Barcodes: labels and readers

How many times have you picked up a sample or container in your laboratory and not been able to read the label? When a sample or container is not properly identified, the skills of any scientist are worthless.

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This issue's V&V column is aimed at discussing barcodes for a number of uses including labelling and identifying samples. This article is aimed at giving you more information about barcodes:

- What is a barcode?
- Linear (one-dimensional) symbologies available.
- Practical ways to print and read barcodes.
- Two-dimensional barcode symbologies.
- Uses for barcodes in scientific data management.

Would your laboratory benefit from the introduction of barcodes? The use of barcoding in a laboratory provides a means for ensuring positive sample identification, eliminating identification and transcription errors as well as increasing productivity and reducing the costs of some operations. Sounds too good to be true? Read on and discover more.

What is a barcode? The essentials

Quite simply a barcode is a means of encoding information in a series of thick and thin black lines and white spaces. A barcode collects and stores information; this information can be sample identity, but it can also be other items, as we'll see later in this article.

When read, the information in the barcode can be captured by a computer system, rapidly and reliably, thus ensuring data integrity. Using a reader, the data encoded into the barcode is captured by the computer for rapid data entry. When linked to the appropriate software, which can be a scientific data management system, for example a Laboratory Information Management System (LIMS), data system or robot, the entered information can be used for a number of operations, such as positive sample identification, input of an operator's identity or updating a database record. This is the essence of barcoding.

Look at a typical barcode, shown in Figure 1, this is a linear or one-dimensional barcode. It comprises black lines (bars) and white spaces, both of which are called an element. The thickness of the bars and spaces can vary and are the means of incorporating information into the symbol; the thinnest element is called a unit or module. Barcodes begin and end with start and stop characters respectively. The information in a barcode comprises sets of characters such as a sample

identity or method number. There are various symbologies (jargon for saying character sets) available that can be used to encode information, which are summarized in Table 1.

Which symbology should I use for my application or needs? This depends upon a number of factors related to the application, for example,

- What is the numeric or alphanumeric information to be encoded?
- What are the security requirements?
- What size label is required?

For many current applications within a laboratory, either interleaved 2 of 5 (numeric only) or Code 93 or 128 (alphanumeric) will be used, depending on whether numeric or alphanumeric information is to be encoded. Numeric barcodes are generally smaller and more compact than alphanumeric ones. Code 39 is a variable length barcode depending on the length of the message.

Interleaved 2 of 5 is a fixed length barcode symbology but is generally shorter as it is numeric only. Therefore, if size is critical a numeric code may be the only choice available. Defining the size of the smallest container or vial to be labelled and how much information is required on the label are the deciding factors for the barcode symbology to use.

The format or layout of the label can be designed: i.e., the barcode symbols can run vertically (picket fence) or horizontally (ladder). Remember humans can't read barcodes very well. Humans as well as barcode readers must be able to read the label; therefore, there should be at least a number printed next to the barcode. Remember what happens in the supermarket when an assistant cannot get the scanner to read the barcode? There is a facility to enter the number manually at the sales point. This fail-safe mechanism must also be present in any barcode system designed for laboratory use. Therefore, decide what human readable text there should be. Colours can be used as background for the labels providing there is sufficient contrast between the bars and spaces; however, the majority of laboratory applications can use black lines on a white background.

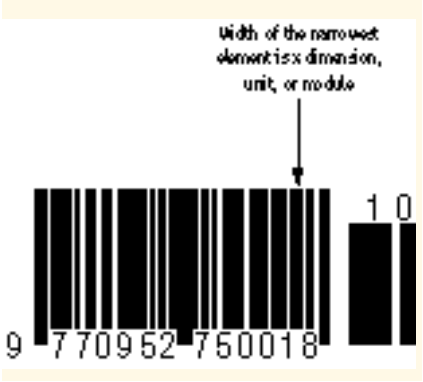

Figure 1 Structure of a typical barcode.

How are barcodes printed?

There are a number of ways to print barcoded labels for use in the laboratory. To deliver consistent, accurate and reliable results, and to ensure data integrity, it is important that the labels are printed with high-quality symbols. The foundation and integrity of any barcoding system will depend, ultimately, on the quality of the generated barcode labels.

The easiest way to obtain barcode labels is to purchase them in a pre-printed roll from suppliers. These can be custom printed for a specific application or provided in a fixed format for short-term identification in, say, a robot application. Generally, these labels are high quality with good print densities. A good test for the print quality is to look at the barcode under magnification to see how ragged the edges of the bars are.

The main types of printer for barcode labels are dot matrix, thermal, laser or inkjet. Each printer has advantages and disadvantages and these are discussed below.

- *Dot matrix printers:* Whilst not used often now — laser and inkjet printers are relatively inexpensive — this option is included for completeness. A dot matrix printer uses a group of 24 pins to impact a multi-pass ink ribbon and transfer the ink to the paper behind the ribbon. The ink coverage on the paper forms the impression for a letter or barcode. Dot matrix printers

Symbology name	Characteristics
Interleaved 2 of 5 (I 2/5)	• Numeric code. • Encoding 0–9 plus start and stop digits. • Condensed code as each codeword encodes two digits. • Prone to truncation errors.
Code 39	• Alphanumeric code (first to be developed). • Codes A-Z, 0–9 and 7 other characters. • Flexible and widely supported. • Can use a check digit. • Not a compact barcode.
Code 93	• Alphanumeric code, is a more compact version of Code 39 by using shorter module widths. • Until the development of Code 49 was the most space efficient alphanumeric code. • Not a standard symbology in most scanners. • Uses 2 check digits. • Can be difficult to print the varying dimensions accurately.
Universal Product Code (UPC)	• Numeric code. • Several variants for package size. • Widespread in supermarkets and general merchandising. • Not used for scientific applications. • Two-part label: limited to 6 or 12 digits.
Code 128	• Alphanumeric code. • Reliable. • Variable length. • Condensed symbology. • Uses start and stop characters. • Densest linear symbology when data contains long strings of numbers.

Table 1 The main barcode symbologies.

were used mainly to print barcodes on pages and forms. They also offer a flexible approach to the barcode format and low price. However, the symbols are relatively low density, only fair print quality, poor edge quality (high-resolution scanners can interpret holes in the edge as spaces) and the ribbon of the printer can wear. If cost is a very important factor, then dot matrix printers could provide a viable alternative. However, for quality there are better alternatives to consider.

- *Inkjet printers:* These printers create an image by projecting single drops or a controlled stream of ink at the paper. The size of the print is highly dependent on the properties of the receiving paper. An inkjet printer can produce high quality barcode labels; however, it has not been widely used to do so. One reason may be potential problems with the robustness of the print: in a mild environment there may be no problems, but what happens to inkjet paper when a chemical solution or a solvent has been splashed on it?
- *Laser printers:* Here an image is written electronically on to a photo conductive drum and transferred onto a paper surface. Laser printers are designed for general office use and not specifically for printing barcode labels. However, they form a very good approach for producing barcoded labels as they are very cost-effective, especially if used at high resolutions (e.g., 600 dpi). If there is a bin feed mechanism attached, a networked laser printer can be multipurpose and be used for labels as well as general office and laboratory printing. They are limited to printing a single sheet at a time. If self-adhesive labels are required, there may be a setting up charge for the label stock or media and a minimum order required.
- *Thermal printers:* These use a heat sensitive label stock passing over a thermal print head consisting of an array of closely spaced rectangular heaters under microprocessor control. By heating these in a precisely controlled sequence a printer can create virtually any type of sequence of barcode, human readable text and, if required, graphics. These printers offer the advantage of flexible formatting and excellent print quality. Besides having flexibility, thermal printers are high throughput and high density with good abrasion resistance. The label stock is unaffected by temperatures under 60 °C. Although prolonged exposure to sunlight over several weeks turns the whole label black and obliterates the printed barcode and text, this should not be a limitation for all but the most demanding applications.

  The cost and single application of the printer offsets the advantages of flexibility and print quality. It cannot be used for any purpose other than printing barcode labels. Therefore, unless a high number of labels are required, a thermal printer might not be applicable or cost-effective.
- *Thermal transfer printers:* These offer similar advantages to the thermal printers: good quality, high speed and a flexible format. The label is printed onto plain label stock using a heat-sensitive film ribbon. This ribbon passes between the print head and the label stock. The print head heats the ribbon and the ink melts onto the paper. This produces a thermal transfer label that is very resistant to extremes of temperature (over 140 °C), sunlight and long-term storage. Similar to thermal printers, thermal transfer printers are only useful for printing labels, the volume of labels must be high enough to justify the cost of the printer, which can be more than double that of a laser printer.

- Select a symbology in the public domain that does not require royalty payments to use.
- Ensure that the symbology is supported by multiple readers and printers.
- Ensure that the symbology is easily and accurately read by a scanner.
- Always include a human readable form of identifying the sample on the barcode.
- Ensure that the label is stable and robust under all conditions of use.
- Train any third party and analytical staff in the optimum way to affix the label to the container.
- Use a high tack adhesive if required.
- Only buy large amounts of label stock when the labels have been pilot tested.

Table 2 Some practical advice for barcodes in the laboratory.

Label adhesive

Normally labels will be stuck onto an item, whatever it may be; unless, of course, you want to glue each one onto a sample individually. Therefore, you will choose self-adhesive labels, and here a critical factor comes into play: the type of adhesive used. Consider what you are going to label:

- Does it have a flat surface?
- Is it a circular container?
- What is the cleanliness of the item to be labelled?
- What will be the impact if the label falls off?
- What are the environmental conditions the label will be used in?

Normal tack adhesive may be suitable for the majority of applications. However, when considering extremes of temperature for instance, normal tack adhesive may not be suitable and the labels may cease to stick. This can be exacerbated if the label is on a circular container. In my experience where small tubes are involved, a high tack adhesive is usually required to ensure the label stays on the container. In addition, be sure to evaluate the label under all

extremes of storage and usage before purchasing large quantities of the label stock. It can be rather embarrassing to ask your boss to authorize payment for more labels with a higher tack adhesive when you have a quarter of a million in the corridor cupboard with the wrong adhesive on them. Of course, this would never happen in your laboratory or even to the writer of this column…

Print quality and data integrity

The majority of problems that arise with barcode systems are not due to the reader or the user but the quality of the label. The performance of a barcode system should be measured in the first read rate. This is the ratio of good reads on the first attempt against the number of scanning attempts. For example 80 beeps out of 100 tries is a first read rate of 80%. Consider again the example of barcodes in the local supermarket.

Another monitoring metric is the substitution error rate, the number of times the system sends a single character error. This is closely related to print quality. The better the print quality the lower the substitution error rate. A 50% first read rate will have a 1 in 30 000 substitution error rate, a 95% first read rate has a corresponding figure of 1 in 10 million.

The three factors affecting the print quality of labels are

- the need to keep the printing within specification
- the quality (spots, voids and edge roughness) of the printed label
- the reflectance and contrast of the label when scanned.

Spots and voids on the white space or label bar respectively will produce substitution errors; this is greater in dot matrix labels and laser printers where the toner is low.

However, all the effort of implementing a barcode system may be frustrated if staff are not trained to stick the labels onto the container with the correct orientation. Hand-held wands do not read labels on the circumference of round containers. The barcode must be on a flat, level surface running the height of the container.

Barcode readers

A barcode reader consists of two parts: the input device and the decoder. The input device emits a beam of light that is absorbed as it passes over the label. The bars absorb light and the spaces reflect it, resulting in varying amounts of light reflected back. The input device converts the reflected light into an electric signal, which is passed to the decoder. This interprets the reflected pattern into computer readable characters for further processing.

Input Devices: Input devices can be grouped into five different categories:

- fixed or moving beam
- hand-held or fixed mount
- contact or non-contact
- visible light or infrared: infrared is used where high security is a requirement and where barcode labels can become dirty or greasy.
- Off-line and on-line readers, which are not physically connected to the data system where the barcodes are entered.

The main types of input device will be discussed:

- The first is the wand, which is a hand-held, fixed beam, contact reader. It is the least expensive reader and probably the simplest. It can either be free standing (with a data store for downloading data later to a computer) or coupled with a PC for direct data entry. It is operator sensitive, the first read rate is low initially and rises with training and experience.
- To overcome the reading problems of the wand, the charge coupled device (CCD), a contact and scanning reader, is popular. The reader is manually placed over the label to be scanned and uses light emitting diodes (LED) to illuminate the barcode, and the CCD collects the reflected light. The user performs no movement as the label is scanned, thus increasing the read rate. However, it is important that the label fits under the scanner, otherwise the label cannot be read.
- A laser scanner is a non-contact, hand-held or fixed mount reader with a moving beam. The beam scans the label about 30 times per second and it usually requires three identical sequential reads to accept the barcode. It is more costly than the wand, but with faster read rates it can increase productivity compared with the wand. It can be either hand held or located on a fixed mount with a foot-activated button for reading. The fact that it is a non-contact reader has safety advantages when dealing with samples that are hazardous.

Readers can be coupled with decoders and personal digital assistants (PDAs). Although they perform the same function, there are two main attributes of decoder: on-line or portable and intelligent or non-intelligent. Most decoders used in laboratories today are connected to a computer system and are non-intelligent; that is, an on-line computer must be used for every transaction. Portable and intelligent readers can be used off-line and the stored information downloaded into a computer system. Alternatively, the decoder can be linked to a radio transmitter for download to the computer (see Table 2).

Ideas for using barcodes?

If you are thinking of implementing an extensive system incorporating barcodes, but don't have many ideas of how they could be used, then you need some inspiration. How can you get this information easily? You need to take a leaf from benchmarking concepts and visit organizations that use barcodes extensively for stock control. Moreover, you need organizations that must have very effective stock control systems to

survive and profit in business to see barcodes used to their most effective, including your local supermarket. Next time you wander the aisles looking for soap powder or corn flakes have a look at what the staff are doing with barcodes.

Different organizations will implement different systems, but there are generalities that can be seen. Firstly, the food and drink industries have standardized a single barcode format so that all products (make, product and size) can be uniquely identified. Next, supermarket staff will go through the store at regular intervals assessing the amount of stock left on the shelf. This information is collected by scanning the product barcode into a portable reader, then using a keyboard on the reader to enter the number of items remaining, giving the amount of stock remaining on the shelf at a specific time. This information can either be relayed back to the store's computer by a radio LAN in real time or be stored in the reader until it can be downloaded to the computer later. Once in the computer more stock can be scheduled to be placed on the shelves and orders placed with the warehouse for delivery to the store later.

Once you have these ideas in place you can start to imagine how a system could work within your laboratories. You may not need all of the high technology gadgets that a supermarket has, but you can scale the ideas to your own situation.

Further uses of barcodes

We have looked mainly at samples for barcoding, but more than just samples can be barcoded...

- *Corporate sample numbering:* Most barcode systems are developed and used locally. Whilst producing benefit locally, it may be better to consider barcoding on a wider scale, as a minimum within the client groups of a laboratory. Labels could be printed in the client departments before sample submission and logged into the laboratory data system. However, in many larger organizations there may be the rationale to develop a production or site-wide system that can uniquely identify any sample. This has the advantage of scale, especially for integrated production and analysis.

  Organizations operating on a global scale have to meet international quality requirements. In the agrochemical and pharmaceutical industries, regulations such as Good Laboratory or Manufacturing Practices (GLP, GMP) have been operating for a number of years. These principles of quality, in the form of ISO 9000, are now being applied to a number of other industries. To meet these requirements, corporate LIMS are a reality. Therefore, as part of one of these systems, or indeed as a means of integrating them, corporate sample numbering systems should be established. This would mean that a sample would have a unique number within an organization regardless of where it originated. This approach would make transfer of information easier than it is at the moment.
- *Chain of custody:* Where sample information of transfers between locations — together with the individuals involved, the time the sample has remained in a location and the work undertaken on it — is required, barcoding is one way of collecting and providing these data. Activities and the corresponding data and time stamps collected using barcoded forms and samples can be used to demonstrate the chain of custody for a sample.
- *Analytical reference samples:* Records of the use and location of analytical reference standards are required under several quality systems. This can bring the laboratory inventory management problems. One way to solve this problem is to use the ubiquitous barcode to overcome the manual paper chase that occurs in many laboratories. For example, analytical reference materials need records to show their use over time. Barcoding analytical reference materials will enable individual samples to be withdrawn from the store, an aliquot weighed and the standard returned.
- *Information storage:* Remember that barcodes are a means of storing information. Thus, computer instructions themselves can be barcoded and printed, and placed by the side of a PC under a laminated film to protect from splashes and abrasion. The whole operation — from weighing the sample to identifying the sample and operator — can be entered by barcode. No entry in a laboratory notebook would be required. The only part of the operation not entered by barcode would be the operator's password to maintain security. Thus, accuracy, real-time data capture and streamlined ways of working can be achieved with the technology available today.
- *Portable barcodes:* Even a terminal need not be important in this weighing operation. Using a portable, intelligent reader with an LCD display the whole operation can be done off-line and downloaded to the computer later. In this way it is not necessary to log onto a computer at all. Data integrity over a manual system would be greater as the logic for using one analytical reference standard for an individual test can be confirmed before weighing out the sample.
- *Sample location:* The manual processes to log and monitor sample location and demonstrate the chain of custody are slow, labour-intensive and boring. Furthermore, if someone wants to know where a sample is located it can take a long time to search the records.

  Computerizing sample location records using barcodes is preferable.

The locations that samples are kept in can be barcoded and the individual shelves within that location similarly labelled. Thus, the physical location of a sample can be identified through a computer system. A sample entering a laboratory is read and then the physical locations, for example room, fridge or freezer and shelf number, are attached to the record via barcodes. If required, the operator responsible for receiving the sample can enter their identity via a barcode. Thus, there is a record on the computer of when the sample was received, by whom and where it is located. Portable and intelligent barcode readers are the best approach to this problem, giving the operator the flexibility to move around unencumbered.

When the sample is required for analysis, the same process can be used; the barcodes for the operator, location, and sample are read and repeated when the sample is put back. Often a laboratory has separate storage locations for samples pending and in-process; this system will increase productivity, finding where a sample is via the terminals in a laboratory. In a laboratory where a sample undergoes several sequential analyses this will be invaluable and will reduce the time spent finding where an urgent sample is located. The completion of the cycle, where the sample is returned to the originator or disposed of, can also be automated in this way. To implement such a system requires all the staff to be involved and kept informed of progress.

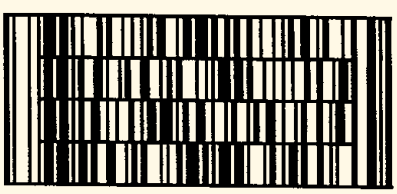

figure 2 An example of a 2D symbology barcode.

- *Instrument identity:* The instruments used in an analysis should be recorded with the analytical results. If the instrument or modules that comprise it are barcoded, the information required can be captured at the time of analysis. For example, in busy routine laboratories, where chromatographs are used on a 24-hour basis, there may be back-up modules to exchange with any requiring servicing. Normally, manual records are kept of the modules used in a particular analysis. If the modules are barcoded, the instrument configuration for the analysis can be recorded in a few seconds. Any replacement modules added during the analytical run can be similarly recorded. This principle can be taken further: chromatography columns can be barcoded and an automatic record kept of their usage, and service records of chromatographic modules can be maintained and updated by barcode.

As laboratory management becomes more sophisticated and budgetary pressures more pressing, the control of supplies and consumables could be linked via inventory software and barcodes. This could place a laboratory on a par with a supermarket, with automatic stock replenishment when an item reaches a pre-defined level. This linkage could be through a central

Symbology	Description
Stacked	
Code 49	• Uniform Symbology Specification — Code 49 from Automatic Identification Manufacturers' (AIM) Association. • Pioneered the use of stacked or multi-row symbologies. • Used large character set and eliminated quiet zones to increase capacity (81 digits). • Infrequently supported or used. • Alphanumeric code with three rows. • Multiple check characters result in very high data security but three rows must be scanned.
PDF417	• Developed as a "portable data file". Uniform Symbology Specification — PDF417 from AIM. • Pioneered the use of scan switching between short rows. • First use of Reed-Solomon algorithms in barcodes to reduce errors and increased capacity over Code 49 (2500 digits). • Broadly supported and promoted.
Other stacked symbologies	• Code 16K. • Codablock. • SuperCode.
Matrix	
Code One	• First matrix symbology to be placed in the public domain. • Uses an internal structure to compensate for image distortion when read and decoded. • Compatible with EAN 128. • Encodes up to 3500 digits. • Eight standard sizes and six reduced versions. • Infrequently supported today.
Data matrix	• Square matrix • Expensive hardware and slower to process. • Latest version includes Reed Solomon encoding for error reduction. • Encodes up to 3116 digits. • Omnidirectional reading: no orientation requirements. • Not widely supported now.
Other matrix symbologies	• MaxiCode: widely supported but fixed size and only 128 digits. Developed by United Parcel Service (UPS). • Aztec Code • QR (Quick Response) Code. • UltraCode.

Table 3 Stacked and matrix 2D symbologies.

site store, purchase department or linked direct to an external supplier.

- *Radio frequency barcodes:* The portable barcode readers discussed so far work off-line and are then connected to a computer for information download after collection. There is usually a delay between collection and transmission. For many laboratories this delay is acceptable and presents no problems. There may be instances, say in a production environment, where information in a remote location is required urgently. Here the use of radio frequency barcode readers may be appropriate. These use a narrow band wireless transmitter to maintain communication with a computer system. The barcode is read in the normal way but is transmitted to a controller module that is connected to a computer; when the signal is received by the controller, the record is updated in the computer.

Two-dimensional barcodes

The linear or one-dimensional barcode can have its limitations. This can be size related: look at your Vehicle Identification Number (VIN) on your car — the barcode of this can be over 5 cm long. This has led the automotive industry plus their business partners, including courier companies, to consider alternative approaches to barcoding including the development of two-dimensional (2D) barcodes (see Figure 2).

The reading of these codes can differ:

- *Linear scanned:* the code can be read in a single scan.
- *Row scanned:* where several linear scans are used to decode the information.
- *Image scanned:* the information is decoded from the image.

The advantage of 2D barcodes is that they offer improved data densities over those offered by 1D symbologies, but at the cost of scanning in two dimensions. The stacked linear codes work best with linear 1D readers. The matrix codes require a scan of the whole barcode. When entering into this area, ensure that you chose a symbology that is in the public domain so that you do not have to pay royalties. This area is still developing and you should be sure about the need to use 2D symbology over the cheaper 1D alternatives (Table 3).

Summary

There you have it, we have discussed what barcodes are, their uses, printing of labels, the 1D and 2D symbologies available and the uses of this technology in the laboratory.

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