HOW BARCODES WORK

➢ INDUSTRIAL TRACEABILITY

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1. Introduction

In recent years, traceability has become a major theme in global commerce. Industries using a large number of component parts that come from many different subcontractors are now beginning to benefit from their investments in traceability. These investments can facilitate better management of product recalls, providing considerable cost savings. They can also improve brand perception in the marketplace. Additionally, traceability gives clients a better understanding about the provenance of a product. It validates whether a product conforms to the needs and specifications of a client. As for the manufacturer, traceability enables better tracking of what is sent to clients and a better understanding of what is produced, assisting in continuous improvement efforts. The sources of real or potential problems can then become easier to identify. Typically, the characteristic traced takes the form of serial numbers, batch numbers, date codes, model numbers, etc., and is linked to a database.

Alphanumeric serial numbers have been used for decades. They are simple and easily read by workers. Barcodes were created in the emerging information technology age of the 20th century. Barcodes provide unique identifiers for retail products. As they can be read automatically, they reduce checkout times and errors. Barcodes were first introduced in the late 1940s. With the introduction of barcode readers and UPC symbols in the 1970s, the now familiar one-dimensional barcodes became the norm. Since only limited information can be stored in these barcodes, databases are often used. They add context to the information extracted from simple barcodes. In the 1990s, the first two-dimensional codes were developed. 2D codes can be used to store even more information on a smaller surface, often even eliminating the need for separate databases.

This eBook was developed to help you make insightful choices regarding the type of traceability format you require. First, we will explain 1D barcode and 2D code functions, and how they differ. Then, we will discuss how the GS1 standard assures barcode quality. Finally, we will explore a comparison of both formats. After reading this document, you should be able to identify the best solution for your needs.

2. Barcode Structures and How They are Read

2D codes have many traceability advantages, but simple 1D barcodes are still used in many industries. Writing and reading 1D codes is easier than 2D codes as no image processing software is needed. Only a light source and a photodetector are required.

2.1 Common Barcode Types

Numerous structures and standards exist for barcodes. All are based on associating black and white lines with symbols. The symbols may be alphanumeric or simply numeric, depending on the standard.

2.1.1 Code UPC-A

UPC-A barcodes (Universal Product Codes) are very common, particularly in retail. However, the standard only references numbers, letters are not considered. This limits their usefulness for industrial traceability.

2.1.2 Codes 128 and 39

Code 128, named for its capacity to represent all characters of the ASCII 128 set (American Standard Code for Information Interchange) is often used internally in manufacturers' supply chains to ensure product maintenance and handling.

On the other hand, Code 39, a less compact equivalent of Code 128, is mainly used in the automotive and defence sectors.

2.2 Barcode Structure and Readability

Figure 1 shows a Code 128 barcode structure. It is divided into four sections and can host 108 symbols. Three of the symbols identify the beginning of the code and two indicate its end. Each section contains a certain number of symbols. A symbol is an alternating combination of three black lines and three blank spaces with varying widths. Each symbol is in turn associated with a specific alphanumeric character from the ASCII 128 character set. Here is a description of each barcode component:

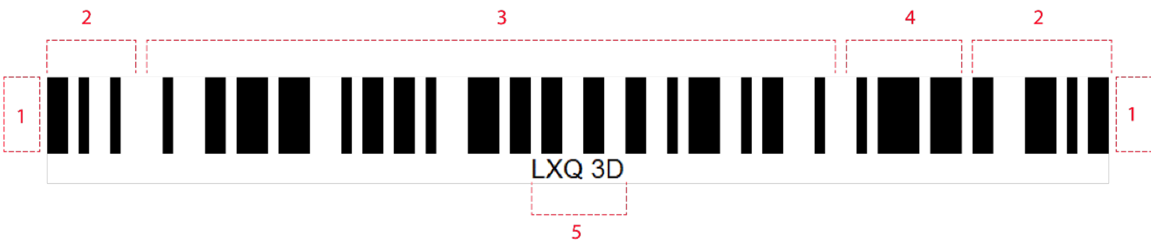

Figure 1: *Example of a 128 barcode and its different sections*

1 – Quiet Zones

The beginning and end of the barcode are each surrounded by a quiet zone. These zones improve the code's retrieval during reading. The quiet zone consists of a series of white lines.

2 – Start/Stop Characters

Every Code 128 barcode has the same three symbols at the beginning and same two symbols at the end. They identify the reading direction.

3 – Code Data

This section always occupies the largest space. It is 103 symbols long and carries the unique information about the marked product.

4 – Validation Character

After the code data, there is a verification symbol to verify if the code data has been read correctly. Each alphanumeric character of Code 128 is associated with a unique number. After decoding the code data, an algorithm takes the numbers paired with the characters and makes a calculation. The result is a new number that represents a unique alphanumeric character. The last symbol of the barcode, the validation character, should be the same as the one calculated by the barcode reader. Otherwise, the code has not been read properly and the barcode will need to be rescanned.

5 – Human-Readable Interpretation

This will be discussed in detail in section *5. Tracking Codes and Global Standards (GS1)*, for now, suffice to say that it is the message encoded in the barcode spelled out in plain English.

2.3. How Barcode Readers Work

Black lines reflect less incident light than white lines. The barcode reader takes advantage of this fact. A light source is directed within a particular field of view that includes the barcode and a photodetector measures the quantity of light that is reflected. Of course, the total energy measured differs depending upon whether the detector “sees” a black or a white line. The photodetector generates an electric current proportional to the light intensity sensed. The variations in the electric current are then analyzed and the alternating black and white lines are extracted. Finally, the electronic data generated is associated with a product, and, of course, to the product’s information in the database (price, model number, serial number, date, work order, batch number, for example).

3. A Closer Look at 2D Codes

2D codes, in the form of the *Quick Response code* (QR code) were invented in 1994 by the Japanese company, Denso Wave. They were introduced to track car and truck parts, during the manufacturing process. QR codes can carry characters beyond the original 128 digits of the ASCII set, including Japanese characters.

Many different structures exist for 2D codes. All are based on the association of each character with a combination of black and white pixels. To read a 2D code, a photograph or digital image is taken and analyzed by image processing software. The pixels are isolated, read and finally interpreted as characters. QR codes are commonly used with cell phones because of their readability and rapid translation speeds. In recent years, data matrix or DM codes, have also become popular in many applications, including the manufacturing of automotive parts.

3.1 Comparing QR and DM codes

3.1.1 Data Matrix

Two adjacent sides of the data matrix code are composed of solid black lines. The other two sides are composed of alternating black and white pixels. The black lines on the left and at the bottom of the data matrix facilitate the image processing software's localization of the code. The other two edges are used by the computer software to pinpoint the spatial frequency of the "dots" used in the data matrix. This frequency is related to the size of the pixels. The edge also indicates the number of columns and lines in the data matrix. The localization features of the data matrix do take up considerable space. In a small data matrix of 22 × 22 pixels, 17% of the total number of pixels are used for code localization. In Figure 2 below, a Data Matrix example is shown on the left. On the right, the localization feature of the same Data Matrix has been highlighted.

Figure 2—Typical Data Matrix Code

3.1.2 Quick Response Code

QR codes look different from Data Matrices (See Figure 3). In this case, the localization pixels are arranged differently. There are three squares at the corners of the image and one square inside the code for localization. The three squares at the corners are made of two lines of alternating black and white pixels that determine the main spatial frequency.

In QR codes, the orientation and localization mechanism occupies a large portion of the code. These features are composed of two lines and four squares. In the case of a 29 × 29 pixels QR code, the localization mechanism occupies 27% of the code's surface. This rather high percentage is easily visible in Figure 3.

Figure 3—Typical QR Code

On the left is a QR code example On the right in red, the zone dedicated to localization is highlighted

Given the same surface area, data matrices can store more information than QR codes. The limited resolution of commercially available barcode readers also favours the use of data matrices.

It is worth noting that both QR codes and data matrices need to be surrounded by a white margin called the quiet zone. The quiet zone prevents surrounding noise from being misinterpreted as actual information.

3.1.3 2D Code Features

The following are some 2D code features that you might want to consider.

3.1.3.1 Size and Requirements

Numerous sizes exist for each type of code. The size of a code is determined by the number of pixels in it, and the physical size of each pixel. The number of pixels in a code limits the amount of information that can be stored in it. The surface quality of the material being marked, the marking technique, the resolution of the code reader and environmental factors, such as ambient light levels, can restrict the minimum physical size of the pixels and their readability.

3.1.3.2 Error Correction Level

Both code types include redundant pixels. These allow a reader to interpret the code even if some pixels are damaged or illegible. This immunity to the degradation of the code can be quantified using the Error Correction (EC) level. This number represents the maximum percentage of the code's surface that can be damaged before any information might become lost.

3.1.3.3 Choice of EC Level

High EC levels are needed when a product is handled in harsh industrial conditions that could lead to the code's deterioration. The marking technique chosen also influences the optimal EC level. Code contrast depends strongly on the marking technique used. Laser marking systems are known for their high contrast and can reduce the need for higher EC levels. The material to be marked also influences the required EC level. For instance, darker materials like cardboard or die cast parts with rough surfaces, need higher EC levels to ensure an acceptable readability.

The Higher the EC level, the higher the number of pixels required to encode its message, and the larger the code will need to be. A bigger code can take a longer time to mark. Since marking time is often limited, in practical terms the code often cannot exceed a certain size. EC levels should be chosen to optimize the application. An EC level of approximately 25% or more is recommended for industrial applications. A lower EC percentage may be acceptable for other uses.

3.1.3.4 Data Matrix vs QR Code

Data matrices can be read even when 14% to 39% of the code's surface is unreadable. A QR code may have one of four different EC levels: Low at a 7% damage rate, Medium at 15%, Quartile at 25% and High at 30%. Thus, if it is highly likely that the code will become damaged, using a data matrix is recommended, due to its higher EC level, which ensures a greater reliability. However, if only a low EC level is required, then a QR code might be a better option, because it allows for the lowest EC level of 7%. This way the code can be smaller or accommodate a longer message.

3.1.3.5 Storage

DM codes have a higher EC level, which ensures that data can still be transmitted in the presence of harsh conditions, while QR codes can store a greater variety of symbols, such as the Japanese alphabet (Kanji).

In terms of capacity, data matrix codes can store up to 2,335 alphanumeric characters or 3,116 numbers. This limitation is due to the maximum size that a data matrix can have, in accordance with the GS1 standard, which is 144 rows by 144 columns.

QR codes can store up to 7,089 numeric and 4,253 alphanumeric characters through its largest size, which is 177 rows by 177 columns. Although QR codes can support the Japanese alphabet, the use of Kanji characters is not recognized by the GS1 standard.

3.1.3.6 Product Shape and Code Shape Limitations

QR codes can only have a square shape as seen by the reader used. This is not an issue when used on flat surfaces. In the case of a cylindrical object, however, it is better to use a rectangular code where the longest portion is not aligned in the direction of a curvature. Data matrix codes can be square or rectangular, and thus are a better solution for cylindrical parts.

4. Barcodes vs 2D Codes: Which One to Choose

4.1 Advantages of Barcodes

Barcodes are easier to read than 2D codes. The incoming signal containing the information from the barcode reader is an electric current, while the signal of a 2D code is an image. This makes 2D codes much more complex to encode and decode. They require image processing software, making them as much as five times more expensive than their simpler counterparts. Barcodes contain a lot less information than 2D codes, but their limited storage capacity can be offset by linking a database to the barcode readout. In most cases, linking a database will not create any difficulties. This approach can also provide a window for continuous, real-time database updates. In these cases, the use of a database is mandatory. The database can be changed constantly, whereas the information in a 2D barcode remains fixed.

4.2 Advantages of 2D Codes

2D codes were created to store more information than their one-dimensional predecessors. Although they require more expensive readers, 2D barcodes are often used when it is important that all information related to the product travels with it. The large volume of information that can be stored in a 2D code is sufficient for most industrial applications. 2D codes also offer greater reliability than barcodes. Barcodes do not have a tunable EC level that preserves the code's effectiveness even when the code is damaged. Some barcodes have systems that indicate when the code is damaged, but none of these mechanisms offer the redundancy of a data matrix code. Therefore, 2D codes are a more robust and complete solution.

5. Tracking Codes and Global Standards (GS1)

To standardize their barcodes, businesses can have their products approved by GS1, an international organization established to standardize barcodes. The GS1 ensures that codes respect certain common characteristics:

Human-Readable Interpretation

The presence of HRI (Human Readable Interpretation) for any GS1 tracking code is mandatory. This takes the form of human readable characters written under the code. The HRI must contain the same information encoded in the bi-dimensional or the one-dimensional code. HRI presence ensures that the code's information is collectable even when severely damaged. It is also useful when the code reader is unable to interpret the code or is simply unavailable. The standard also states that HRI must be a certain size and not interfere with the barcode's quiet zone.

Contrast

Contrast is also evaluated. Contrast quantifies the difference between the greyscale value of the barcode's whitest and blackest pixels. The higher the contrast, the easier it is to read the code. However, for some metals (especially aluminum, lead and titanium) acceptable contrast may be difficult to obtain. In these cases, high-contrast techniques, such as laser marking, may be helpful.

Modulation

The modulation of the symbol is evaluated. It represents the consistency of the printing and the change in contrast values for all pixels. The benchmark for this characteristic should be low to provide maximum contrast.

Quiet Zone

The size of the quiet zone is determined through GS1. Be sure that it is large enough for the reading system to localize and isolate the code, as established in the standard.

Readability Robustness

For 2D codes only, the robustness of the code to deterioration is specified. GS1 specifies that error correction be respected by checking that the code is still readable even if a particular percentage of the information pixels are damaged.

6. Conclusion

2D codes allow for extremely compact information storage. At the same time, they provide considerable immunity to potential damage through EC and HRI functionality. Recently, several marking techniques have been improved or developed to meet today’s more demanding requirements. These techniques are often applicable to a variety of materials. Additionally, some industries now require more dense information in their barcodes than previously. This means that precise and rapid marking techniques, often involving a high level of automation, are needed now more than ever. Choosing the appropriate barcode and marking technique can help users rise to the challenge of the new levels of traceability demanded by many industries. Laser marking, to use one example, has been particularly effective in meeting these challenges. This marking technology can be used for a broad range of materials: aluminum, steel, copper, lead, wood, plastic, ceramic and more. Thus, laser marking could be the traceability solution for a wide variety of diverse businesses.

7. About Laserax

Laserax is a laser systems manufacturer that provides efficient, high-performing and safe solutions for the most demanding industrial applications. Our customers range from upstream to downstream in the aluminum manufacturing value chain, including metal and alloy transformation, plus other manufacturing industries.

Laserax provides a complete range of products, including laser markers, optional equipment, and turnkey laser systems. You can rely on our team of laser technology experts to ensure the safety of your laser applications and provide proper safety training to your team.

Appendix A – Storage Capacity Data Matrix

Data Matrix Codes have different error correction level (ECC) such as ECC 000, ECC 050, ECC 080, ECC 100, ECC 140 and ECC 200. Some of these error correction levels are no longer in use but mentioned here for completeness. GS1 only supports ECC 200 so that is the Data Matrix we have chosen to illustrate in the following table.

Symbol size		Maximum data capacity	
Row	Col	Numeric	Alpha-numeric
10	10	6	3
12	12	10	6
14	14	16	10
16	16	24	16
18	18	36	25
20	20	44	31
22	22	60	43
24	24	72	52
26	26	88	64
32	32	124	91
36	36	172	127
40	40	228	169
44	44	288	214
48	48	348	259
52	52	408	304
64	64	560	418
72	72	736	550
80	80	912	682
88	88	1152	862
96	96	1392	1042
104	104	1632	1222
120	120	2100	1573
132	132	2608	1954
144	144	3116	2335

Symbol size		Maximum data capacity	
Row	Col	Numeric	Alpha-numeric
8	18	10	6
8	32	20	13
12	26	32	22
12	36	44	31
16	36	64	46
16	48	98	72

Appendix B – Storage Capacity QR Code

Symbol size	Error correction level	Data Capacity	
		Numeric	Alpha-numeric
21	L	41	25
	M	34	20
	Q	27	16
	H	17	10
25	L	77	47
	M	63	38
	Q	48	29
	H	34	20
29	L	127	77
	M	101	61
	Q	77	47
	H	58	35
33	L	187	114
	M	149	90
	Q	111	67
	H	82	50
37	L	255	154
	M	202	122
	Q	144	87
	H	106	64
41	L	322	195
	M	255	154
	Q	178	108
	H	139	84
45	L	370	224
	M	293	178
	Q	207	125
	H	154	93
49	L	461	279
	M	365	221
	Q	259	157
	H	202	122
53	L	552	335
	M	432	262
	Q	312	189
	H	235	143
57	L	652	395
	M	513	311
	Q	364	221
	H	288	174

Appendix B – Storage Capacity QR Code

Symbol size	Error correction level	Data Capacity	
		Numeric	Alpha-numeric
61	L	772	468
	M	604	366
	Q	427	259
	H	331	200
65	L	883	535
	M	691	419
	Q	489	296
	H	374	227
69	L	1022	619
	M	796	483
	Q	580	352
	H	427	259
73	L	1101	667
	M	871	528
	Q	621	376
	H	468	283
77	L	1250	758
	M	991	600
	Q	703	426
	H	530	321
81	L	1408	854
	M	1082	656
	Q	775	470
	H	602	365
85	L	1548	938
	M	1212	734
	Q	876	531
	H	674	408
89	L	1725	1046
	M	1346	816
	Q	948	574
	H	746	452
93	L	1903	1153
	M	1500	909
	Q	1063	644
	H	813	493
97	L	2061	1249
	M	1600	970
	Q	1159	702
	H	919	557

Appendix B – Storage Capacity QR Code

Symbol size	Error correction level	Data Capacity	
		Numeric	Alpha-numeric
101	L	2232	1352
	M	1708	1035
	Q	1224	742
	H	969	587
105	L	2409	1460
	M	1872	1134
	Q	1358	823
	H	1056	640
109	L	2620	1588
	M	2059	1248
	Q	1468	890
	H	1108	672
113	L	2812	1704
	M	2188	1326
	Q	1588	963
	H	1228	744
117	L	3057	1853
	M	2395	1451
	Q	1718	1041
	H	1286	779
121	L	3283	1990
	M	2544	1542
	Q	1804	1094
	H	1425	864
125	L	3517	2132
	M	2701	1637
	Q	1933	1172
	H	1501	910
129	L	3669	2223
	M	2857	1732
	Q	2085	1263
	H	1581	958
133	L	3909	2369
	M	3035	1839
	Q	2181	1322
	H	1677	1016
137	L	4158	2520
	M	3289	1994
	Q	2358	1429
	H	1782	1080

Appendix B – Storage Capacity QR Code

Symbol size	Error correction level	Data Capacity	
		Numeric	Alpha-numeric
141	L	4417	2677
	M	3486	2113
	Q	2473	1499
	H	1897	1150
145	L	4686	2840
	M	3693	2238
	Q	2670	1618
	H	2022	1226
149	L	4965	3009
	M	3909	2369
	Q	2805	1700
	H	2157	1307
153	L	5253	3183
	M	4134	2506
	Q	2949	1787
	H	2301	1394
157	L	5529	3351
	M	4343	2632
	Q	3081	1867
	H	2361	1431
161	L	5836	3537
	M	4588	2780
	Q	3244	1966
	H	2524	1530
165	L	6153	3729
	M	4775	2894
	Q	3417	2071
	H	2625	1591
169	L	6479	3927
	M	5039	3054
	Q	3599	2181
	H	2735	1658
173	L	6743	4087
	M	5313	3220
	Q	3791	2298
	H	2927	1774
177	L	7089	4296
	M	5596	3391
	Q	3993	2420
	H	3057	1852

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