ISyE 3103 and ISyE 6203

Transportation and Supply Chain Systems

Automatic Identification and Data Collection Technologies

1 Introduction

Item identification and data collection are extremely important in supply chain systems. Many different models are used to optimize and control various portions of a supply chain. All these models depend on having quality data as inputs; without the data the models are useless. Anyone who has ever done any work in industry can tell a story of a problem they have had with data when working on a problem.

Manual collection of data can be slow and hence costly and more importantly is highly prone to errors. For example, if part numbers are manually input by a keyboard, the error rate is approximately 1 in 300. However, if the same data is collected with bar codes, the error rate is approximately 1 in 3 million, a huge difference. Thus, we turn our attention to automatic identification and data collection (AIDC) technologies that can be used to collect the required data accurately and at a reasonable cost. After data has been collected with these technologies it must be stored and processed by information systems (typically a database), this subject is covered elsewhere.

We mentioned that models require quality data to be useful. What exactly is meant by "quality" data? Some characteristics of quality data are the following.

- *Accuracy.* The data must be correct.
- *Timely.* The data must be available when it is needed for making decisions.
- *Effective.* The data must be relevant for the decisions being made. For example, data about the exact specifications of a product is probably not necessary for making decisions about which mode the product should be shipped by.
- *Reliable.* The data must satisfy the above qualities consistently. Data that is occasionally of poor quality won't be trusted and hence is less likely to be used, even if it is usually good.

2 Types of AIDC Technologies

Below we list some of the many different types of AIDC technologies.

- *Bar coding.* The is the most prevalent form of AIDC and it will be discussed more extensively later in this document.

- *Radio Frequency Identification.* With this technology, identification and data capture is done via radio waves.

- *Optical Character Recognition.* This technology can read the same printed words and symbols that we read and convert them into electronic format. This technology is heavily used by the United States Postal Service for reading addresses.

- *Magnetic Ink Character Recognition.* This technology is heavily used in the banking industry, for example by encoding the check and bank routing number on checks in magnetic ink. The data can then be read in a way similar to optical character recognition.

- *Magnetic stripes.* Data is stored in a magnetic stripe, such as on the back of a credit card.

- *Smart cards.* Data is stored in a small chip embedded in a card, such as American Express cards. One advantage over magnetic stripes is that more data can be stored in the chip.

- *Biometrics.* This includes technologies that can identify a person by looking at their fingerprints or eye.

This document will focus on bar coding and radio frequency identification (RFID) since they are the most widely used AIDC technologies in supply chain systems.

3 Uses of AIDC

AIDC technologies are used in a wide range of industries. In this section we describe some examples.

Retail

Bar codes are on essentially every product we buy. By one estimate, the retail industry does 3.5 million bar code scans per minute [1].

Manufacturing

Bar codes and increasingly RFID are used extensively in the manufacturing industry to track inventory and work in progress, and to assist in quality assurance.

Distribution

AIDC technologies are used in distribution systems to automatically record incoming and outgoing shipments.

Healthcare

This is an industry that has been slower to adopt AIDC technologies in all areas, but there is great potential. For example, consider a nurse administering medicine. Before administering he scans the patient tag, his own id, and the medicine. If he is attempting to administer the wrong medicine, or medicing that should not be taken with other medications the patient is taking, a warning goes off.

Bar codes have even been used to keep track of bees in experiments! Little bar codes have been placed on the bottoms of the bees for identification purposes.

4 Bar Coding

We now turn to talking specifically about bar coding, the most prevalent type of AIDC technology. A bar code is defined as a spacial representation of encoded characters.

4.1 Bar Code System Steps

There are a number of steps that typically must be followed when implementing a bar code system.

1. Coding requirement. The first step is to determine what data needs to be stored on the bar code. For example, are we storing part numbers, lot numbers etc.?

2. Machine readable language. A standard format for the bar code that can be read by a machine must be decided upon. This is referred to in the bar coding terminology as "symbology."

3. Bar code printing. The bar codes must be printed onto labels or directly onto the items they will be identifying.

4. Bar code verification. Quality control measures must be taken to ensure the bar codes can be read reliably.

5. Bar code scanning. This is the step where data is actually captured.

6. Transmit data. After being captured the data must be transmitted to an information system.

7. Use the data. This step is almost too obvious to mention, but it's too important not to mention. If there is no use for the data, the bar code system is just a waste of resources.

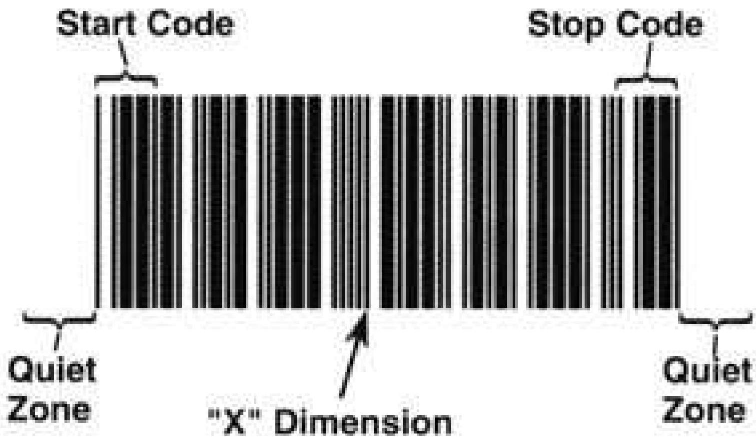

Figure 1: A basic bar code symbology.

4.2 Symbology and Data Structure

A bar code requires both a symbology and a data structure. Symbology is how the symbols in the bar code translate into raw data numbers. The data structure is what the number means. For example, the data structure might specify that the first four digits represent the part number, the second four digits represent the lot number, etc.

There are many different types of symbologies. The most basic symbologies use a series of bars as in figure 1. In this case, the code has to do with the width of the bars and the widths of the spaces between the bars. Another type of bar symbology uses two different heights of bars; the United States postal service uses this type of bar code on mail. There are also two-dimensional bar codes. For example, many different short rows of one dimensional bar codes can be stacked on top of each other. This type of bar code is used on the back of a Georgia driver's license. Another type of two-dimensional bar code is the matrix code, an example of which is given in figure 2. The advantage of two-dimensional bar codes over one-dimensional codes is that there is a higher data density, so more data can be stored in the same space.

In addition to specifying what the numbers stored in a bar code mean, the data structure is also used for error checking. For example, bar codes usually have a start and stop code at the beginning and end of the bar code so that it can be read upside down without any risk that it will be read backwards. Also, the data structure can include self-checking mechanisms such as the use of check characters to help ensure that reads are valid. A check character is a number that is mathematically calculated based on the content of the data (for example it could be the last digit of the sum of the data). This number is then stored along with the data and is read when the bar code is read. After reading, the number is recalculated based on the data read, and compared against the check digit read. If they don't match, you know there was an error in the read. If they do match, this doesn't guarantee there was no error, but it decreases the likelihood of an error.

Figure 2: The top bar code is a two-dimensional stacked bar code and the next one down is a matrix bar code.

Data structures are used for both bar coding and RFID. The Global Trade Item Number (GTIN) is an umbrella group under which all different types of data structures now fall. The GTIN allows for 14 digits, but the specific data structures that fall under GTIN may not use all 14 digits. The most common example of a specific data structure is the UPC, which is on most of the products you purchase. The data structure that is becoming standard for use in RFID chips is known as EPC. The EPC structure consists of a header plus three sets of data. The header includes information such as the EPC version number so that changes to the EPC structure itself can be managed. The first set of data is a code for the EPC manager, such as the manager of the product. The second set of data indicates the object class, which specifies the exact type of product (e.g. Diet Coke, 330 ml can). The final data set stores a serial number which is specific to the specific item.

4.3 Bar Code Readers

Bar code readers can be hand-held or hands-free. Hands free scanners are more efficient when it is easier to bring the bar code to the scanner than it is to bring a hand-held reader to the bar code. Hands free laser scanners are often used in checkout lines in grocery stores. We discuss three of the most common types of hand-held bar code readers below.

Figure 3: A wand bar code scanner.

Figure 4: A Charged Couple Device.

Wands

Wands are pen-like readers with a laser at the tip, see figure 3. A bar code is read by a wand by moving the wand over the bar code. The advantages of wands are that they are lightweight, inexpensive and rugged. In addition, they require less power than other types of readers and hence could be good for mobile use in which the reader must be powered by a battery. One disadvantage of a wand is that there is relatively more training required for people to use them. In addition, because wands have to be moved across the bar code they are less efficient, and because they come in contact with the code during the scan, they can eventually damage the bar codes if they are read repeatedly.

Charged Couple Devices (CCD)

CCDs work by flooding the entire bar code with light. An example of a CCD is shown in figure 4. CCDs are moderately costly and are easy to use. In addition, they are rugged because they do not have any moving parts to break. Other advantages of CCDs is that they are lightweight and typically produce decoded output. The primary disadvantage of CCDs is their limited depth of field. The field of depth of a reader is the distance from the bar code which the reader must be in order to successfully read the code.

Laser

The most commonly used hand-held bar code reader is the laser, an example is shown in figure 5. Because they are so common, lasers have the advantage of being widely accepted

Figure 5: A Laser Bar Code Scanner.

Figure 6: These bar codes can dissolve in water.

by users. The other primary advantage of lasers is that they have a wider depth of field than the other hand-held readers. One disadvantage of lasers is that they have moving parts (mirrors to direct laser beams), and hence can break-down easier. In addition, they have higher power requirements than the other types of readers and are more expensive.

4.4 Bar Code Labels

It is often more convenient to print bar codes on a label which is subsequently placed on a product than to put the bar code directly on a product. There are a huge variety of different types of bar code labels that can be useful for widely different applications. Bar code labels characteristics include cost, texture, ease of application, resistance to the elements, tendency to peel, life expectancy and resistance to scratching and tearing. There are even bar code labels that are made that are designed to dissolve in water (see figure 6). Bar code labels can be made from a variety of materials including paper, vinyl and polystyrene. When choosing the type of bar code label to use, it is important to find the bar code label that meets the specific needs of the application they will be used for.

4.5 Bar Code Printing

The first major decision to make with bar code printing is whether to have the printing done on-site or off-site. With on-site printing, also known as imprint or on-demand printing, there is a large initial investment that must be made to purchase the printers

Figure 7: An on-site bar code printer.

and software. However, once this investment is made, the set-up cost per job is low. Thus, on-site printing works well when the labels to be printed have variable data. For example, if the label is going to include the lot number for each product, the lot numbers change often and so it would be convenient to be able to print these labels on-demand.

Off-site printing, also called pre-print, is more suited for labels that will be used in high volumes and have static data. For example, if only a product identification number will be represented on a label, this data won't change at all for a particular product. Off-site printing provides high quality labels and can be done efficiently. The primary disadvantage of off-site printing is the higher set-up cost per job, caused by the need to procure an order and have the printed labels shipped etc. This is the reason off-site printing is generally more appropriate for high volume orders.

If on-site printing is used, a further decision must be made about which type of printer(s) to buy. Printers vary based on price, speed, contrast and accuracy. It is important to select a printer that meets the objectives for the specific application the printer will be used for. For example, if only simple bar codes will be printed and occasional inaccuracies won't have great negative consequences, then spending more for the best printer may not be appropriate. An example of an on-site printer is shown in figure 7.

4.6 Bar Code Verification

Bar code verification is a very important step in the bar coding process. It can be seen as the bridge between bar code printing and scanning. Bar code verification is basically a form of quality control for checking that the printed bar codes are readable. One of the primary reasons for using bar codes is to minimize errors in data collection. However, if bar codes aren't verified for quality and accuracy, this advantage of bar coding can be effectively lost. Companies take the quality of bar codes on their products seriously. For example, Wal-mart has been known to fine its suppliers $50,000 for having poor bar codes on the cases they supply.

Bar code verification involves more than just scanning the bar code after printing to see if it scans. Separate machines are used for verification which measure various characteristics of the printed bar codes to judge whether the bar code can be read reliably by different types of readers and whether it is likely to continue to be readable even after slight degradation. At a minimum, verification should be done at the beginning, sometime at the middle, and at the end of the printing process. In addition, any time something is done to the bar code, such as being laminated or varnished, verification should be done again. Some major users of bar codes, such as the Department of Defense, have specific guidelines on how bar code verification should be done.

4.7 Costs of Bar Coding

The average bar coding implementation can cost between 50 and 250 thousand dollars. However, companies have reported that the average payback on this investment is typically quite short, averaging about 5 months. When considering the costs of a bar coding implementation, it is important to compare it to the costs of not implementing bar coding and the data errors that can result. For example, there are costs associated if you ship the wrong item to a customer. Imagine the potential costs if a company installs the wrong part on an aircraft. Some costs of potential data errors cannot even be measured, for example if the wrong medicine is administered to a patient leading to a fatal reaction. Considering the potential costs of data errors, bar coding will generally be considered a bargain.

4.8 Advantages and Disadvantages

Two advantages of bar coding are that it is relatively inexpensive and widely used and accepted in industry. In addition, bar coding is based on an open system. Thus, the standards for symbologies and data structures are not owned by a single company and are open knowledge so that no royalties have to paid for the use of a specific bar coding method. In addition, the prevalence of established standards for bar codes facilitates the use of bar codes that can be used throughout the supply chain by different companies.

A primary disadvantage of bar codes is that the symbol must be visible to be read. For example, if there is a bar code on each case on a pallet and each case must be identified, the pallet may hay have to be unstacked to read the bar codes of all the cases. Another disadvantage is that the data in a bar code is static. Thus, if the data changes, a new bar code must be printed and the old bar code must be rendered unreadable. Additionally, bar codes are susceptible to damage from harsh conditions and could be rendered unreadable or separated from the product.

5 Radio Frequency Identification

Radio Frequency Identification (RFID) is an AIDC technology that is being used increasingly in supply chains because it can effectively overcome some of the disadvantages of bar coding. RFID is a system in which data is stored on a machine-readable tag and is transmitted to the reader by radio waves. Therefore, no line-of-sight is required to read the data stored in RFID tags as is required to read bar codes. In addition, RFID tags can be built to be more resistant to the elements (and can be enclosed inside protective packaging) and so can be used in harsh conditions in which bar codes would be less effective.

RFID is gaining in prominence due to some recent requirements set by major customers. For example, Wal-Mart is requiring its top 100 suppliers to put RFID tags on all their pallets by the end of the year, and is requiring the same of all its suppliers by 2006. In addition, Wal-Mart has strict requirements on the capabilities these RFID tags must have. For example, they require that the tags should be readable when on conveyors moving as fast as 540 feet per minute. These types of requirements will push the development of RFID technologies. Similarly, the United States Department of Defense is requiring its suppliers to put RFID tags on its products, and is even requiring that the tags be put on individual cases or items in some cases.

5.1 RFID System Components

An RFID system consists of the transponders or tags that are placed on the items and the antenna and transceiver devices used to read the data.

RFID tags can be classified as active or passive and as read/write or read-only. The difference between active and passive tags is that active tags have their own power source whereas passive tags get all their power from the radio waves transmitted to them. Active tags use battery power to transmit and receive data and can store fairly substantial amounts of data, as much as 1 MB. Because they have their own power source they have a longer read range than passive tags. The disadvantage of active tags is that they are larger and more expensive, and have a limited lifespan based on the battery life (although lifetimes can be as long as 10 years).

Passive tags have shorter read ranges and require a more powerful reader. The advantage of passive tags, however, is that they are lighter, less expensive and have a virtually unlimited lifetime. If made cheap enough, there is speculation that passive tags could eventually replace bar codes on products. An example of a passive tag is the anti-theft hard plastic tags used in retail stores. These have a small RFID chip in them that can be read by transceivers at store exits to detect if an item is being taken out of the store without being paid for.

With read/write tags, it is possible to write new data onto a tag as well as read the data on the tag. Read-only tags can only have data written to them once, after which the data can only be read. Typically read/write tags are active whereas read-only tags are passive.

Figure 8: An RFID Antenna.

Another key component of an RFID system is the antenna, which is what actually transmits the radio waves to the tag (or from the tag in the case of an active tag). RFID antennae come in many different shapes and sizes (an example is in figure 8) and can use many different frequencies and typically have limited range so that interference with other wireless technologies can be avoided. One limitation of RFID antennae is that they have difficulty transmitting through metallic objects.

The final component of an RFID system is the transceiver or controller, which is what takes signals from the antenna and transmits it to a computer. Often the transceiver and the antenna are bundled together as a single item.

5.2 Applications of RFID

RFID has applications in many industries and the number of applications is growing quickly. Following are some examples.

- *Transportation and distribution.* For example, in the rail industry, they have placed RFID tags on rail cars, and installed antennae by tracks and wayside huts to keep track of where rail cars are which facilitates improved fleet utilization.
- *Pharmaceuticals.* The Food and Drug Administration has given a timeline to adopt RFID for all medications by 2007 to combat counterfeit drugs [2].
- *Retail.* We have already mentioned that RFID tags are used for electronic surveillance of products to prevent theft.
- *Automated Toll Collection.* RFID tags can be placed in cars to record when a car passes through a toll booth so that the toll can be deducted from the driver's account, rather than the driver having to stop to pay the toll.
- *Controlled Access of Personnel.* RFID tags can be placed in personnel name tags to restrict access to secure and hazardous locations.
- *Flexible Manufacturing Systems.* RFID tags on products can be easily read to identify specific product variants for automatic process control.

5.3 Item-level RFID

As RFID tags become cheaper, it may become cost-effective to place RFID tags on every item for items that are not too cheap. The implications for a retailer in this case are huge. It would then be possible to know exactly how many of each product are on the shelf at any time, allowing for improved control. In addition, this technology could eliminate the need for scanning every item when a customer checks out. Instead, the customer could just push their cart through the RFID reader and the total charge could be instantly calculated.

There are a couple challenges that need to be overcome before RFID will become prevalent at the item level. First, RFID tags still are not cheap enough to be placed on the majority of products. Second, there is a disconnect between who benefits from item-level RFID tags (retailers) and who has to pay to put them on (manufacturers). Therefore, before RFID will be implemented at the item level in large scale, a mechanism has to be created to allow the manufacturers to share the benefits. Finally, there are people who are concerned with privacy issues with putting RFID tags on all items we buy. People may be unhappy with the prospect that companies can keep track of everything they own and buy. These same types of issues came up with the introduction of bar codes and the concerns generally were proven to be unfounded, or at least consumers were willing to accept them to achieve the increased convenience offered by bar codes. The same may occur with RFID technology, but it will require careful attention to consumer desires (such as the option to disable an RFID chip after a product is purchased) and education of consumers (such as informing them that it would not be possible to read an RFID chip on a product in their house from the street).

5.4 Advantages and Disadvantages

One of the principle advantages of RFID over bar coding is that there is no line of sight required to read an RFID tag. In addition, active RFID tags have the capability to be read/write so that the data stored can be changed over time. This capability allows tags to be used as a sort of moving database. RFID tags also have the advantage of being more suitable for harsh conditions since they can be placed inside protective packaging and still be read.

The principle disadvantage of RFID tags is their cost. Even the cheaper passive tags are still significantly more expensive than bar codes, and until this cost can be brought down substantially, there will still be a large role for bar codes to play in supply chain automatic identification and data collection. Another disadvantage of RFID tags is the challenge of gaining consumer acceptance and overcoming the privacy concerns consumers may have.

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