The Relationship of 2D Barcode Size and its Ability to Decode

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Abstract

The forthcoming Sunrise 2027 mandate, initiated by GS1, compels retail and consumer goods sectors to transition from traditional one-dimensional (1D) barcodes to two-dimensional (2D) barcodes at point-of-sale (POS) and point-of-care (POC) systems. This shift necessitates the adoption of QR codes capable of encoding substantially more data, including batch numbers, expiration dates, and pricing, while remaining scannable within the spatial constraints of product packaging. The objective of this research is to determine the smallest viable QR code size that maintains scanability and verification accuracy, considering both the amount of data encoded and the generation method employed.

This study tested QR codes across seven data volumes and three generation methods: Adobe InDesign (vector format), a standard web-based generator (non-GS1), and a GS1-compliant generator. Each QR code was scaled incrementally from 100% to 10% of its original size and verified using a Cognex DataMan 8072V verifier in accordance with ISO 15415 grading standards. Results indicate that QR codes generated via the web-based tools, including GS1-compliant formats, remained verifiable at scales as low as 13%, whereas InDesign-generated codes demonstrated higher minimum scale thresholds.

The findings underscore the importance of barcode generation method, encoded data volume, and QR code design parameters—such as quiet zones and fixed pattern integrity—in achieving optimal readability on packaging. This research offers practical insights for CPG companies preparing for the Sunrise 2027 compliance deadline, enabling informed decisions about QR code implementation within constrained design environments.

Introduction

Retail and consumer goods industries working with Global Standards 1(GS1), a global non-profit organization that manages standards for identification, capturing, and sharing information across the supply chain, have established a

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target date, known as Sunrise 2027, to transition from 1 dimensional barcodes to 2 dimensional barcodes at point-of-sale (POS) and point-of-care (POC) systems (GS1US, n.d.).

Figure 1: 1-dimensional barcode

Figure 2 2-dimensional barcode

Unlike traditional barcodes, 2D barcodes can store significantly more information, including batch and lot numbers, weight, price, and expiration dates (The World of 2D Barcodes, n.d.). They can also provide access to product promotions, usage instructions, and recall notifications—all within this single barcode. This enhanced data capacity allows brands and consumers across the supply chain to access critical product information efficiently through a single scan (The World of 2D Barcodes | GS1 US, n.d.)

Currently, QR codes used in consumer packaging are typically placed for consumer use. The Consumer Product Companies (CPG) will encode a website or tiny url containing consumer-facing information such as product information, enriched content, sustainability practices, etc. This generates a small barcode that is easily placed on products and scanned by the consumer. When Sunrise 2027 goes into effect, the addition of pricing information, batch and lot numbers, weight, price, etc., will increase the data and therefore the size of the QR code. The resulting QR code size will directly affect printers that produce packaging for CPGs.

The need for this research was initiated out of an interest from CPGs that will need to move from their current 1D barcode to the new 2D barcode. As mentioned, the amount of information that can be encoded in the 2D barcodes, far exceeds it predecessor. This study looks at the amount of information encoded in a QR code, its resulting size, and the smallest scale that QR code can be read and verified. This will be very important when redesigning product labels and packaging because the code will not only need to fit in the limited space but also be readable by POS scanners as well as smartphones.

Purpose of the study

The purpose of this study is to determine the smallest QR code that can be scanned and verified based on the amount of information encoded. There are 40 different versions of a QR code. Version 1 encodes the smallest amount of data, and the resulting size is 21x21 modules. The largest QR code, version 40, encodes the most amount of data and is 177x177 modules in size (Information Capacity and Versions of QR Code, n.d.). When each of these QR codes is placed on packaging, it needs to fit within the size and layout of the final product. This study is determining the smallest size the resulting QR code can be scanned by both a barcode verifier and a smartphone.

Hypotheses developed in this research:

- H_1—QR codes with less data encoded will scan and verify at smaller sizes than codes with more data encoded.
- H_2—Generation method of QR codes will have no impact on scan ability or verification.

Review of Related Literature

Most of the research on QR codes occurred over ten years ago and consists of the technology behind the codes, how the use of them in many markets can ease in data collection, and consumer use in advertising. The use of QR codes has greatly increased since 2020, resulting from the COVID-19 outbreak and the need for a touch-free society. Since this resurgence, the QR code is now headed to replace the one-dimensional codes that have been used since 1973 in retail POS. There is a current need to determine the limitations of QR code use in packaging with the onset of Sunrise 2027.

GS1, the organization behind Sunrise 2027, developed a standard that defines how identification keys, data attributes and barcodes must be used in business applications across the globe. These standards provide a common language shared by both businesses and consumers. Their efforts allow consumers to follow the food they eat—from the farm to the table, as well as a shopper to access detailed product information from their mobile device, and for companies to save through greater product and item visibility in their supply chain (GS1 standards, n.d.). GS1 barcodes are designed to meet the requirements of ISO 15415, ensuring their readability and accuracy in scanning for retail point of sale and distribution.

ISO 15415:2024 specifies methodologies for the measurement, evaluation, and grading of two-dimensional bar code symbols. The bar code symbol must be produced in such a way as to be reliably decoded at the point of use.

There are many factors that ensure the QR code is reliably decoded, and the combination of these factors will result in an overall scan grade. This scan grade is derived from taking the lowest grade achieved in any one of the eight measured parameters. A passing grade is 2 or higher.

Numeric	Alphabetic Grade
4	A
3	B
2	C
1	D
0	F

Table 1 Quality grading

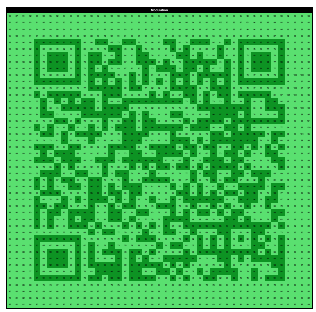


Figure 3 Modulation (Grade: A)

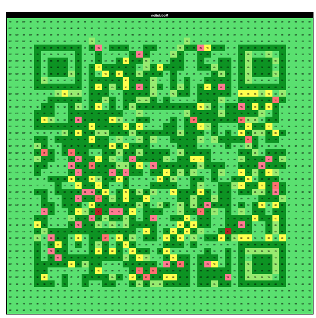


Figure 4 Modulation (Grade: D)

Symbol Grading

The eight parameters used in the overall symbol grading include unused error correction, symbol contrast, modulation, reflectance margin, axial nonuniformity, grid nonuniformity, fixed pattern damage, and decode. Unused Error Correction (UEC) is a parameter that tests the extent to which regional or spot damage in the symbol has eroded the reading safety margin that error correction provides. Symbol contrast tests that the two reflective states in the symbol are distinct within the symbol. Modulation (MOD) measures the uniformity of reflectance of the dark and light modules respectively. Factors such as print growth (or loss), and uneven printing may reduce the absolute value of the difference between the reflectance of a module and the Global Threshold. Reflectance Margin (RM) measures how well each module is correctly distinguishable as light or dark in comparison to the global threshold. Factors such as print growth (or loss), uneven printing, or encoding errors, may reduce or even eliminate the margin for error between the reflectance of a module and the Global Threshold. Axial Nonuniformity (ANU) measures and grades the spacing of the mapping centers. It also tests for uneven scaling of the symbol. Grid Nonuniformity (GNU) measure and grades the largest vector deviation of the grid intersections from their ideal theoretical position. Fixed Pattern Damage (FPD) tests damage to the finder pattern, quiet zone, timing, navigation and other fixed patterns. The Decode grade is either pass or fail— it tests whether the symbol's features are sufficiently correct to be readable by the reference decode algorithm.

Quality Parameters		Grade	Grade	
1. Unused Error Correction (UEC)	101%	4.0	A	PASS
2. Cell Contrast (CC)	90%	4.0	A	PASS
3a. Cell Modulation (CMOD)		4.0	A	PASS
3b. Reflectance Margin (RM)		4.0	A	PASS
4. Axial Nonuniformity (ANU)	0.1%	4.0	A	PASS
5. Grid Nonuniformity (GNU)	0.0%	4.0	A	PASS
6. Fixed Pattern Damage (FPD)		4.0	A	PASS
7. Upper Left Pattern (ULP)		4.0	A	PASS
8. Upper Right Pattern (URP)		4.0	A	PASS
9. Lower Left Pattern (LLP)		4.0	A	PASS
10. Horizontal Clock Track (HCT)		4.0	A	PASS
11. Vertical Clock Track (VCT)		4.0	A	PASS
12. Alignment Pattern (ALP)		4.0	A	PASS
13. Version Information Block (VIB)		4.0	A	PASS
14. Format Information Block (FIB)		4.0	A	PASS

Table 2 Verification Report Quality Parameters (Grade: A)

UEC	Grade
>= 0.62	4
>= 0.50	3
>= 0.37	2
>=0.25	1
<0.25	0

Table 3 Grading of Unused Error Correction

SC	Grade
>= 70%	4
>= 55%	3
>= 40%	2
>=20%	1
<20%	0

Table 4 Symbol Contrast grading

MOD or Margin	Grade
>= 0.50	4
>= 0.40	3
>= 0.30	2
>=0.20	1
<0.20	0

Table 5 Module grading for Modulation and Reflectance Margin

UEC	Grade
<= 0.06	4
<= 0.08	3
<= 0.10	2
<=0.12	1
>0.12	0

Table 6 Axial Nonuniformity grading

UEC	Grade
<= 0.38	4
<= 0.50	3
<= 0.63	2
<=0.75	1
>0.75	0

Table 7 Grid Nonuniformity grading

Symbol Readability

There are five factors that affect the readability of the QR code. As with one-dimensional codes, a quiet zone is necessary to prevent from scanner mis-reads. When placing the QR code, it is recommended to use a four-module quiet zone on all four sides of the code (shown in Figure 1). The finder pattern shown in Figure 2 is used by the scanning device to identify it as a QR code. This also allows the device to determine the orientation of the code—rotating the code has no impact on the readability. The Timing Pattern shown in Figure 3 determines the module size and location of data. The Alignment Pattern (ALP) ensures the code can be read when it is distorted. Distortion can occur when scanning from an angle, or on a curved surface. Larger QR codes will have more alignment patterns to ensure accurate scanning. The code shown in Figure 4 has only one. The Format Information Block (FIB), highlighted green in Figure 5, specifies the code's structure, version (Figure 5, highlighted orange), error correction, and data masking pattern. Not only is it important to ensure these elements are all present in the QR code when it is generated and placed, but it is also important to pay attention to these areas when printing. If they are missing or printed poorly, this can make the QR code unreadable.

Figure 5 Quiet Zone

Figure 6 Finder Pattern

Figure 7 Timing Pattern

Figure 8 Alignment Pattern

Figure 9 Format Information Block

Data Capacity

The amount of data that can be encoded in a QR code depends on three factors: symbol version, type of data encoded, and the level of error correction. As the amount of data increases, more modules are added to the resulting code. Figure 6 shows three different module configurations, and Table 8 shows the data capacity of three different QR code sizes. QR codes use the Reed-Solomon Error Correction algorithm (Garg, 2025).

21x21 25x25 45x45

Figure 10 Version module configuration

Version	Number of Modules	Error Correction Level	Data Bits (mixed)	Numeric	Alpha-numeric	Binary	Kanji
1	21x21	L (7%)	152	41	25	17	10
		M (15%)	128	34	20	14	8
		Q (25%)	104	27	16	11	7
		H (30%)	72	17	10	7	4
2	25x25	L	272	77	47	32	20
		M	224	63	38	26	16
		Q	176	48	29	20	12
		H	128	34	20	14	8
40	177x177	L	23,648	7,089	4,296	2,953	1,817
		M	18,672	5,596	3,391	2,331	1,435
		Q	13,328	3,993	2,420	1,663	1,024
		H	10,208	3,057	1,852	1,273	784

Table 8 Data capacity of QR codes

Research Methods

The QR codes used in this research were generated using three different methods, and in seven different encoding sizes (Table 9). One set of QR codes was generated using Adobe InDesign and the other two sets of codes were generated using the website barcode.tec-it.com. The web generated QR codes are indexed gifs, and the InDesign-generated code is vector. It should be noted that the InDesign-generated QR code and one set of the gif barcodes are not GS1 compliant. These barcodes are primarily used for consumer-facing information and marketing purposes; they cannot be scanned by point-of-sale (POS) scanners. The second set of gif barcodes generated are GS1 compliant, incorporating the GS1 Global Trade Item Number (GTIN), allowing it to be scanned by POS scanners and mobile devices. The same URLs were used in creating each set of QR codes.

All QR codes were colored black and placed at the sizes shown in Table 9, then duplicated and reduced in scale by 10% increments from 100% down to 20%, the smallest three codes were scaled by 1% increments from 19% to 10% (as shown in Figure 7).

The test sheets were printed on 80# silk cover, using a Konica Minolta Accurio C12000 digital press, and scanned/verified using a Cognex DataMan 8072V Verifier.

2D Barcode Verifier

Barcode verifiers analyze the structure of the symbol and the reflectance of each of the modules. These codes are then graded according to the eight different parameters discussed earlier using the ISO 15415 standard. The Cognex Dataman Verifier scans with an aperture of 08 and a 660 nanometer (red) light with a 45º angle of illumination. The lens of the model used captures a 1” x .78” field of view. Due to this constraint, the study read barcode sizes .7” and smaller. Three test sheets were printed and scanned for every code. The resulting scan grades were averaged and are shown in Table 12, 13, and 14.

QR Code	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7
Number of Alphanumeric characters	5	19	46	72	84	113	190
InDesign module size	21x21	25x25	33x33	37x37	37x37	45x45	61x61
Web generated gifs module size	21x21	25x25	29x29	33x33	37x37	41x41	49x49

Table 9

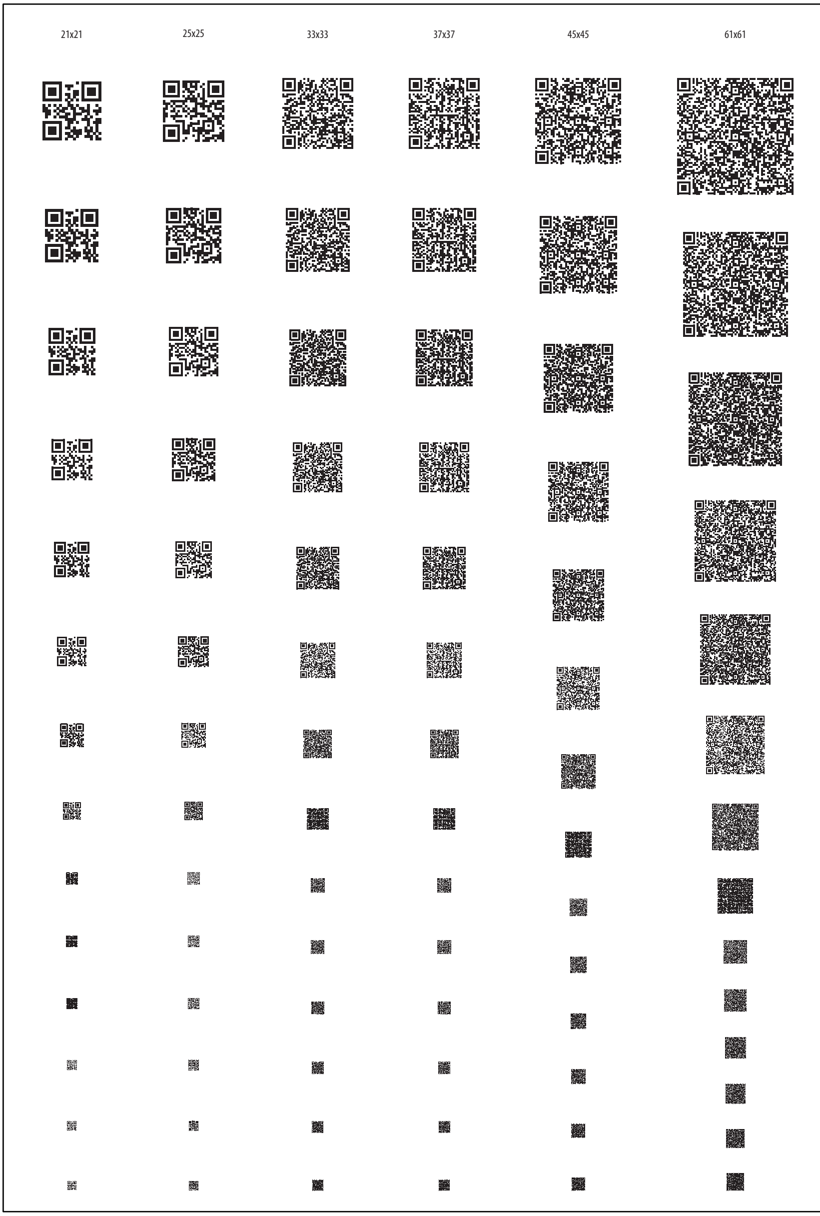


Figure 11 InDesign file layout

QR Code Size

The number of modules in the barcode have a direct effect on the resulting barcode size. The sizes of these QR codes, when placed at 100% are shown in Table 10. As the number of modules increases, the overall code size increases. The same URLs were used for each set of QR codes. Interestingly, three of the URLs created resulted in a different number of modules when created using InDesign versus the online generation (see Table 10). This accounts for some of the empty cells shown in Table 11.

URL	InDesign	Online Generated
3	33x33	29x29
4	37x37	33x33
6	45x45	41x41

Table 10 Module Size Discrepancies

	InDesign		Online GIFs	
Module Size	Millimeters	Inches	Millimeters	Inches
21x21	22	.866	30	1.18
25x25	23	.906	36	1.42
29x29			41	1.61
33x33	24.5	.965	47	1.85
37x37	26.5	1.04	52.5	2.07
41x41			58.5	2.30
45x45	32	1.26		
49x49			69.5	2.74

Table 11 Module configuration and resulting code size at 100%

Findings

This study examined the readability and verification performance of QR codes generated using different methods, encoded with varying amounts of data, and scaled to multiple sizes. The primary goal was to identify the smallest QR code that could be reliably scanned and verified, in compliance with ISO 15415 grading standards. Key findings are summarized below:

Effect of Encoded Data Volume on Scanability

The results confirmed that QR codes with fewer alphanumeric characters (e.g., 5 to 19 characters) were consistently scannable at smaller sizes than those with more extensive data (e.g., over 100 characters). As data volume increased, the number of modules in the QR code increased, necessitating larger physical dimensions to achieve acceptable scan grades. This supports Hypothesis H1, indicating that lower data density improves scanability at reduced scales.

Performance of Different QR Code Generation Methods

The method used to generate QR codes significantly influenced their scanability. QR codes generated via online tools—especially GS1-compliant GIF versions—consistently achieved high scan grades down to 13% of their original size across all module configurations. In contrast, QR codes created in Adobe InDesign exhibited diminished performance at smaller scales, with readable results tapering off below 14–15% scale. This refutes Hypothesis H2 and highlights that vector-based QR codes generated via InDesign are less suitable for applications requiring minimal barcode size.

Impact of Module Configuration and Scaling

The physical size of a QR code at 100% scale varied depending on the module count and generation method. Online-generated codes were often larger in physical dimensions than their InDesign counterparts at the same module size yet remained more readable when scaled down. Across all tests, the smallest successful scan sizes by module configuration were as follows: 21x21 modules at 4 mm, 25x25 at 4.5 mm, and up to 49x49 modules at 9 mm (see Table 15 for more information). These measurements offer concrete benchmarks for packaging design and barcode placement.

Influence of External Factors

Scan inconsistencies in the larger codes shown in Tables 12–14 was attributed to a couple of variables. One, when hand-marking the codes on the test sheets, some of the numbers written next to each QR code fell inside the quiet zone area. Secondly, there was a scratch on the lens of the verifier. The larger QR codes filled the scanning area, and the scratch acted as damage to the finder pattern. These issues are shown in Figure 12. When the scale size decreased, scan grades improved, especially for smaller codes that occupied less of the scanning field. This underscores the importance of proper printing practices and environmental control during barcode verification and packaging production.

Statistical Analysis

A univariate ANOVA confirmed a significant inverse relationship between scale percentage and scan grade ($F(1, 11) = 37.21$, $p < .0001$). The regression model accounted for 77.2% of the variance in scan grade ($R^2 = .772$), with a root mean square error of 0.50. Specifically, for 21x21 module QR codes, each 1% increase in scale resulted in a 0.057 unit decrease in scan grade ($B = -0.057$, $SE = 0.009$).

These results statistically validate the relationship between code size and readability.

% Scale	21x21	25x25	33x33	37x37	45x45	61x61
80%	B	D				
70%	B	B	D	C		
60%	C	D	B	B	D	
50%	A	A	A	A	B	
40%	B	B	A	A	B	
30%	A	A	A	A	A	
20%	A	A	B	C	C	
19%	A	A	C	D	D	
18%	A	A	D	D		
17%	A	A	D			
16%	A					
15%	B					
14%	C					
13%						
12%						

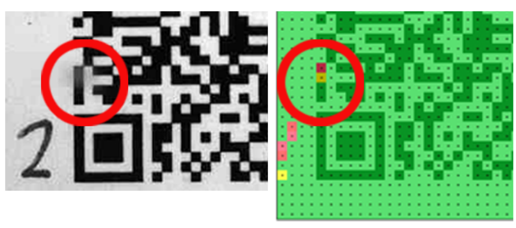
Table 12 Scan Grade for InDesign Generated QR Codes

% Scale	21x21	25x25	29x29	33x33	37x37	41x41	49x49
60%	D						
50%	B	D					
40%	B	B	B	D			
30%	A	A	A	A	A	B	
20%	A	A	B	A	A	B	A
19%	B	A	A	A	A	A	A
18%	B	A	A	A	A	A	A
17%	A	A	A	A	A	A	A
16%	A	A	A	A	A	A	A
15%	A	A	A	A	A	A	B
14%	A	A	A	A	A	A	B
13%	A	C	A	A	A	B	A
12%	C	D	B	B	A	A	B

Table 13 Scan Grade for Online Generated QR Codes

% Scale	21x21	25x25	29x29	33x33	37x37	41x41	49x49
60%	D						
50%	B	C					
40%	C	B	A	C			
30%	A	A	A	A	A	A	
20%	A	A	A	A	A	A	A
19%	A	A	A	A	A	A	A
18%	A	A	A	A	A	A	A
17%	A	A	A	A	A	A	A
16%	A	A	A	A	A	A	A
15%	A	A	A	A	A	A	A
14%	A	A	A	A	A	A	A
13%	A	A	A	B	A	A	A
12%	A	B	D		B	A	B

Table 14 Scan Grade for Online Generated GS1 QR Codes



1. Unused Error Correction (UEC)	101%	4.0	A	PASS
2. Cell Contrast (CC)	95%	4.0	A	PASS
3a. Cell Modulation (CMOD)		4.0	A	PASS
3b. Reflectance Margin (RM)		4.0	A	PASS
4. Axial Nonuniformity (ANU)	0.3%	4.0	A	PASS
5. Grid Nonuniformity (GNU)	0.0%	4.0	A	PASS
6. Fixed Pattern Damage (FPD)		1.1	D	FAIL
7. Upper Left Pattern (ULP)		4.0	A	PASS
8. Upper Right Pattern (URP)		4.0	A	PASS
9. Lower Left Pattern (LLP)		1.1	D	FAIL
10. Horizontal Clock Track (HCT)		4.0	A	PASS
11. Vertical Clock Track (VCT)		4.0	A	PASS
12. Alignment Pattern (ALP)		4.0	A	PASS
13. Version Information Block (VIB)		-		
14. Format Information Block (FIB)		4.0	A	PASS
15. DECODE		4.0	A	PASS
16. Minimum Reflectance (MR)		-		

Figure 12 Fixed Pattern Damage

	21x21	25x25	29x29	33x33	37x37	41x41	49x49
Millimeters	4	4.5	5	6	6.5	7.5	9
Inches	0.016	0.177	0.197	0.236	0.256	0.295	0.354

Table 15 Smallest scan size scanned by number of modules

Discussion

The results of this study provide valuable insights into the practical considerations and limitations associated with implementing QR codes in product packaging, particularly in anticipation of GS1's Sunrise 2027 initiative. As companies transition from one-dimensional (1D) barcodes to two-dimensional (2D) QR codes, understanding the minimum viable scale for readability and verification becomes critical for maintaining compliance and usability across POS systems.

The findings support the first hypothesis (H1), demonstrating that QR codes with less encoded data can be scanned and verified at smaller sizes than those containing more complex data sets. This relationship is reinforced by the strong statistical correlation observed between scale percentage and scan grade. The more modules required to represent the data, the larger the symbol must be to maintain readability. As such, brands must carefully consider data optimization strategies, such as minimizing non-essential information or using shorter URLs, to reduce symbol complexity without compromising functionality.

Conversely, the second hypothesis (H2)—which proposed that the generation method would have no impact on scanability or verification—was not supported. Notably, QR codes generated through online tools, particularly GS1-compliant generators, performed significantly better than those created in Adobe InDesign. The InDesign-generated codes exhibited limitations at smaller scales, likely due to rendering differences and the absence of optimization for standardized scanning environments. This suggests that the method of QR code creation plays a pivotal role in ensuring consistent and compliant results, especially when dealing with space-constrained packaging formats.

Furthermore, the observed discrepancies in scan grades for larger QR codes, despite their size advantage, highlight the importance of environmental and printing factors—such as damage to the quiet zone or finder patterns and scanner lens imperfections. These variables emphasize the need for rigorous quality control during barcode placement and printing, including maintaining clear quiet zones and protecting key pattern areas from obstruction or distortion.
Importantly, this research contributes to the broader industry understanding by quantifying the trade-offs between data capacity, barcode size, and verification standards. The study provides baseline measurements for minimum readable sizes by module count, offering a practical reference for packaging engineers, designers, and production teams.

In the context of Sunrise 2027, the implementation of QR codes must be approached with a cross-disciplinary perspective—incorporating technical barcode standards, graphic design limitations, and production constraints. Further research is encouraged to evaluate performance under varying substrate materials, curved surfaces, and real-world POS environments to strengthen the generalizability of these findings.

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