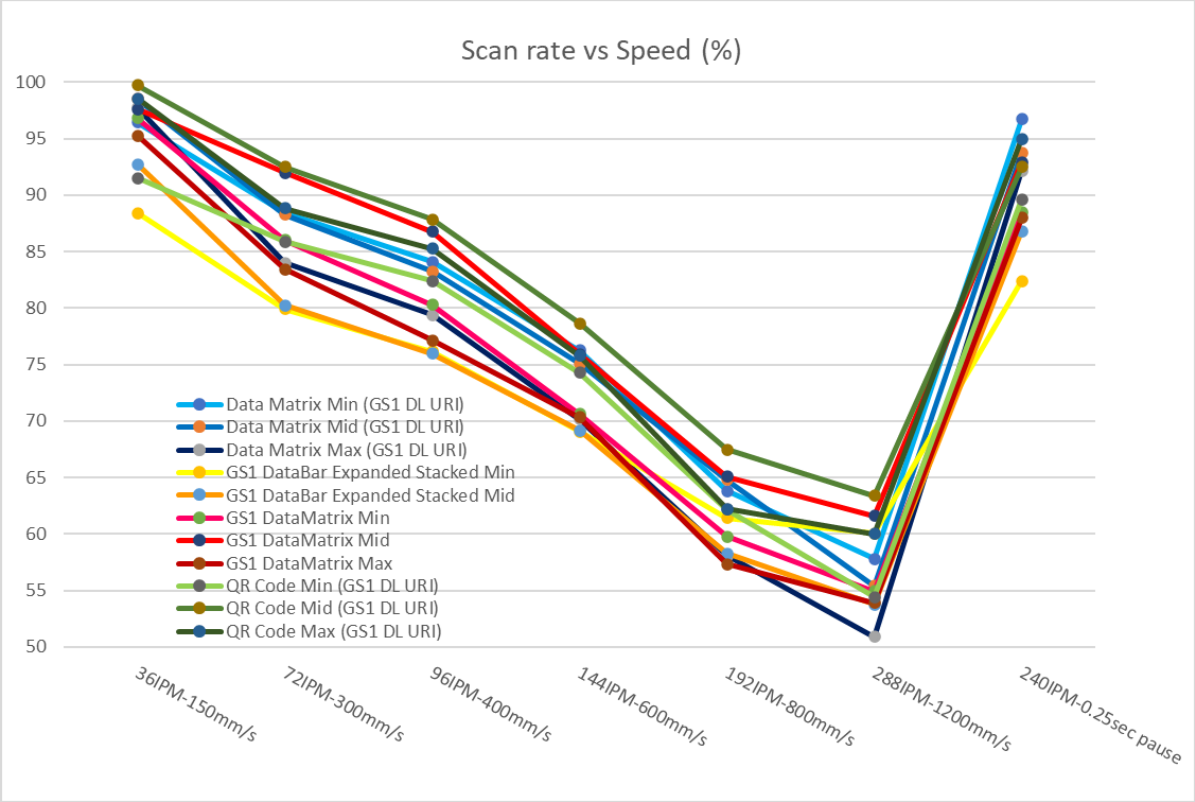
4.2 Items per minute (IPM) results (across all tested speeds)

As noted earlier, this Tier of tests is designed to identify opportunities for scanner improvements. The below chart shows the scan rate percentage based against the projected IPM for the full suite of tests as described in section 3.

The graph below visualises the throughput of what the scanning systems are currently capable based on all factors that affected the Tier 2 scan rates. The percent of the maximum items per minute scanned can be calculated by using the average scan rate at each scan speed multiplied by the speed → IPM table conversion values.

The barcodes are sorted based on their size (minimum to maximum X-dimension see section 4.9). The graph shows that barcodes printed based on GS1 General Specification limits perform similarly across all tests and that the higher barcode test card speeds would exceed the current retail norms. It also shows that adding the 0.25 second pause was a significant performance improvement.

Figure 4-3 Barcode scan rates across all IPM/speeds (%)



4.3 Average total scan time

This test measures the time required for a scan system to deliver the decoded barcode data to the AIDC test lab data acquisition system. The time start is triggered with the leading edge of the test card entering the bio-optic scanner station. The average scan times in Table 4-2 is a combination of the physical movement of the test card as well as system processing time, and is the sum of all the below elements of time:

- Optical sensor trigger time (start)
- Time of test card passing scan surfaces
- Bi-optic scanner capture and processing time for images of test card
- Decode process of located barcode(s) on captured images
- Data conversions performed by the scanner system
- Data transmission time

QR Code (GS1 Digital Link URI) clearly decoded in less time when compared to GS1 DataMatrix or Data Matrix (GS1 Digital Link URI) and was approximately 50 ms slower than 1D barcodes.

Table 4-2 Average total scan time (milliseconds)

Barcode type	150mm/s (ms)	300mm/s (ms)	400mm/s (ms)	600mm/s (ms)	800mm/s (ms)	1200mm/s (ms)	¼ sec pause (ms)
UPC-A	442	286	224	161	135	111	160
GS1 DataBar Expanded Stacked	491	330	254	184	156	129	190
GS1 DataMatrix	574	443	354	291	260	227	336
Data Matrix (GS1 DL URI)	577	414	362	291	248	233	301
QR Code (GS1 DL URI)	520	355	282	221	191	158	308

4.4 Number and type of barcode decoding algorithms enabled

The bi-optic scanner gives the user the ability to set which barcodes the scanning system will detect or ignore. This is enabled by allowing a set of barcode decoder algorithms to be switched on in any particular scanner. This test was designed to measure the effect of an increased number of barcode decoder algorithms being enabled on 1D and 2D barcodes on scanner performance.

Barcodes are randomly arranged so the any combination of barcode could be next to cross the scanners field of view. For example, a QR Code (GS1 DL URI) could be followed by a UPC-A or GS1 DataBar or GS1 DataMatrix. We tested the following scenarios:

- 1D and 2D barcode decode algorithms enabled
  - **Test 1:** EAN/UPC, GS1 DataBar Omnidirectional, GS1 DataBar Expanded Stacked, Data Matrix and QR Code
  - **Test 2:** EAN/UPC, GS1 DataBar Expanded Stacked, GS1 DataBar Omnidirectional, Data Matrix, QR Code, ITF-14, PDF417, Code 128, ISBN and watermark

The result of this set of tests showed there is little measurable effect on total scan time as a result of the number of enabled barcode decoder algorithms. This result is valid for the set of tests run on single barcodes present on the Tier 2 test cards and may be different when we execute Tier 3 tests in which multiple barcodes encode are presented to the scanners within the same scan window.

Table 4-3 Total scan time vs. number of barcode decode algorithms (in milliseconds) by barcode

Barcode type	Test 1 (ms)	Test 2 (ms)
UPC-A	207	232
GS1 DataBar Expanded Stacked	262	265
GS1 DataMatrix	334	362
Data Matrix (GS1 DL URI)	339	370
QR Code (GS1 DL URI)	320	312

4.5 Data Conversion (GS1 Digital Link URI → GS1 element string)

A comparison of the additional time required to convert the data extracted from a Data Matrix or QR Code that is encoded with GS1 Digital Link URI into a GS1 element string structure was performed and the data is in Table 4-4. The bi-optic scanner models names have been given aliases (e.g., Alpha#, Beta#, Delta#). The scanner manufactures receive their data to support future development if required.

For example if a QR Code or Data Matrix is encoded with a URI (https://example.com/01/09501101530003/10/AB-123?17=241021), scan system Delta and Alpha scanners will facilitate the conversion to (01)09501101530003(10)AB-123(17)241021 (and disregards "example.com"). The Beta scanner has the factory default software and settings and no ability to convert the decoded data.

The ability for the scanning system to do this translation is important to retailers, as it removes the requirement to make any changes to the POS backend systems within a particular retail environment. No appreciable delay was identified between units with GS1 Digital Link URI → GS1 element string conversion enabled vs. those without.

- **Note**: The bi-optic scanner models names have been given aliases (Alpha#, Beta#, Delta#). The scanner manufactures receive their data to support future development if required.

Table 4-4 Data conversion in milliseconds

Barcode type*	Alpha2 (ms)	Alpha5 (ms)	Beta3 (ms)	Delta0 (ms)	Delta1 (ms)
GS1 DataBar Omnidirectional: GTIN-only	190	158	231	290	195
GS1 DataBar Expanded Stacked: GTIN+	250	203	280	347	218
GS1 DataMatrix: GTIN-only *	228	469	407	553	241
GS1 DataMatrix: GTIN+	270	307	455	477	244
Data Matrix: GTIN-only * (GS1 DL URI)	234	500**	399	581	248
Data Matrix: GTIN+ (GS1 DL URI)	278	307**	467	484	246
QR Code: GTIN-only * (GS1 DL URI)	239	301	430	455	246
QR Code: GTIN+(GS1 DL URI)	240	237	470	377	271

*GTIN-only rows are data from Tier 1 testing. GTIN+ are the results of Tier 2 testing where additional data beyond the GTIN is present.

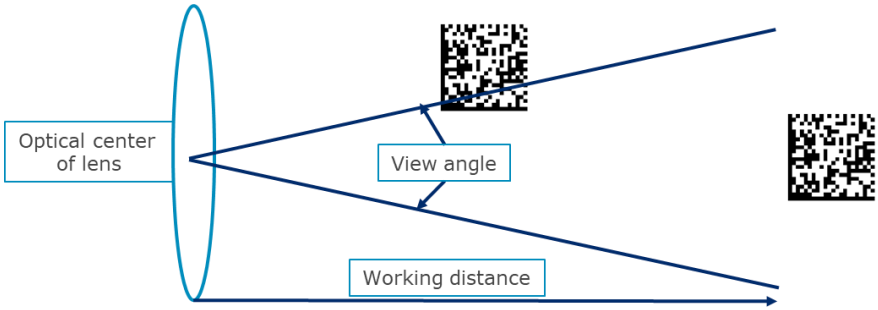
** Decreased data conversion time highlighted for this scanner is the result of scanner manufacturer optimisation of systems. This optimisation has resulted in a reduced scan time when additional data is present beyond the GTIN when compared to initial, GTIN-only Tier 1 tests.

4.6 Distance from scanner surface

The minimum to maximum distance from the scanner surface was determined for each scanning system, based on scanner system specifications. A safety margin was added to the lower limit to avoid any test cell robot collisions. The test was design to identify any concern with the distance from the barcode being scanned to the scanner itself. Ranges were tested from minimum specified range (+safety margin) to maximum specified range. The Tier 2 barcode test card design was optimised to better ensure the barcode was within the scanner's field of view.

For Tier 2 testing, 25mm was the minimum and 55mm was the maximum distance from the scanner vertical and horizontal surface. Table 4-5 is the average scan rate at accepted retail target IPM's (40 to 70) through all tilt angles, rotations and at each distance. See Appendix D for average scan rate across all speeds, tilt angles, rotations and at each distance.

Figure 4-4 Distance from scanner angles



The barcode test samples were produced to approximate the minimum, median and maximum size (X-dimensions) and is explained in the next section.

Table 4-5 Barcode to scanner distance at retail speeds (40-70 IPM) (scan rate %)

Barcode type	25mm vertical distance (%)	55mm vertical distance (%)	25mm horizontal distance (%)	55mm horizontal distance (%)
UPC-A Mid	96	90	98	90
GS1 DataBar Expanded Stacked Min	80	89	96	81
GS1 DataBar Expanded Stacked Mid	72	68	85	78
GS1 DataMatrix Min	93	90	95	90
GS1 DataMatrix Mid	86	83	94	84
GS1 DataMatrix Max	84	87	95	90
Data Matrix Min (GS1 DL URI)	91	89	98	90
Data Matrix Mid (GS1 DL URI)	87	89	98	90
Data Matrix Max (GS1 DL URI)	83	84	98	89
QR Code Min (GS1 DL URI)	94	88	99	90

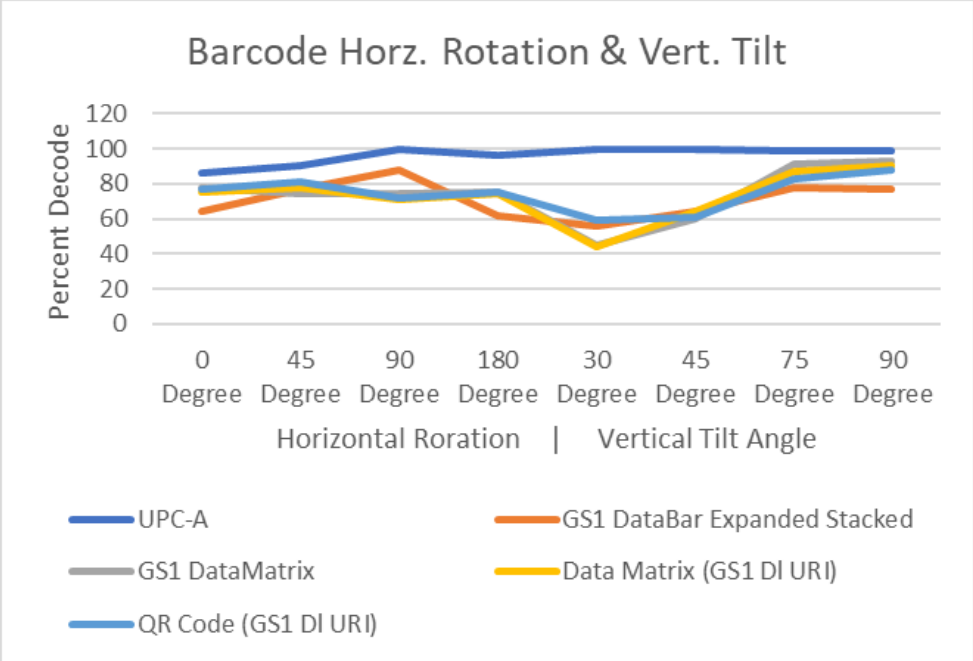
Barcode type	25mm vertical distance (%)	55mm vertical distance (%)	25mm horizontal distance (%)	55mm horizontal distance (%)
QR Code Mid (GS1 DL URI)	90	85	98	90
QR Code Max (GS1 DL URI)	87	84	98	89

4.7 Rotation in plane and tilt angle comparison

The effect of 1) barcode rotation in plane and 2) tilt angle towards vertical camera were explored. The barcode rotations and tilt angles were tested across varied surface offset and velocity settings. This test was designed to isolate and identify any concern with the direction or tilt of the barcode as it passes over the scanner.

Rotating the barcode test card in plane did not appear to impact the scan rate, however barcode test card tilt angle was determined to be impactful to scan rates, with larger angles reducing the scan rate for all the bi-optic scanners under test. Interestingly a 30-degree tilted barcode caused the largest reduction in scan rates for most scanners.

Figure 4-5 Barcode rotation and tilt scan rate across all tested speeds (%)



- **Note**: Barcode rotation and tilt angle scan rate in percentage

4.8 Printing technology comparison

Five printer manufacturers produced the test card barcodes using current production printing technologies. Each barcode was encoded to be unique and also was used to identify the printing technology used. The below table 4-7 shows the relative scan rates per technology across all card velocities.

One scanner manufacture had issues decoding the reverse reflectance test symbols (i.e., white on black) that were generated by created by laser printing. Otherwise, results were similar across all printing technologies with additional data.

Important to note is the significant performance gain at the very highest speed for ALL symbologies, due to the introduction of a ¼ second pause between adjacent scans. This ¼ second pause is intended to mimic the scenario of very fast passing of barcodes across scanners but only at a frequency that more accurately represents the fastest checkout staff.

Table 4-7 Printing technology scan rate with full test suite in percentage

Print type	150mm/s (%)	300mm/s (%)	400mm/s (%)	600mm/s (%)	800mm/s (%)	1200mm/s (%)	¼ sec pause (%)
CIJ *	92	83	78	67	56	49	88
Laser	85	79	73	63	53	48	82
Laser Jet	89	82	78	68	58	54	94
Thermal Transfer	93	83	79	71	61	58	88
TIJ	92	83	79	68	59	54	96

* Continuous Ink Jet printing used a new generation printer called Super Piezo Inkjet (SPI) that significantly improve the printing performance.

4.9 Barcode size (X-dimension) comparison

The range of 1D and 2D barcode sizes allowed at retail POS size is defined in GS1 General Specifications section 5.12.3.1 Symbol specification table 1 (shown below). The testing limited the X-dimension for all barcodes to be compliant with this table, insofar as was possible for each of the chosen printing technologies. The barcode test samples were produced to approximate the minimum, median and maximum X-dimensions wherever possible for each printing technology.

Figure 4-6 . GS1 symbol specification table 1

Main symbol(s) specified	X-dimension mm (inches)			Minimum symbol height for given X mm (inches)			Quiet Zone		Minimum quality specification
	Minimum	Target	Maximum	For minimum X-dimension	For target X-dimension	For maximum X-dimension	Left	Right	
EAN-13	0.264 (0.0104")	0.330 (0.0130")	0.660 (0.0260")	18.28 (0.720")	22.85 (0.900")	45.70 (1.800")	11*X*	7*X*	1.5/06/660
EAN-8	0.264 (0.0104")	0.330 (0.0130")	0.660 (0.0260")	14.58 (0.574")	18.23 (0.718")	36.46 (1.435")	7*X*	7*X*	1.5/06/660
UPC-A	0.264 (0.0104")	0.330 (0.0130")	0.660 (0.0260")	18.28 (0.720")	22.85 (0.900")	45.70 (1.800")	9*X*	9*X*	1.5/06/660
UPC-E	0.264 (0.0104")	0.330 (0.0130")	0.660 (0.0260")	18.28 (0.720")	22.85 (0.900")	45.70 (1.800")	9*X*	7*X*	1.5/06/660
GS1 DataBar Omni-directional	0.264 (0.0104")	0.330 (0.0130")	0.660 (0.0260")	12.14 (0.478")	15.19 (0.598")	30.36 (1.195")	None	None	1.5/06/660
GS1 DataBar Stacked Omni-directional	0.264 (0.0104")	0.330 (0.0130")	0.660 (0.0260")	25.10 (0.988 ")	31.37 (1.235")	62.70 (2.469")	None	None	1.5/06/660
GS1 DataBar Expanded	0.264 (0.0104")	0.330 (0.0130")	0.660 (0.0260")	8.99 (0.354")	11.23 (0.442")	22.44 (0.883")	None	None	1.5/06/660
GS1 DataBar Expanded Stacked	0.264 (0.0104")	0.330 (0.0130")	0.660 (0.0260")	18.75 (0.738")	23.44 (0.923")	46.86 (1.845")	None	None	1.5/06/660
GS1 DataMatrix	0.375 (0.0148)	0.625 (0.0246)	0.990 (0.0390)	Height is determined by the X-dimension and data that is encoded			1X on all four sides		1.5/08/660
GS1 QR Code	0.375 (0.0148)	0.625 (0.0246)	0.990 (0.0390)	Height is determined by the X-dimension and data that is encoded			4X on all four sides		1.5/08/660

Figure 4-7 Symbol specification table 1 addendum 2 for 2D Barcodes

Symbol(s) specified	X-dimension mm (inches)			Minimum symbol height for given X mm (inches)			Quiet Zone	Minimum quality specification
	Minimum	Target	Maximum	For minimum X-dimension	For target X-dimension	For maximum X-dimension	Surrounding Symbol	
GS1 DataMatrix (ECC 200)	0.396 (0.0150")	0.495 (0.0195")	0.990 (0.0390")	Height is determined by X-dimension and data that is encoded			1X on all four sides	1.5/12/660
Data Matrix (GS1 Digital Link URI) (ECC 200)	0.396 (0.0150")	0.495 (0.0195")	0.990 (0.0390")	Height is determined by X-dimension and data that is encoded			1X on all four sides	1.5/12/660
QR Code (GS1 Digital Link URI)	0.396 (0.0150")	0.495 (0.0195")	0.990 (0.0390")	Height is determined by X-dimension and data that is encoded			4X on all four sides	1.5/12/660

Within normal retail speeds and when test barcodes pass directly in front of the scanner's camera surfaces, the result showed acceptable scanner performance for all standards-based sizes of both 1D and 2D barcodes.

However, when we add all the test factors (e.g., maximum barcode distances, barcode tilt angles, higher speeds, print technologies, etc) the percentage of successful scans drops. The 2D barcodes

with additional data performed equivalently or better than the 1D barcodes with equivalent data. In some cases, the 2D barcode was successfully scanning as the control UPC-A.

Table 4-8 Barcode scan rate across all tested speeds (%)

Barcode type	36 IPM 150mm/s	72 IPM 300mm/s	96 IPM 400mm/s	144 IPM 600mm/s	192 IPM 800mm/s	288 IPM 1200mm/s	240 IPM ¼ sec pause
UPC-A Mid	97	95	95	95	91	91	95
GS1 DataBar Expanded Stacked Min	88	80	76	69	61	60	82
GS1 DataBar Mid	93	80	76	69	58	54	87
GS1 DataMatrix Min	91	81	77	71	60	55	89
GS1 DataMatrix Mid	98	92	87	76	65	62	93
GS1 DataMatrix Max	95	83	77	70	57	54	88
Data Matrix Min (GS1 DL URI)	96	88	84	76	64	58	97
Data Matrix Mid (GS1 DL URI)	99	88	83	75	65	55	94
Data Matrix Max (GS1 DL URI)	98	84	79	70	58	51	92
QR Code Min (GS1 DL URI)	92	86	82	74	62	54	90
QR Code Mid (GS1 DL URI)	99	93	88	79	68	63	93
QR Code Max (GS1 DL URI)	99	98	85	76	62	60	95

5 Conclusions and recommendations

The scanner manufacturers agreed that the rigors of this set of tests would uncover opportunities for improvements in decoding and locating algorithms. The tests were determined to be a good and challenging lab representation of the retail POS scan environment.

GS1, the University of Memphis and the scanner manufacturers also agreed that retail store pilots are needed to continue the learning and vetting of POS scanner improvements. As stated in our Tier 1 report, we have had over 45 years to optimise scanners for 1D barcodes and will need the stakeholders to collaborate to continue to improve 2D scanning performance for all scanners that have been tested.

Tier 1 testing was used to set the baseline for improvements and therefore, no 2D setting optimisation was done by any bi-optic scanner solution provider. Prior to Tier 2 tests, the scanner manufacturers supplied currents scanner setting optimisation that improved 2D barcode performance over similar tests conducted during Tier 1. Tier 2 also saw a software update (from two

scanner manufacturers) to enable the conversion of 2D barcodes leveraging GS1 Digital Link URI syntax with GTIN and additional data attributes to a format that current POS systems can use (GS1 element strings). The ability for the scanning systems to do this conversion is important to retailers, as it removes the requirement to make changes to the POS backend systems within a particular retail environment.

The results show that 2D barcodes encoded with GTIN and additional attributes can meet today's retail throughput requirement of ~40-70 items per minute in a controlled environment. It is important to note that the tests performed in these Tier 2 tests did not include any additional "noise" surrounding the barcodes (label graphics, reflective surfaces, curved surfaces, etc). It is also important to note that a lab robot cannot simulate human motions and that lab testing cannot fully replicate a retail environment. Therefore, retail pilots continue to be seen as essential to complement to the results captured in these lab tests.

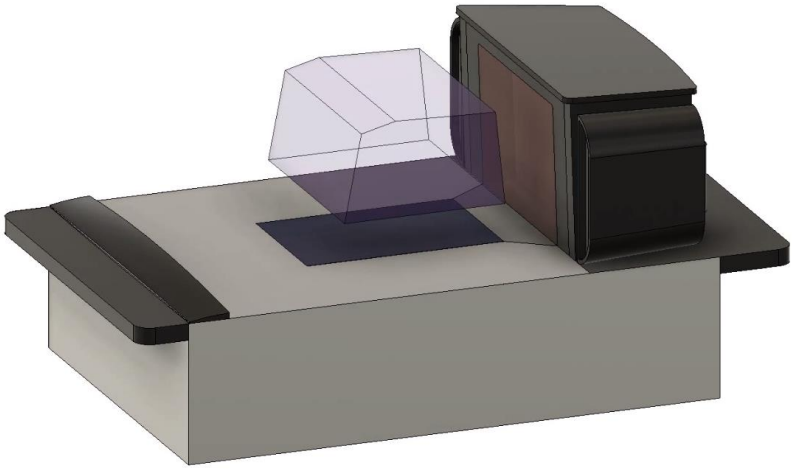
The lab tests have shown that the current GS1 standards for barcode dimensions work with a representative sample of today's most popular scanning systems. Future tests will need to be done to understand how earlier generations and other manufacturers' bi-optic scanner solutions decode the Tier 2 barcode test cards. Once this bi-optic test complete, presentation and handheld scanners testing is also planned, to understand the impacts and potential changes to these retail scanning tools.

The Tier 2 tests showed that barcode direction and the number of barcode types (decode algorithms) enabled do not adversely affect the throughput, as the average decode time were not meaningfully different when these variables were changed.

The Tier 2 tests began to show differences in total scan time between 2D symbologies, with QR code consistently decoding faster than any Data Matrix symbology. We will more deeply analyse this in our Tier 3 testing.

Barcode test card distance to the scanning surface and tilt angle did impact the barcode scan rate. Scanning at the minimum distance caused lower scan rates at higher speeds. Barcode test card tilt angle was determined to be impactful to scan rates, with larger angles reducing the scan rate for all the bi-optic scanners under test. For Tier 3 testing the 2D barcode scanning envelope (see Figure 5-1) will be determined to optimise the initial label path across the scanner before any directional offsets.

Figure 5-1 Optimal 2D scanning envelope



For the Tier 3 tests, scanner solution providers will deliver new software that will build on the first two tiers of testing findings. This new software will be able to deliver multiple decodes if the label contains co-located barcode encode with GTIN or GTIN plus additional data.

A Annex: Tier 2 barcodes

During the Tier 2 test, twenty barcodes were tested. The barcodes varied in:

- Barcode type
  - UPC family
  - GS1 DataBar family
  - GS1 DataMatrix
  - Data Matrix (GS1 Digital Link URI)
  - QR Code (GS1 Digital Link URI)
- Data encoded
  - GTIN, batch/lot number and expiration date
  - GTIN, batch/lot number, expiration date and domain name
  - GTIN, batch/lot number, expiration date and packaging component number
  - GTIN, batch/lot number, expiration date, packaging component number and domain name
  - GTIN, batch/lot number, expiration date, packaging component number and serial number
  - GTIN, batch/lot number, expiration date, packaging component number, serial number and domain name
- Size (X-dimension)
- Print technology used to produce
  - Thermal transfer printing
  - Laser printing
  - New Generation Continuous inkjet (CIJ/SPI)
  - Thermal inkjet (TIJ)
- Print quality (various levels of contrast)
- Error correction level (for QR Code only)

Below image show a sample of the barcodes created for the test on the test card carriers. No barcode from outside of the GS1 system (e.g., Code 39, MaxiCode, JAB Code, etc.) were used in this testing

Figure A-5-2 Barcode test cards

The table below shows the different barcodes and the characteristics of the barcodes. Note that the data encoded was a GTIN + attributes unless the barcode was a QR Code or Data Matrix, in which case a GS1 Digital Link URI was encoded to comply with the minimum requirements.

Table A-5-3 Tier 2 test card barcodes

Symbologies	URL	Data (GTIN or GTIN+)			Error Correction	X-dimension (min, target)	Print Tech (Thermal, CIJ, TIJ, Laser)
GS1 DataBar Expanded Stacked		**0095214100001**	5	(10)10ABC(17)271231		0.264 (0.0104")	Laser Jet
		0095214100002	2	(10)10ABC(17)271231		0.330 (0.0130")	Thermal
		0095214100003	9	(10)10ABC(17)271231		0.660 (0.0260")	Thermal
		0095234100004	4	(10)10ABC(17)271231		0.330 (0.0130")	TIJ
		0095224100005	2	(10)10ABC(17)271231		0.330 (0.0130")	LASER
		628242245654		(17)500723(10)VPET08201G			LASER
GS1 DataMatrix		**0095216100006**	4	(10)10ABC(17)271231		0.375 (0.0148)	Laser Jet
		0095216100007	1	(10)10ABC(17)271231		0.990 (0.0390)	Thermal
		0095246100008	5	(10)10ABC(17)271231(243)1234		0.625 (0.0246)	CIJ
		0095236100009	3	(10)10ABC(17)271231(21)392874		0.625 (0.0246)	TIJ
		0095226100010	0	(10)10ABC(17)271231(21)39287(243)1234		0.625 (0.0246)	LASER
		0095246100008	5	(10)10ABC(17)271231(243)1234			SPI
QR Code (DL URI)	https://dalgiardino.com	**0095217200006**	0	(10)10ABC(17)271231	L	0.396 (0.0150")	Laser Jet
	https://dalgiardino.com	0095217200007	7	(10)10ABC(17)271231	M	0.743 (0.0293")	Thermal
	https://dalgiardino.com	0095247200008	1	(10)10ABC(17)271231(243)1234	L	0.495 (0.0195")	CIJ
	https://dalgiardino.com	0095237200009	9	(10)10ABC(17)271231(21)392874	M	0.625 (0.0246)	TIJ
	https://dalgiardino.com	0095227200010	6	(10)10ABC(17)271231(21)39287(243)1234	L	0.625 (0.0246)	LASER
	https://dalgiardino.com	0095247200008	1	(10)10ABC(17)271231(243)1234			SPI
Data Matrix (DL URI)	https://dalgiardino.com	**0095218200006**	7	(10)10ABC(17)271231		0.396 (0.0150")	Laser Jet
	https://dalgiardino.com	0095218200007	4	(10)10ABC(17)271231		0.743 (0.0293")	Thermal
	https://dalgiardino.com	0095248200008	8	(10)10ABC(17)271231(243)1234		0.495 (0.0195")	CIJ
	https://dalgiardino.com	0095238200009	6	(10)10ABC(17)271231(21)392874		0.625 (0.0246)	TIJ
	https://dalgiardino.com	0095228200010	3	(10)10ABC(17)271231(21)39287(243)1234		0.625 (0.0246)	LASER
	https://dalgiardino.com	0095248200008	8	(10)10ABC(17)271231(243)1234			SPI

B Annex: Test profiles

Twenty-three different test profiles (summarised in the table below) were run to analyse and understand the read rates of different barcodes. The parameters that were adjusted are explained as follows:

A. The number of enabled barcode decode algorithms varied from a limited profile, only looking for expected barcodes, 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 (Test 2) in all scanners: Data Matrix, QR Code, GS1 DataBar Expanded Stacked, GS1 DataBar Omnidirectional, EAN/UPC, ITF-14, PDF417, Code 128, Code 39, ISBN, watermark
B. When the barcode symbol was passed in front of the scan window, the height or distance from the scan window was tested at 25, 55mm.
C. 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 1500mm/s + a 250ms pause.
D. The barcodes were presented at different tilt angles from parallel to the scan window: 0°, 30°, 45°, 75°, and 90°.
E. Within the parallel presentation to the scan window, the barcodes were rotated clockwise: 0°, 45°, 90°, and 180°.

Table B-5-4 Test Matrix

Auto Discriminate	height	speed	Tilt Angle from Horzontal	CW Rotation in Plane	Test ID
Test 1	all (25, 55)	all	0	0	test8
				45	test9
				90	test10
				180	test11
			30	0	test12
			45	0	test13
			75	0	test14
			90	0	test15
Test 2	all (25, 55)	all	0	0	test16
				45	test17
				90	test18
				180	test19
			30	0	test20
			45	0	test21
			75	0	test22
			90	0	test23

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 Specification Section 5.12 Barcode production and quality assessment. Only barcodes that received a 1.5 (C) and above were acceptable for testing.

Table C-5-5 Verification table

Symbology	Data	Acceptance Criteria	SYMBOL ANSI GRADE	ANSI Letter Grade	ANSI Numeric Grade
GS1 DataBar Expanded Stacked	0100952341000044101 0ABC17271231	GS1 Acceptance Criteria PASS	A(4.0/10/660)	A	4
GS1 DataBar Expanded Stacked	0100952141000022101 0ABC17271231	GS1 Acceptance Criteria PASS	A(4.0/10/660)	A	4
GS1 DataMatrix	0100952161000064101 0ABC17271231	GS1 Acceptance Criteria PASS	A(4.0/08/660)	A	4
GS1 DataMatrix	0100952161000071101 0ABC17271231	GS1 Acceptance Criteria PASS	A(4.0/20/660)	A	4
GS1 DataMatrix	0100952361000093101 0ABC17271231	GS1 Acceptance Criteria PASS	A(4.0/12/660)	A	4
Data Matrix	https://dalgiardino.com/01/00952182000067/10/10ABC?17=271231	GS1 Acceptance Criteria PASS	B(2.6/08/660)	B	3
Data Matrix	https://dalgiardino.com/01/00952182000074/10/10ABC?17=271231	GS1 Acceptance Criteria PASS	A(4.0/15/660)	A	4
Data Matrix	https://dalgiardino.com/01/00952382000096/10/10ABC?17=271231	GS1 Acceptance Criteria PASS	A(4.0/12/660)	A	4
Data Matrix	https://dalgiardino.com/01/00952282000103/10/10ABC?17=271231	GS1 Acceptance Criteria PASS	A(4.0/12/660)	A	4
QR Code	https://dalgiardino.com/01/00952172000077/10/10ABC?17=271231	GS1 Acceptance Criteria PASS	A(4.0/15/660)	A	4
QR Code	https://dalgiardino.com/01/00952372000099/10/10ABC?17=271231	GS1 Acceptance Criteria PASS	A(4.0/12/660)	A	4
QR Code	https://dalgiardino.com/01/00952272000106/10/10ABC?17=271231	GS1 Acceptance Criteria PASS	A(4.0/12/660)	A	4
QR Code	https://dalgiardino.com/01/00952172000060/10/10ABC?17=271231	GS1 Acceptance Criteria PASS	C(1.5/07/660)	C	2
GS1 DataBar Expanded Stacked	0100952141000015101 0ABC17271231	GS1 Acceptance Criteria PASS	A(4.0/05/660)	A	4
GS1 DataMatrix	0100952261000100101 0ABC17271231213928724312 34	GS1 Acceptance Criteria PASS	A(4.0/12/660)	A	4
QR Code	https://dalgiardino.com/01/00952472000081/10/10ABC?17=271231&243=1234	GS1 Acceptance Criteria PASS	C(1.7/6.0/660)	C	2
GS1 DataMatrix	0100952461000085101 0ABC172712312431234	GS1 Acceptance Criteria PASS	A(4.0/10/660)	A	4
Data Matrix	https://dalgiardino.com/01/00952482000088/10/10ABC?17=271231&243=1234	GS1 Acceptance Criteria PASS	A(4.0/10/660)	A	4
UPC-A	4569956100265	GS1 Acceptance Criteria PASS	A(4.0/10/660)	A	4
QR Code		GS1 Acceptance Criteria FAIL	FAIL Decode	F	0

D Annex: Distance from scanner surface (all speeds)

Table C-4-6 is the average scan rate across all speeds, tilt angles, rotations and at each distance. For Table C-4-6 the major reason for the 10%-15% decrease in performance at the nearest distance from the scanner glass is related to the limited time the barcode test card is in the scanner's field of view at higher speeds.

Table C-5-6 Barcode to scanner distance across all speeds (scan rate %)

Barcode type	25mm vertical distance (%)	55mm vertical distance (%)	25mm horizontal distance (%)	55mm horizontal distance (%)
UPC-A Mid	92	88	97	89
GS1 DataBar Expanded Stacked Min	71	84	82	78
GS1 DataBar Expanded Stacked Mid	65	73	62	74
GS1 DataMatrix Min	70	82	84	86
GS1 DataMatrix Mid	65	83	79	81
GS1 DataMatrix Max	62	76	76	85
Data Matrix Min (GS1 DL URI)	69	85	62	74
Data Matrix Mid (GS1 DL URI)	65	85	80	85
Data Matrix Max (GS1 DL URI)	61	79	77	81
QR Code Min (GS1 DL URI)	70	79	82	78
QR Code Mid (GS1 DL URI)	67	86	78	85
QR Code Max (GS1 DL URI)	66	84	76	83