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The Development of a Generic Model for Choosing a Suitable Traceability System for use in a Manufacturing Environment

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This final year thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Industrial Engineering at Stellenbosch University.

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Verklaring/Declaration

I, the undersigned, hereby declare that the work contained in this final year project is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Ek, die ondergetekende verklaar hiermee dat die werk in hierdie finalejaar projek vervat, my eie oorspronklike werk is en dat ek dit nog nie vantevore in die geheel of gedeeltelik by enige universiteit ter verkryging van 'n graad voorgelê het nie.

… ……. …04/03/09…

Handtekening Datum

Signature Date

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My parents for supporting me and allowing me to follow my dreams.

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Synopsis

Traceability systems are capable of both tracking and tracing parts. They offer many benefits to an organisation from assisting with recall applications to monitoring the everyday workings of a production line or supply chain. There are numerous methods able to act as traceability systems but only a few can be regarded as automatic and unique identifiers.

Automatic traceability of individual entities is the future. It is already widely used by a number of leading companies throughout different business sectors and wide mass adoption is imminent. At present, they are slightly more expensive than the simpler technologies but once mass produced, the cost will come down.

To completely understand how traceability systems are implemented, practical experience is required. When starting a traceability project, there are a lot of different options. The different systems offer their own set of advantages and some don't work in certain environments. It was for this reason that The Decision Making Model was developed to assist users through the difficult initial stages of traceability implementation (i.e. choosing the system most suitable to a particular environment).

This model was programmed in Excel and supplies the user with a number of questions regarding the environment the system would work in as well as the user's requirements. The answers to these questions help the user work through the different types of traceability options to eliminate unsuitable choices. The result is an easy to use program designed with the ability to be upgraded as the technologies evolve.

Opsomming

Opspoorbaarheid stelsels bied vele voordele aan ‘n onderneming, van assestering in terugroep applikasies tot monitering van die dag tot dag bedrywe van ‘n produksie lyn of verskaffersketting. Daar is vele metodes beskikbaar, maar slegs ‘n handie vol dien as outomatiese en unieke identifiserings metodes.

Automatiese opspoorbaarheid van individuele parte is die toekoms. Dit word reeds gebruik deur die voorste maatskappye regdeur die verskeie besigheids sektore. Dit is egter tans relatief duurder as die eenvoudige tegnologie wat beskikbaar is, maar sodra massa produksie kan plaasvind sal dit die kostes verlaag.

Praktiese ondervinding is nodig om ten volle te verstaan hoe opspoorbaarheid stelsels geimplimenteer word. Aan die begin van ‘n traceability projek is daar talle verskillende opsies. Die verskillende stelsels bied elkeen hul eie voordele terwyl sommige stelsels nie in sekere omgewings werk nie. Vir hierdie spesifieke rede was die Besluitneming Model (The Decision Making Model) ontwerp om gebruikers deur die ingewikkelde aanvangsfases van opspoorbaarheid implimentering te assesteer (maw om die mees gepaste stelsel vir ‘n spesifieke omgewing te kies).

Die model is geprogrammeer in Excel en verskaf die gebruiker met ‘n aantal vrae rakende die omgewing waarin die stelsel moet funksioneer en die gebruiker se behoeftes. Die antwoorde op hierdie vrae help die gebruiker om deur die verskillende tipes opspoorbaarheid opsies te werk en die ongepaste opsies te elimineer. Die resultaat is ‘n eenvoudige program wat ontwerp is om opgegradeer te kan word soos wat tegnologie verander.

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Glossary

ASCII:	American Standard Code for Information Interchange is a character encoding based on the English alphabet. It includes definitions for 128 charcacters.
Dissolution:	The process of dissolving a solid substance into a solvent to yield a solution.
Electrolyte:	Any substance containing free ions that behaves as an electrically conductive medium.
Electropolishing:	An electro mechanical process that removes material from a metallic workpiece.
Galvanometer:	A type of ammeter, an instrument for detecting and measuring electric current. It is an analog electromechanical transducer that produces a rotary deflection, through a limited arc, in response to an electric current flowing through its coil.
ISO 9001:	An international standard established by the ISO International Standards Organisation to certify quality management systems.

1. Introduction

1.1 Problem Definition

Traceability can be defined as the ability to trace the history, application or location of an entity by means of recorded identifications [1]. To understand the capabilities of a traceability system one needs to define the difference between tracking and tracing (a traceability system is capable of both) [2]:

- Product tracking is the capability to follow the path of a specified unit of a product through the supply chain as it moves between organisations. Products are tracked routinely for obsolesce, inventory management and logistical purposes.
- Product tracing is the capability to identify the origin of a particular unit and/or batch of product located within the supply chain by reference to records held upstream in the supply chain. Products are traced for purposes such as product recall and investigating complaints.

This thesis will focus on achieving cradle to grave automatic and unique traceability of entities mainly in the manufacturing industry. The manufacturing industry poses unique problems due to the vast difference in the make-up and appearance of parts and the numerous processes and changing environments parts are exposed to during the manufacturing procedure. For the above reasons, the type of traceability system used differs largely between companies and sometimes even within the same company. This results in a lengthy and difficult process when deciding what the most suitable traceability system for a particular situation is.

1.2 Objectives

The primary objective of the thesis is to develop a generic model to be used when deciding which traceability system is best suited to a particular situation. The generic model consists of numerous questions examining the conditions around the marking and reading process as well as certain requirements the user has.

A further objective is to acquire in-depth knowledge of the different types of traceability systems and their application in different industries.

1.3 Research Approach

Theoretical information and practical experience are combined to develop the generic model. The theoretical information is determined through a thorough research study and the practical experience was gained by conducting a few case studies at mostly manufacturing companies.

Although the primary focus is on the manufacturing industry, traceability systems in other industries (e.g. food and retail) were investigated in order to obtain a broader understanding of the subject of traceability and to incorporate case studies on the implementation of traceability systems in this thesis from these different industries.

Chapter 2 of this report explains why the traceability of entities is absolutely necessary in the modern world. Chapter 3 explains and compares the different systems currently available. Chapter 4 looks at how these traceability systems are implemented in different industries and Chapter 5 analyses a few case studies that were conducted. Chapter 6 presents the decision making model and the workings of the associated program are discussed.

2. The Importance of Traceability

To achieve full cradle to grave traceability, it is in most cases necessary to uniquely identify all entities. This unique identification offers benefits to users in the following fields [3]:

- Recall applications
- Quality and process improvement applications
- Proof of quality and proof of origin applications
- Logistics applications
- Security applications
- After sales applications
- Accounting applications

It is difficult to quantify the benefits a traceability system would offer but the benefits the system would offer in each area will be explained.

2.1 Recall Applications

The use of traceability systems in recall applications is arguably its most prominent application. The costs of a recall can include [3]:

- Local internal and external costs of recall in labour and materials
- Loss of the use of key personnel and resources during the recall
- Damage to the company's reputation, which may affect sales
- Increase in insurance premiums

When a customer realises that the product he/she received is either defective or the wrong product there are two steps the supplier needs to take. Firstly, rectify the particular customer's problem and secondly, ensure all related products are returned and that the mistake doesn't happen again [4]. In order to achieve this, the supplier needs to know exactly

- When the part was made
- What materials were used
- Who worked on the part
- Why the part is defective

By answering the above questions, the supplier should be able to trace all related parts and ensure the same mistake doesn't happen again. An effective traceability system will allow the supplier to achieve this with the minimum amount of recalls, using the minimum amount of resources in the quickest time possible.

Systems that do not make use of unique identification would take a lot longer and most likely require a lot larger recall batch to rectify the problem. For example, if a particular tool was the reason for the problem, a unique identification traceability system would be able to identify exactly what parts were worked on by that tool, whereas another system would require all the parts made in that time period to be recalled. This could result in a huge time and money saving, depending on the number of the same tool you have (e.g. if you use four of the same tools and only one of the tools was found to be creating the problems, you would reduce your recall batch by as much as 75%).

2.2 Quality and Process Improvement Applications

When a sub-standard quality part is discovered, total traceability coupled with the knowledge of why the quality is not up to standard will ensure the future improvement of similar parts. This is due to the fact that the exact time, place and people who were involved with making the part are known and any error that resulted in a defective part can be directly addressed.

Being able to track individual parts through the production process simplifies the process of searching for problems and identifying bottlenecks. Instead of dealing with the average throughput, the analyst can have exact process times for each individual part and accurately pin point and rectify reasons for delays.

Traceability systems can also be used to ensure the right person is working on the right part at the right time. This can be achieved by having readers situated at every machine with something like a red light-green light system. If the part is scanned and found not to be the correct part, machine or worker the red light would shine. The worker could then take the part to a central station to find out exactly what the problem is. This would ensure that all the parts that make it through the production line are the correct parts and if they have a quality defect, the source can be easily located and rectified.

2.3 Proof of Quality and Proof of Origin Applications

The usefulness of this application of traceability systems can be best described by examining the food industry. Events such as the BSE (Bovine Spongiform Encephalopathy, which is better known as mad-cow disease) outbreak in the late 20th century have made it necessary to know, for example, where the meat came from, what type of feed was used and what treatments the animals were given. An effective traceability system coupled with sufficient data capturing can guarantee this information is readily available. This would enable the authorities to act swiftly to ensure:

- The outbreak is controlled
- All infected meat is recalled
- Only the infected meat is recalled i.e. not unnecessarily recalling an extremely large batch resulting in a massive financial loss

The corresponding situation in the manufacturing industry will be to prove to customers a certain part followed the required steps (e.g. it had all the relevant safety checks). Strategically placed readers and a well organised back end system allow the users of the traceability system to verify the origin and the path followed by a particular entity.

2.4 Logistics Applications

The visibility that a traceability system offers through a supply chain allows all members of the supply chain to react efficiently to recorded events. This is demonstrated in the following example. The ability of the purchaser to track the order will allow the buyer to plan the distribution of the order with more certainty allowing the buyer to react to replenishment needs more quickly when changes occur in the sales situation. With prior notification of delivery of the order to the warehouse, the buyer could also modify the distribution pattern [3]. This type of visibility and ability to dynamically change the production and distribution plans will be of particular importance to a company using a just-in-time philosophy.

The tracking ability of a traceability system enables the quality assurance department to use the collected data to ensure that all the required process steps were completed when making the part.

A case study conducted at Nippondenso, a large Australian automotive parts manufacturer, reveals the uses of a traceability system beyond just tracking and tracing parts. The traceability system was also employed as a factory management system where daily production was planned, machine/line utilisation analysed and internal or external part shortages notified [3, 5].

By examining Ford's Total Traceability Vision, it can be seen how the whole supply chain is involved in the traceability system. Currently Ford marks a number of components for traceability reasons including [6]:

- Engine Program
    - Cylinder Blocks
    - Cranks
    - Cylinder Heads
    - Camshafts
    - Fuel Rail Assemblies
- Transmission Program
    - Torque Converters
    - Transmission Housing
    - Output Shafts
    - Transfer Plates
    - Valve Body
    - Front & Rear Planet
    - A Number of the Individual Gears

Figure 1 shows what Ford hopes to achieve in the future. It basically consists of a central database that enables different people to track the parts in the different stages of a cars life. The outside circle moves anti-clockwise showing the different stages in the part's/car's life. Users are able to update the data in the database and retrieve additional data about the part. To achieve this goal, Ford mainly used two types of traceability technology, Radio Frequency Identification (RFID) and Direct Part Marking (DPM). These technologies will be explained in detail in later chapters. They use DPM to mark the parts mentioned above and RFID tags are coded with production data to assist the workers (explained in more detail in Chapter 4).

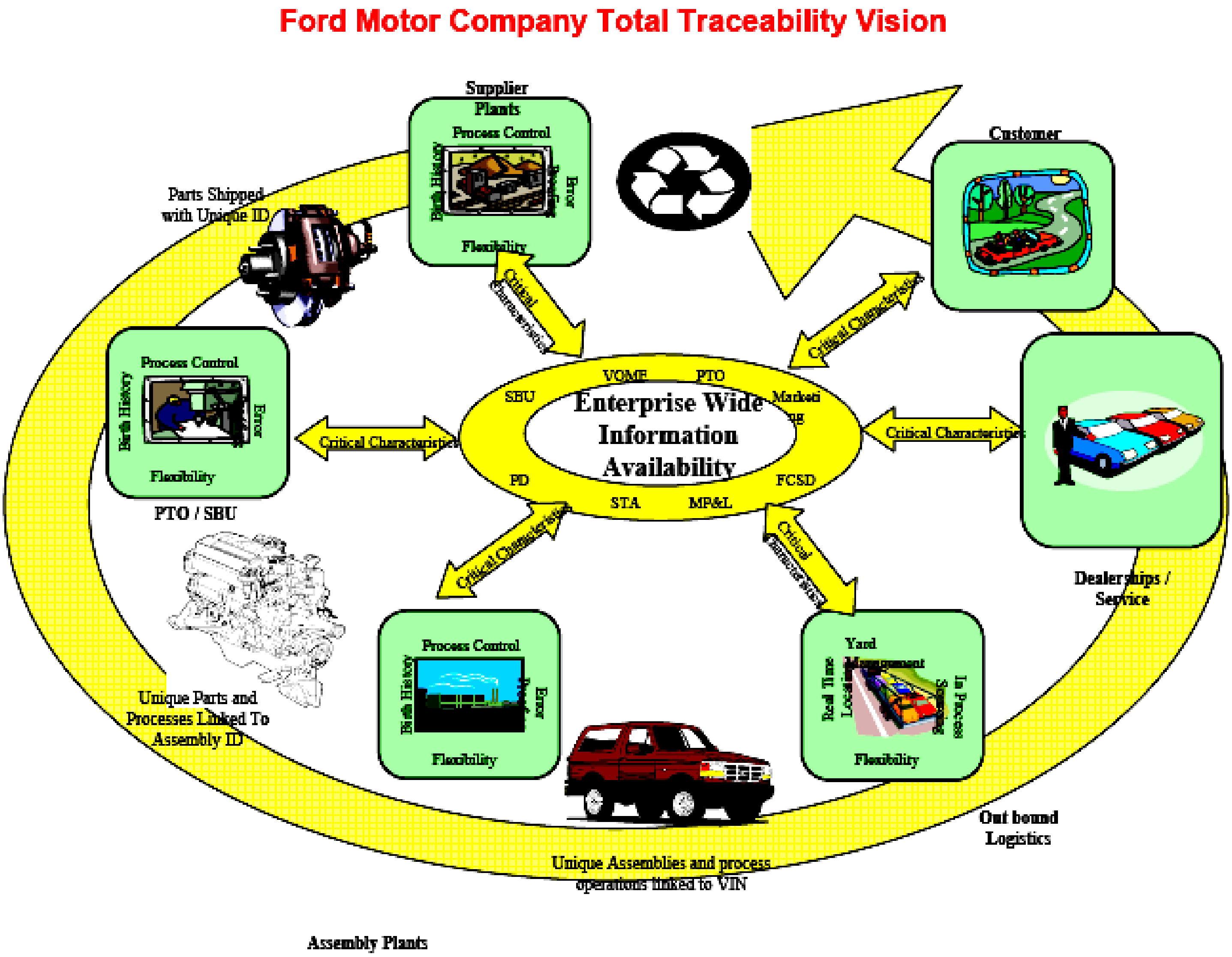


Figure 1: Ford Motor Company Total Traceability Vision [6]

2.5 Security Applications

If a part goes missing during the production process, a traceability system will be able to identify who the last responsible person for the part was and where last the part was in the factory. This is due to the fact that parts are scanned in and out of all major workstations.

By identifying individual parts, the traceability system will also assist the manufacturer in identifying and eliminating counterfeit parts from the market. If counterfeit parts are a major problem for a manufacturer they could allow their customers access to their database to validate part serial numbers or to register their product.

2.6 After Sales Applications

The major after sales use of a traceability system has to do with maintenance. This includes [3]:

- Insuring the correct maintenance is done at the correct time by the correct person
- Keeping track of all the maintenance carried out on a certain part
- Examining the quality of a part throughout its life cycle (Valuable information when estimating the life span of an entity)
- Warranty validation

2.7 Accounting Applications

A traceability system can be used as a vital tool in determining costs incurred and work-in-progress inventory values. Due to the traceability system being able to log each part that is in the system, an accurate and real time figure of the number of parts in the system at a given time can be determined [3].

2.8 Conclusion

This chapter has shown that traceability systems have many uses in different aspects of the general operation of an organisation. Therefore, if a traceability system is implemented for a particular reason, there are many additional value adding features which aid in achieving the ROI (Return on Investment) for the traceability project. Traceability systems offer a more efficient and effective method of assisting companies in the areas mentioned above. They are able to be implemented in conjunction with existing back-end systems (e.g. ERP) as they are just a better technique of gathering the required data. The type of software used determines how the data is processed and what it is used for.

3. Traceability Systems

This chapter will give a brief overview of various traceability methods. Being able to identify individual parts or traceable units is the first step in achieving total traceability and this chapter will discuss a few methods of doing this. A traceable unit can be a single part or a batch of parts that are produced under exactly the same conditions, from the raw materials used to the workers working on the parts. For an assembly to be regarded as being completely traceable all the components that make up the assembly need to be traceable and linked to each other. Figure 2 shows an example of this for the assembly of an automobile engine.

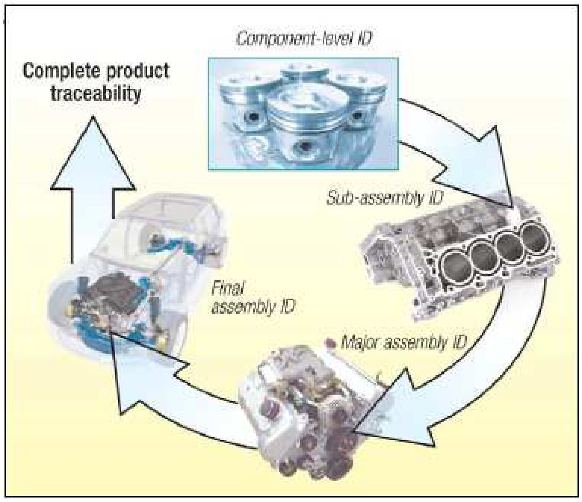


Figure 2: An example of an assembly being marked at the different stages [7]

According to German research organisation Fraunhofer-Gesellschaft, the following characteristics make up a traceability system: the technology used (barcodes etc.), the accessibility of the data (internal/external), the layout of the system (how parts are handled), activity level (passive or active), the hierarchy level that is marked (carton, pallet, container etc.), the attributes that are captured (ID number, location etc.), and when the data is captured (continuously, intermediately or on-demand) [40]. This chapter contains information on the technology used, the other characteristics listed above influence what technology is chosen.

Presently there are six core automatic identification technologies [8]. They are

- One dimensional barcodes
- Two dimensional barcodes
- Radio frequency identification
- Optical character recognition
- Magnetic stripe cards
- Biometric identifiers

As this study is only concerned with tracking and tracing entities in a manufacturing environment and not humans, magnetic stripe cards and biometric identifiers were ignored. Two methods of applying barcodes will be explained i.e. labelling and direct part marking.

3.1 Labelling

Labels are generally applied using some kind of adhesive or wet glue. For traceability purposes, it needs to be ensured that the label is never separated from the part otherwise total traceability is lost. When choosing a suitable labelling option, the following needs to be considered:

- Type of Code
- Printing Technologies

3.1.1 Type of Code

There are three main options of code that can be applied to the label, namely:

- One Dimensional Barcodes
- Two Dimensional Barcodes
- Smart Labels

3.1.1.1 One Dimensional Barcodes

One dimensional (linear) bar codes can be divided into two categories, width modulated and height modulated. Width modulated consists of bars and spaces of varying width and can be seen in Figure 3. Height modulated consists of evenly spaced bars of varying height. Height modulated bar codes have limited use and are mainly employed in the document and mail tracking industries and not in the manufacturing industry.

Figure 3: Example of a width modulated barcode containing 0123456789 [9]

There are numerous types of barcodes that fall into one of the two categories mentioned above. Table 1 is a brief overview of the more popular one dimensional barcodes.

1D Barcode type	Character Set	Length	Description
Interleaved 2 of 5 12345678	Numbers only	Variable	• High density barcode • Can only encode pairs of numbers (must have an even number of digits)
Code 39 1 2 3 4 5	43 characters: 0-9, A-Z, and space $%+-./	Variable	• First alpha-numeric barcode • The most widely used non-retail barcode
Code 93 CODE 93	47 characters: 0-9, A-Z, and space $%+-./ and 4 special characters for full ASCII encoding	Variable	• Was introduced in1982 and is a compressed form of Code 39 • Not as widely used as code 39

Code 128	Full alpha-numeric plus high density numeric mode	Variable	• High-density and used throughout the world • Used when a large amount of data needs to be placed in a small place
EAN Barcodes	Numbers only	Fixed length, 8 or 13 digits	• European Article Numbering system unique numbering • Virtually used throughout Europe • Barcode number is assigned by the International Article Numbering Association • Two different versions (EAN 8; EAN 13)
UPC Barcodes	Numbers only	Fixed length, 7 or 12 digits	• Similar to the EAN barcode except used in North America • Two different versions (UPC A – 12 digits; UPC E – 7 digits) • Barcode number assigned by the Uniform Code Council

Table 1: Types of one dimensional barcodes [10, 11]

One dimensional barcodes offer many benefits including cost, accuracy, reliability and the speed at which the code is read. The problem with using one dimensional barcodes is the limit to the amount of data that can be stored.

3.1.1.2 Two Dimensional Barcodes

There are over 30 different types of two dimensional coding, they were designed as a more space efficient alternative to conventional linear barcodes and in most cases have a greater data capacity. Automotive, aerospace and electronics manufacturers have adopted 2D code standards and formats to meet their application needs [12]. Table 2 contains a few examples of two dimensional barcodes.

2D Barcode type	Character Set	Length	Description
Aztec Code	Full ASCII; FNC1 and ESI control codes	Variable: Min 12 Max 3832	• Invented in 1995 • Designed for ease of printing and ease of encoding • Symbols are square overall on a square grid with a square central bulls eye finder
Data Matrix	All ASCII characters	Variable	• Designed by Siemens • Maximum theoretical density of 500 million characters to an inch • Encoded by absolute position instead of relative dot position there this code has a high level of redundancy
Maxicode	All ASCII characters	93	• Developed by United Postal Service in 1992 • Made of hexagons instead of square dots therefore it can be at least 15% denser than a square dot code

QR Code	All ASCII characters	Variable – up to 7366 numeric characters or 4464 alphanumeric characters	• Quick Response Code was developed by Nippondenso ID Systems • Symbology has the ability to directly encode Japanese Kanji and Kana characters
PDF-417	All ASCII characters	Variable	• Portable Data File-417 is a stacked symbology and was invented in 1991 • High density printers (thermal transfer or laser) should be used to print this symbol

Table 2: Types of two dimensional barcodes [13, 14]

3.1.1.3 Smart Labels

Smart labels are produced by a smart label printer/encoder that programs an RFID tag embedded inside label material and prints text and barcode on the outside. Smart labels are a convenient option because they can be produced on demand and a single smart label can meet RFID, barcode and text marking requirements [15]. Due to all the information contained on the label, they are generally very large and not suitable to be applied to small objects. The amount of data does offer benefits across the supply chain when different handlers of the use different technology and numbers to identify the object. Radio Frequency Identification (RFID) will be explained further in chapter 3.4. Figure 4 shows a smart label printer/encoder and the RFID tag on the bottom of the label.

Figure 4: Smart label printer/encoder [16]

3.1.2 Printing Technologies

This section will briefly explain the 5 options available when choosing a suitable label printing technology.

3.1.2.1 Dot Matrix Printing

Dot matrix technology uses a hammer or a pin to transfer pigment from a ribbon onto the substrate. This method does not offer sufficient dot overlap and placement to print one dimensional codes but two dimensional dot codes are possible to print [17]. Figure 5 demonstrates how the printer works and the figure on the right demonstrates difficulties that could be encountered when attempting to print one dimensional codes with this technology.

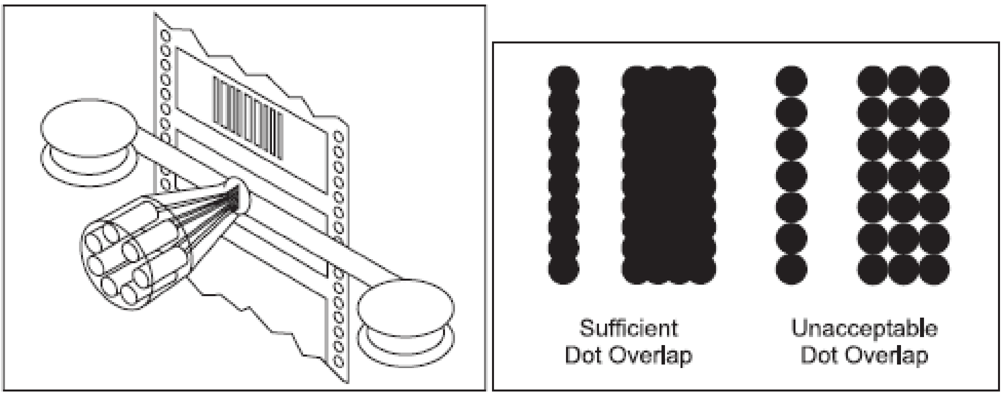


Figure 5: Dot matrix printing and the difficulties associated with printing high density code [17]

Table 3 highlights a few advantages and disadvantages of using dot matrix printing.

Advantages	Disadvantages
Readily accessible and inexpensive	Inaccurate dot placement causes problems printing high density code
Can print on numerous materials	Limited durability, cannot produce chemical or water resistant labels
Use multi-pass ribbons so reduced overall cost for ribbons and label materials	No graphics printing technology

Table 3: Advantages and disadvantages of dot matrix label printing [17]

3.1.2.2 Ink Jet Printing

Ink jet printers spray ink onto the label surface in either a continuous stream, covering the entire print width with one spray, or one drop at a time [17]. Figure 6 demonstrates how an ink jet printer sprays one drop at a time.

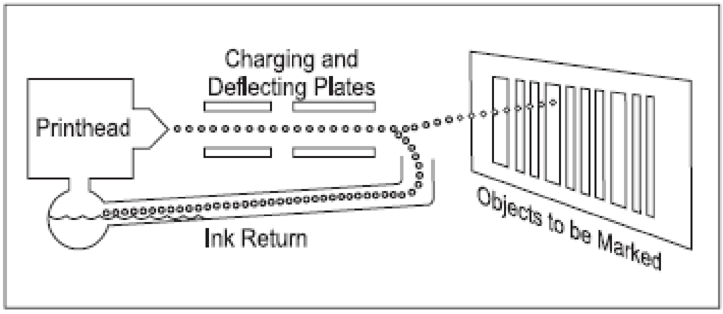


Figure 6: Ink Jet Printing [17]

Table 4 contains a few advantages and disadvantages of ink jet label printing

Advantages	Disadvantages
Printing is done quickly so this method is favoured on high speed production lines	System installation is costly as it is designed for high volume barcode printing
Capable of printing on a label or directly onto the part	Requires diligent supervision and maintenance to ensure consistent print quality and prevent ink jet clogging
	Dot placement accuracy and barcode density/resolution are limited due to ink splatter

Table 4: Advantages and disadvantages of ink jet label printing [17]

3.1.2.3 Laser Printing

Laser printing projects controlled streams of ions onto the surface of a print drum, resulting in a charged image which then selectively attracts toner particles transferring the image onto the paper substrate. After the image is transferred to the media, the heat and pressure of the fuser cause the image to adhere to the media [17]. Figure 7 demonstrates how this process works.

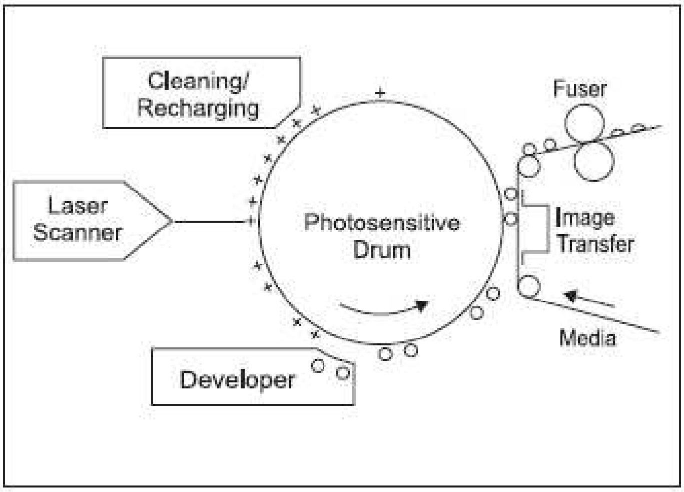


Figure 7: How laser label printing works [17]

Table 5 has a list of a few advantages and disadvantages of laser label printing.

Advantages	Disadvantages
Can print high quality text and graphics on paper documents and can double as document printer	Can be wasteful as they cannot produce single or small labels
High bar code density and resolution	Label adhesives must be carefully selected to ensure stability under the heat and pressure of the fuser
Good at producing plain paper documents that require bar codes	Limited durability, cannot produce chemical or water resistant labels
	Susceptible to toner flaking and smudging, therefore unsuitable for long term bar coding

Table 5: Advantages and disadvantages of laser label printing [17]

3.1.2.4 Direct Thermal Printing

Direct thermal printing utilises heat-sensitive media that blackens as it passes under the print-head. It is a very simple process as it requires no ribbon [17]. Figure 8 shows how this process works.

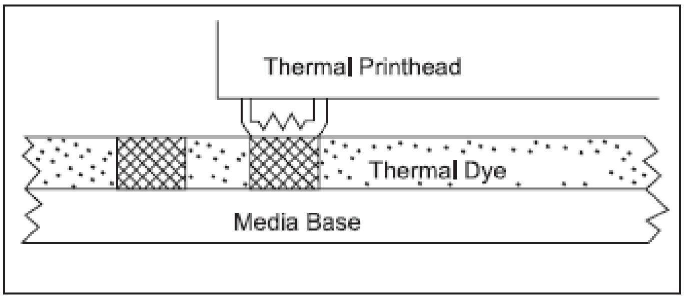


Figure 8: Direct thermal printing [17]

Table 6 contains a list of a few advantages and disadvantages of direct thermal printing.

Advantages	Disadvantages
Produces sharp print quality with good scannability	Extremely sensitive to environmental conditions such as heat and light (fluorescent or sunlight)
Simple to operate and require low maintenance as there is no ink, toner or ribbon to monitor or replace	Direct thermal paper remains chemically active after printing and so have to be top coated to resist light exposure, chemicals and abrasion
Able to print batches or single labels with virtually no waste	

Table 6: Advantages and disadvantages of direct thermal printing [17]

3.1.2.5 Thermal Transfer Printing

Thermal transfer printing uses a thin ribbon roll that when heated by the print-head, melts onto the label to form the image [17]. This process can be seen in Figure 9.

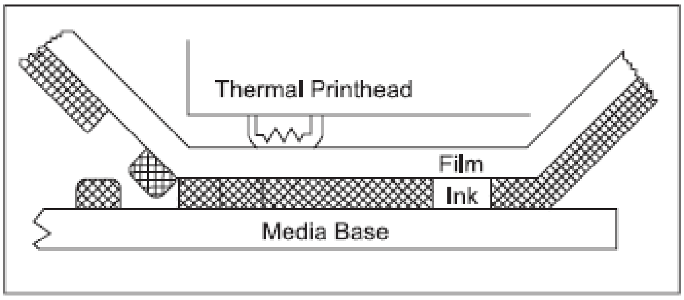


Figure 9: Thermal transfer printing [17]

Table 7 lists a few advantages and disadvantages of thermal transfer printing.

Advantages	Disadvantages
Delivers crisp, high definition text, graphic and bar code print quality for maximum readability and scannability	Supply costs are higher than direct thermal as thermal transfer printing requires ribbon
Long-life image stability	Have to ensure the ribbon and media substrate are compatible otherwise the print-head could melt the ribbon
Enables batch or single label printing with virtually no waste	
Low long term maintenance costs	

Table 7: Advantages and disadvantages of thermal transfer printing [17]

3.1.2.6 Comparison

When choosing a label printing system, people new to bar code printing tend to use familiar technologies (laser, dot matrix or ink jet printers) [17]. By looking at a simple comparison table (Table 8) it can be seen that this will likely be the wrong choice both from a quality of mark and financial point of view. The two thermal technologies are clearly the better options and if the label is going to be exposed to any light or chemical, thermal transfer printing is the best option.

Technology	Print Quality	Scanner Readability	Initial Installation Cost	Long-Term Maintenance Cost	Materials Waste
Dot Matrix	Fair	Low	Low/Moderate	Moderate/High	High
Ink Jet	Moderate	Low/Moderate	High	Moderate/High	High
Laser	Moderate	Moderate	Moderate/High	Moderate/High	High
Direct Thermal	Moderate/Excellent	Moderate/Excellent	Moderate/High	Low	Low
Thermal Transfer	Excellent	Excellent	Moderate/High	Low	Low

Table 8: Bar code print technology matrix

3.2 Optical Character Recognition

Optical Character Recognition (OCR) was first used in the 1960's. Special fonts were developed that stylised characters so that they could be read both by people and automatically by machines [18]. This is the technology long used by libraries and government agencies to make lengthy documents quickly available electronically [19]. For traceability purposes, it offers the advantage of an automatic identification system as well as not requiring readers at all stations as the data can also be manually entered. These OCR traceability systems mostly print date codes and lot codes on items and are usually used in the food industry to enable the customer to also read the information (sell by date, batch code for future reference etc.). OCR systems have however failed to become universally applicable because of their high price and the complicated readers they require in comparison with other identification procedures [18]. An example of the use of OCR in the automotive industry would be the reading of the Vehicle Identification Numbers (VIN) [82].

Figure 10: Optical Character Recognition on food packaging [82]

3.3 Direct Part Marking

There are 7 main areas of consideration when implementing a DPM traceability system [12]:

- Code selection
- Data encoding
- Marking processes
- Mark placement
- Verification
- Reading systems
- Connectivity

These areas will be individually discussed and analysed with regard to cradle to grave automatic traceability.

3.3.1 Code Selection

An efficient and effective traceability system is one which relies as little as possible on human intervention (i.e. automatic) and one which can uniquely identify each part from cradle to grave (throughout a parts life cycle). With this in mind, barcodes will be looked at as the main options for DPM. The other options would be date stamps and alphanumeric serial codes. Both are viable options for uniquely marking parts but due to their dependence on human intervention and the possibility of the mark becoming unreadable (due to wear and tear damage) they were not looked at in this project. The two types of barcodes currently available are one dimensional and two dimensional.

One dimensional barcodes are explained in detail in 3.1.1.1. As explained in 3.1.1.1, this type of barcode will generally be applied by first printing the code on a label then applying it to a part. Although it is possible to use DPM marking methods to apply 1D barcodes, this is normally not the case. If it is applied directly to a part it will not be done using dot peen markers as this technology battles to achieve the mark density required to produce one dimensional barcodes.

Two dimensional barcodes are described in 3.1.1.2. These are more widely used in DPM and from here on it will be assumed that only two dimensional codes are applied using DPM technology.

3.3.2 Data Encoding

The types of two dimensional barcode are shown in Table 2. Two of the more popular types are the data matrix code and the Rolls-Royce DMT code.

Data matrix coding is the most widely used two dimensional code. The data matrix can contain up to 500 characters in a 0.05 inch area and the code can be read from any angle of rotation and from any distance. One of the main advantages of data matrices is that they have sufficient storage capacity to allow error correction through a redundancy of information. This error correction allows the code to be read even when as much as 60% of the code is damaged, missing or obscured. This is essential as the code is only machine readable, there is no option to enter the code in manually. The data matrix code is extremely easy to produce and is not as reliant on contrast as the one dimensional code [12]. Figure 11 is an example of a data matrix code.

Figure 11: Example of a data matrix code [20]

The Rolls-Royce DMT code was created by Rolls-Royce when they encountered problems when marking their parts with a laser. The mark was removed during bead honing and electro-polishing operations and so the identification code had to be remarked and there was concern about the laser marking process damaging some of the parts [21]. For those reasons it was decided that the code should be marked by a pin marker. There was difficulty reading the data matrix code when using the pin marker therefore they developed the DMT code which can be seen in Figure 12.

Figure 12: An example of Rolls-Royce DMT code [21]

3.3.3 Marking Processes

Factors that influence the marking process are [12]:

- Material composition
- Environmental operation
- Production volume
- Available space for the marking
- Part life expectancy

Direct part marking involves the marking of the actual surface of the part. The four most common methods used to apply direct part markings are:

- Dot Peen
- Electro Chemical Etching
- Laser Marking
- Ink Jet Marking

This section contains an explanation of each method. Appendix A presents tables obtained from Microscan which show advantages and disadvantages for using these methods on different materials.

3.3.3.1 Dot Peen

The dot peen method involves a pin, otherwise known as a stylus, that is pneumatically or electromechanically driven into the surface of the part to produce round indentations [22]. This process is shown graphically in Figure 13.

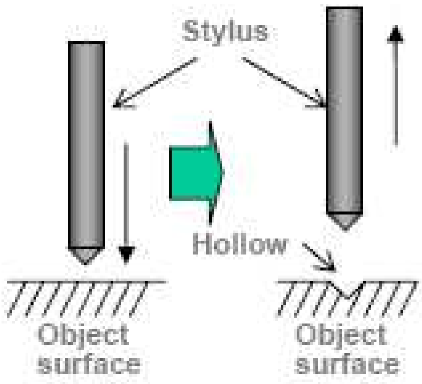


Figure 13: How dot peen marking works [23]

The stylus is usually carbide tipped. The size and appearance of the dot are determined by the stylus cone angle, marking force and material hardness. The depth of the penetration is proportional to the resistance of the code to mechanical damage. The deeper the penetration, the wider the dot and the more resistant the code is to mechanical damage. This type of marker is computer controlled and works quickly. It is better suited to dot codes than matrix codes. Figure 14 shows the stylus marking a part and the resultant mark.

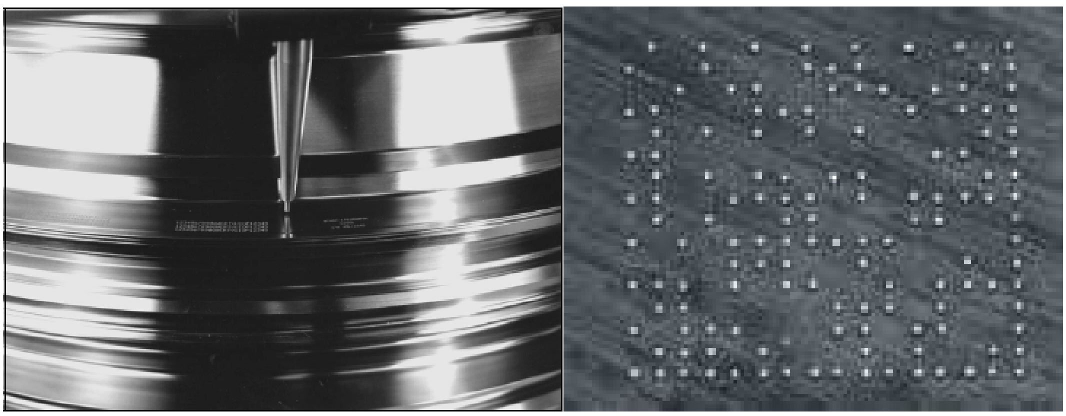


Figure 14: A carbide tipped stylus marks codes permanently by dot-peen indentations & an example of a dot peen mark [24]

Table 9 contains a few advantages and disadvantages of dot peen marking.

Advantages	**Disadvantages**
No consumables	Stylus wear and movement
Not affected by heat	Noisy, slow process
Can sometimes be coated over and still read	Parts must be secure while marking

Table 9: Advantages and disadvantages for dot peen [23]

3.3.3.2 Electro Chemical Etching

Electro chemical etching works by the electro-chemical dissolution and/or oxidation of metal from the surface being marked through a stencil impression to give the required mark [10]. The stencil is sandwiched between the surface being marked and an electrolyte soaked pad and a low voltage current is passed between the two. Figure 15 shows an example of a mark created by electro chemical etching.

Figure 15: An example of an electro chemical etch mark [81]

This is the least popular of the four methods as it is mostly limited to human readable data and some basic symbol information only. Table 10 contains a few advantages and disadvantages of electro chemical etching.

Advantages	Disadvantages
Permanent	Consumables
Flexible	Very little mark contrast
Can mark odd shaped parts	Parts must be secured while marking
Cost effective	Slow

Table 10: Advantages and disadvantages for electro chemical etching [23]

3.3.3.3 Laser Marking

Laser (Light Amplification by Stimulated Emission of Radiation) marking is a process which uses the thermal energy of the laser beam to vaporize, melt/bond or change the conditions of the surface [22]. Figure 16 shows an example of a mark created by a laser marker and shows the actual marking process.

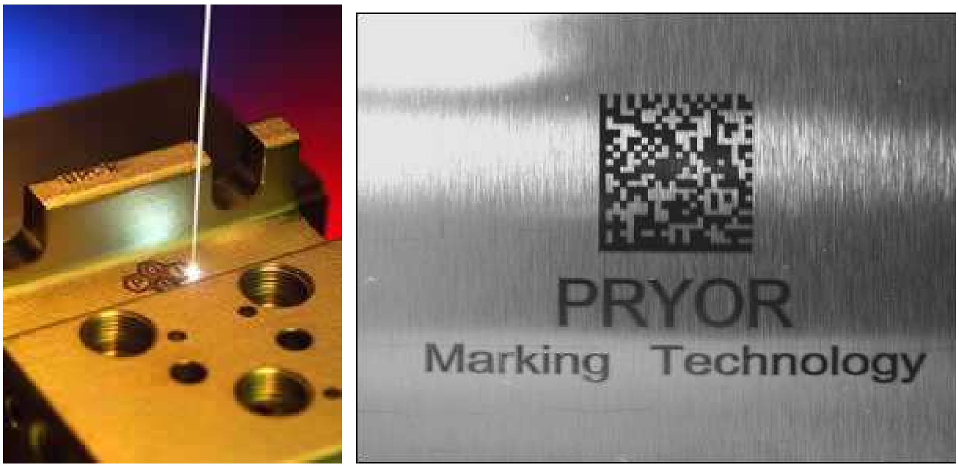


Figure 16: Part being permanently marked using a laser marker and an example of a laser marked data matrix [24]

The technology behind laser marking is more complicated than the other 3 methods thus it will be explained in greater detail. There are generally three areas that need to be looked at when deciding on an appropriate method to create a laser mark, they are [26, 27]:

- Laser type
- Beam control and delivery
- Marking method

The types of laser used can be classified by the wavelength of the laser. For marking purposes, these wavelengths can be broken into three main categories which are shown in Table 11.

Wavelength	Description	Laser types
Short wavelengths	• Also known as ultra-violet lasers • Utilise light in the lower end of the light spectrum • Mark using a cold marking process • Excimer lasers are used to mark extremely thin materials	• Excited dimmer (excimer) lasers
Visible wavelengths	• Utilise light in the visible light spectrum • Produce marks using heat action or pressure • Generally used to mark metal substrates	• Neodymium doped: Yttrium Lithium Fluoride (Nd:YLF) • Neodymium doped: Yttrium Aluminium Garnet (Nd:YAG) • Neodymium doped: Yttrium Aluminium Perovskite (Nd:YAP) • Neodymium doped: Yttrium Vanadate Orthovanadate (Nd:YVO_4)
Long wavelengths	• Also known as infrared lasers • Utilise light in the infrared spectrum • Mark created by directing a concentrated beam of coherent light onto the surface of a part using galvanometer-controlled mirrors • Carbon dioxide lasers are effective for marking organic materials such as wood, leather and some plastics	• Carbon dioxide lasers

Table 11: The different laser wavelengths [26]

There are two methods commonly used for laser beam control and delivery [26]:

- Galvanometer beam steering
- Flying optics

Galvanometer laser marking systems are driven by computer controlled mirrors that move the beam by reflecting it to a specific location. Figure 17 shows the laser beam being reflected off the mirrors and finally going through a focusing lens onto the item to produce the mark [26]. The galvanometer offers benefits of speed and throughput over the flying optics system but the engraving area is limited to a much smaller area that is defined by the focus length of the lens [29].

Figure 17: Galvanometer beam steering [30]

Flying optics laser marking systems are controlled by belt or gear driven motors that move fixed mounted mirrors along x and y coordinates [26]. Figure 18 shows how it works. The flying optics system offers benefits of flexibility, price and a more consistent spot size and shape over the galvanometer [29]. The more consistent spot size and shape is due to the flying optics system always being at a normal angle to the piece being marked [29].

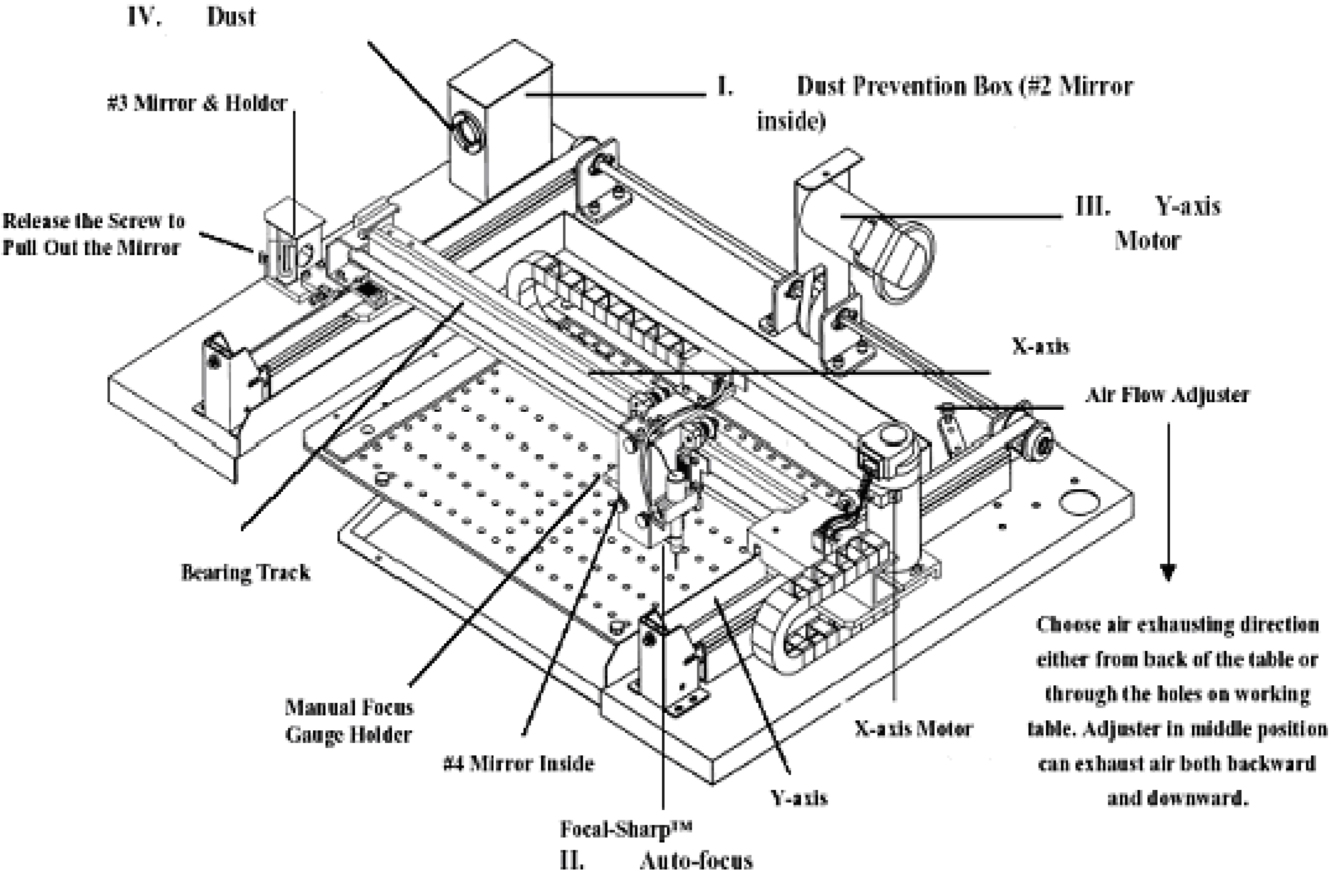


Figure 18: Flying optics laser marking system [26]

There are numerous marking methods that could be used. Table 12 contains a description and comparison of 6 of them.

Marking Process	**Description**	**Laser Type**	**Marking Speed**	**Marking Quality**	**Mark Durability**	**Removes Part Material**
Laser Coloration	A process used to discolour metallic substrate material by passing a low power beam across a surface at slow speed without burning, melting or vaporising the substrate material	Nd:YAG	Slow	Excellent	Excellent	No
Laser Etching	Similar to laser colouring except that the heat applied is increased to a level that causes substrate surface melting	Nd:YAG	Fast	Very Good	Excellent	Yes
Laser Engraving	Involves more heat than laser etching and results in the removal of substrate material through vaporisation	Nd:YAG	Fast	Good	Excellent	Yes
Laser Bonding	An additive process that involves the bonding material to the substrate surface using the heat generated by a laser	CO_2 LVO_4 Nd:YAG	Slow	Excellent	Good	No
LISI	Laser Inducted Surface Improvement is similar to laser bonding except the additive material is melted into the metallic host substrate to form an	Nd:YAG	Slow	Good	Excellent	No

	improved alloy with high corrosion resistance and wear properties					
LIVD	Laser Induced Vapour Deposition works by vaporising material from a marking media trapped under a transparent part using heat generated by a laser	LVO_4 Nd:YAG	Slow	Excellent	Good	No

Table 12: Laser marking processes [27]

Laser marking is the most expensive of the four marking methods but it is extremely quick. The major disadvantage of this method is the distortion of the material caused by the interaction of the laser beam with the material surface. For most parts this isn't a serious problem but for fragile parts it can have detrimental consequences for its later use. Laser marking is mainly used for matrix codes. Table 13 contains a list of some of the advantages and disadvantages of laser marking

Advantages	Disadvantages
Speed	Higher cost for marker
Extreme precision	Low contrast on some materials
High code density possible	Some laser types do not mark certain materials
	Some materials are distorted due to the laser

Table 11: Advantages and disadvantages for laser marking [23]

3.3.3.4 Ink Jet Marking

Ink jet marking is a process that involves the propulsion of ink drops to the target surface with an extremely quick drying time [22]. There are two primary methods for doing this [26]:

- Continuous Ink Jet method
- Drop-on-Demand method

The continuous ink jet method is preferred over the drop-on-demand method in industrial applications due to limitations on the distance at which the drop-on-demand method can be used. The continuous ink jet method works by making a continuous single jet of ink pass between two variable voltage plates whose voltage can be adjusted. The voltage changes adjust the vertical location at which the drops will land. The horizontal position is varied by moving the target in reference to the print head [26]. Figure 19 shows a typical setup.

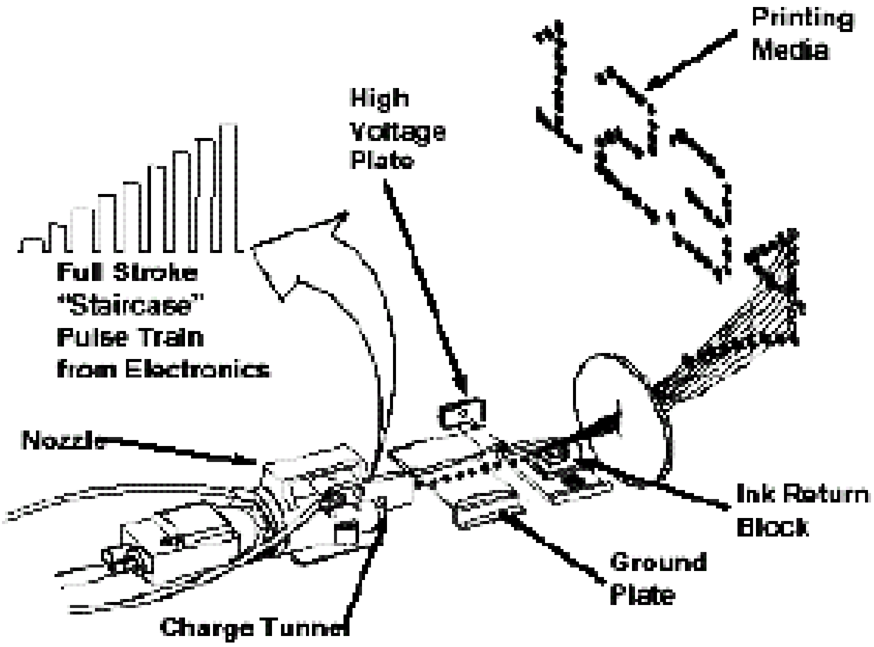


Figure 19: How ink jet marking works [23]

The disadvantages of this method include inaccuracy and restrictions with respect to the type of ink that can be used. Marking is done at extremely high speeds and so this process is often used on a production line. It does not make a physical impression on the part and it's suitable for dot and matrix codes. Table 14 contains a few of these advantages and disadvantages.

Advantages	**Disadvantages**
Fast marking of moving parts	Jets can clog
Good contrast	Dot misplacement and skew
Non-intrusive	Run out of ink

Table 14: Advantages and disadvantages for ink jet marking [23]

Figure 20 is an example of the resultant mark.

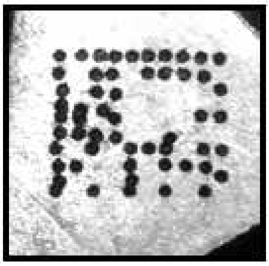


Figure 20: An example of an ink jet mark [23]

3.3.3.5 Comparison of DPM Marking Methods

This section gives a brief comparison between the different marking methods. Table 15 is a side by side comparison of the methods.

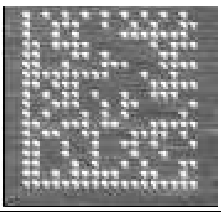
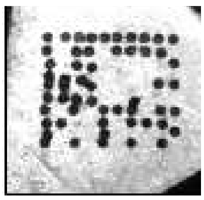
Marking Method / Characteristic	Dot Peen	Electro Chemical Etching	Laser	Ink Jet
Mark Generation	Stylus driven into surface of part, produces round indentations	Electro-chemical dissolution and/or oxidation of metal from surface through a stencil	Thermal energy of laser beam vaporizes, melts/bonds or changes conditions of surface	Propulsion of ink drops to target surface with extremely quick drying time
Types of Code	More suited to dot codes	Only recently capable of producing matrix codes	Mainly used for matrix codes	Suitable for dot and matrix codes
Surface Damage	Surface is damaged but not detrimental to the part	Damage to part surface is limited	Causes distortion of material	No physical impressions on part
Sectors used in	Automotive and aerospace	Automotive and aerospace	Semiconductor, electronics, medical and some automotive and aerospace applications	Electronics, pharmaceutical, packaging and some aerospace applications
Visual Representation				

Table 15: Comparison of the different DPM marking methods

Each of these four marking methods have situations were one is better than the others. Marks generated by ink jet printers are not as clear as the other three. Electro chemical etching was mainly used for human readable data up to a short while ago and is the least popular option out of the four. Dot peen marking is mainly suited to dot codes and laser marking is mainly suited to matrix codes. Some of the marking methods are not suitable to be used with certain materials. Appendix A contains a table showing which marking method is best suited to a material. For instance, dot peen marking is not suited to be used with glass, plastics or rubber but it is more suitable to be used on any other highly reflective material [31].

3.3.4 Mark Placement

A very important point to consider when marking the part is the location of the code. It needs to be easily visible throughout the manufacturing process and preferably needs to be marked on a flat surface. When trying to find a position for the mark, the following should be avoided [12]:

- Where there may be a surrounding surface relief that could potentially affect the illumination of the code by the reader's light source
- Features or part edges should not contact the code or come between the code and the reader
- The reader should be located away from sources of electrical noise
- When placing a mark on a cylindrical part, care must be taken in selecting the size of the code as surface curvature can distort the code and make illumination difficult
    - A code size that is no larger than 16% of the diameter or 5% of the circumference is recommended

3.3.5 Verification

The original quality of a two- dimensional code – which serves as a part's permanent identity – can greatly affect the readability of a part as it travels throughout the manufacturing process, throughout the supply chain, and ultimately to the end use of the part [32]. Thus verification of this mark is vitally important to the traceability process. Cognex is one of the world leaders with regard to machine vision. In 2005 they released a white paper containing 10 important points that should be considered when implementing a direct part mark verification system [32]:

- What is verification and how is it used?
- Reading vs. verification
- DPM verification challenges
- DPM marking methods
- An introduction to standards
- Choosing the right quality metrics for the job
- Implementation guidelines
- Data validation, collection and reporting
- Types of DPM verification systems
- Vendor selection

3.3.5.1 What is Verification and how is it used?

Direct part mark verification systems operate by capturing and analysing the image of a code and rating the image on a number of quality assessment metrics. The verification system then generates an overall score or grade for the code and provides process feedback about the marking equipment that manufacturers can use for preventative maintenance [32]. Apart from assisting with diagnosing problems, the DPM verification system can also assist with the initial setup of the marking machine. The main role of a DPM verification system is to analyse the mark and ensure it is a good one from the start. Through part handling and usage, the mark will obviously be degraded thus the verification system cannot guarantee readability throughout the part's life, the quality of the mark with regard to readability is at its best when it is verified. The data Matrix code will be examined as an example. There are several attributes of the Data Matrix symbol that contribute significantly to its overall readability. The quiet zone or clear area surrounding the symbol on all four sides should be free of defects. The finder pattern should be well formed, and the modules or light and dark cells that make up the clock track and data region should be uniform and easily distinguishable [32].

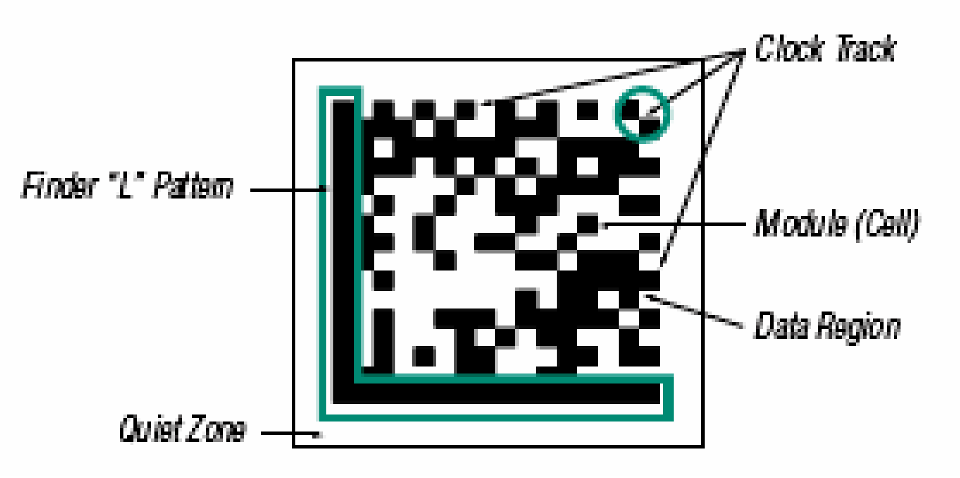


Figure 21: Attributes of a data matrix symbol [32]

The key attributes that are measured during verification are [25]:

- Size and centre offset
- Axial uniformity
- Print growth
- Error correction

Figure 22 gives a variety of possible outcomes when conducting a verification scan. Everything except for the first one (High Quality) is unacceptable and will have to be remarked.

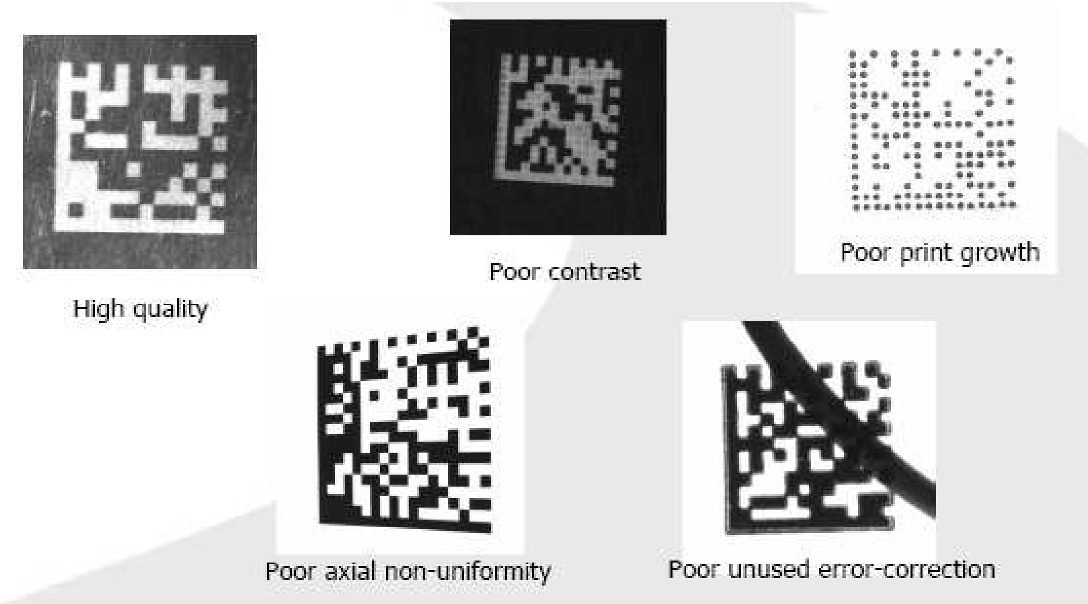


Figure 22: Possible results after a verification scan [6]

3.3.5.2 Reading versus Verification

The goal of DPM code reading is to read a code as quickly as possible despite the appearance of a code, and report the results [25]. It is important to note that just because a code is readable doesn't mean that it's of a high quality and thus should not be used as a basis for determining mark quality. The quality of mark can vary widely from part to part due to [25]:

- Quality of code
- Part presentation
- Process effects
- Part surface characteristics

The goal of a DPM verification system is to confirm that the mark meets an acceptable level of quality as defined by particular quality specifications and industry standards. In order to achieve this, the DPM verification system must generate a consistently formed image of a 2D mark that is free from variations in lighting, part presentation or process degradation [25]. The verification system isolates the mark from variables such as lighting changes and variation in part position and this allows the total focus of the system to be on mark quality.

The difference between verification and reading can be seen in Table 16.

Verification	Reading
Inspect the mark structure for conformance to specified requirements	Capture, locate and decode a mark as quickly as possible
Output a grade of the code's quality	Output the data encoded in the mark
All environmental variables must be controlled and all mark attributes are measured	A good reader can handle variations in marking method, surface texture etc.
Requires a minimum resolution of 10 pixels/cell	Can read with as few as 3 pixels/cell

Table 16: The difference between verification and reading [7]

3.3.5.3 DPM Verification Challenges

The greatest challenge faced by a verification system is to achieve accurate and repeatable results when working with a wide variation of mark type and surface conditions [25]. To achieve such results, the DPM verification system must operate under tightly controlled conditions. The following characteristics need to be configured based on the specific surface characteristics of a part and the marking method and redefined for each new verification application [25]:

- Lighting
- Part fixturing
- Camera resolution
- Optical settings

The code must then be accurately located and once that is done, the various reference points can be located.

3.3.5.4 DPM Marking Methods

The various types of direct part marking methods are explained in detail in 3.3.3. With regard to verification, the main goal is to produce a high quality mark that is readable throughout the part's lifecycle.

3.3.5.5 An Introduction to Standards

ISO (International Standards Organisation) addresses three areas of quality for direct part marking [25]:

- Symbology
  - Defines what the code is, the code structure, symbol formats, error correction rules and decoding algorithm
- Print quality
  - This defines the underlying quality assessment metrics, methods and grading used to analyse code quality
- Conformance specification
  - Defines the testing that a DPM verification supplier needs to perform on its systems to ensure that results are within a certain tolerance of the expected results of the ISO print

3.3.5.6 Choosing the right Quality Metrics for the Job

The verification system should satisfy certain industry standards as well as any possible level of standards that might be required from it by a customer. The company implementing the system should look at its customer base and the industry and develop a level of standards that would suit them.

3.3.5.7 Implementation Guidelines

When setting up a DPM verifier, the following general image formation guidelines should be followed [25]:

- Camera resolution
  - In verification applications, a cell resolution of 2-3 times higher than that required for reading DPM codes
- Lighting
  - DPM verification systems need to have the ability to accommodate a variety of lighting approaches including bright-field, dark-field and diffuse dome illumination, these different approaches can be seen in Figure 23. Bright-field is when diffuse light is directed at the marked code approximately at a 90 degree angle, this is ideal for high contrast printed or marked codes on non-reflective surfaces. Dark-field is when light is projected at a low angle to the part surface, causing any variations to deflect light up into the camera, this technique is ideal for dot peen and highly reflective laser marked codes. Diffuse dome provides a non-directional, soft illumination free of harsh shadows that is well suited for highly specular objects, this technique is ideal for imaging marks on curved, highly reflective surfaces and dot peen codes on rough surfaces.

Figure 23: The different types of lighting approaches [25]

- Ambient lighting
  - The verifier should either be shrouded to eliminate the effects of ambient light or should apply a cut filter that only allows light from the vendor's light source into the camera
- Part fixturing

  - Parts should be consistently positioned in the centre of the camera's field of view and at a constant working distance, this will help the verification system generate consistent and meaningful results
- Set-up routine
  - A routine should be developed so as a repeatable and reproducible set-up of the verification system is possible

3.3.5.8 Data Validation, Collecting and Reporting

The goal of data validation is to ensure that the correct syntax, semantics and data has been encoded within the data matrix in the right format. The system should also be able to record the overall score and quality metrics for each part that is verified, time and date stamp each verification and store bitmaps of each image [25]. The verification system should enable operators to export the recorded data to third party databases and spreadsheet programs.

3.3.5.9 Types of DPM Verification Systems

There are two main types of verification systems [25]:

- In-line fixed mount
- Stand-alone or bench top fixed mount

In-line fixed mount DPM verification systems can be mounted on the marking machine, directly after the marking station or above the fixtured part at the marking station. This allows the quality of the mark to be checked straight after the marking process. As suggested by its name, the system consists of precisely mounted components that are designed so that the entire image formation system is configured to the specific marking method and surface characteristics of the parts being marked [25].

Stand-alone verification systems are used as first article inspection tools or as incoming quality inspection stations. They incorporate a stand, verifier and lighting to accommodate flat parts, nameplates and other small parts that can be brought to the station.

3.3.5.10 Vendor Selection

As in most other applications, when selecting a vendor, one should ensure they have a reliable track record with sufficient experience in the industry. The company should also be well established so that one can be sure they will still be around in the future.

3.3.6 Reading Systems

Scanners or code reading systems are used to decode the markings on a part. With the help of software, they decode the code and store the information on a database. The full process that occurs during a matrix code read [20]:

- A part sensor is triggered, indicating a new code has been placed within the camera field of view
- The matrix code reader stores the image from the camera in an image buffer. During this process the image is converted from an analogue signal to a digitised format. The digitised format allows the matrix code reader to analyse the image
- A part locator is executed. The locator finds the matrix code and separates it from the background
- The matrix code reader converts any distortion in the image that caused the code to be non-square
- The visual information is converted into a binary array of 1s and 0s
- The array is decoded using a decode algorithm
- The decoded information is sent to the source, if appropriate a no-read indication is sent

There are three categories that code readers fall under [12]:

- Hand-held readers
- Fixed-mount readers
- Presentation readers

3.3.6.1 Hand-held

As the name suggests, hand-held readers are manually operated and are easily moveable. They are usually preferred in situations where part handling is not automated or when parts vary greatly in size. They are used in job shop manufacturing operations, quality control test stations and in logistic areas. They can either be tethered or cordless. The advantage of tethered hand held readers is that they cannot be removed from the workstation where they are being used. Cordless operation is required in cases where part size or position limit cord length [12].

Figure 24: Hand held 2D barcode reader [83]

3.3.6.2 Fixed-mount

Fixed-mount readers are stationary and are best suited for use on production lines. They are used to identify parts that are handled and moved automatically by conveyor, indexer or robot [12]. This type of reader is mounted in a fixed position where the mark can repeatedly be placed in front of the reader in a continuous or indexed motion. A trigger signals a reader that the part is ready for reading. This trigger signal can be sent by an external sensor that detects the presence of the part or by an encoder that knows the position of the part at all times and can signal the reader to decode [12].

Figure 25: Cogenex InSight fixed-mount reader [16]

3.3.6.3 Presentation readers

Presentation readers provide a fast way of reading part codes in areas where parts are handled manually. A presentation reader can either be hand-held or fixed. The fixed type is similar to a fixed-mount reader in that it is mounted in a fixed-position. The difference is that it operates in a continuous reading cycle, automatically performing the decoding task once the operator places the part in front of the reader [12]. The hand-held type can be fixed and also offers the user the possibility to remove it from its stand and take it to the part.

3.3.7 Connectivity

Connectivity refers to the method of interfacing the reader or verifying to a controller, such as a PLC or PC, so that the result of the decoding is communicated [12]. The type of connectivity differs between hand-held and fixed-mount readers. In the case of fixed-mount readers, the reader should offer both serial and network communications as the information is usually sent over the factory network. Serial communications are used typically in applications where the read or verification results stay local to the work cell or factory automation equipment. Network connectivity enables the reader to communicate decoded results to PCs and databases at the enterprise level [12].

With handheld readers, connectivity depends on whether the reader is cordless or not. Tethered readers (readers with a cord) often communicate the read results through what is called a 'keyboard wedge' interface, which emulates the keystroke of a keyboard making integration to a PC very simple [12]. A cordless hand-held reader will have to use some sort of wireless technology e.g. Bluetooth to communicate to the base PC station or to another controller.

3.4 Radio Frequency Identification

Radio frequency identification can be defined as the use of radio waves to identify or locate an item [34]. This is by no means a new technology and has a history that spans 60 years. RFID technology was first invented in 1948 after major WW II development efforts. It was used by the British to identify incoming allied aircraft (Identification: friend or foe) [35]. Figure 26 shows how this technology has been used from the middle 1940's till 2005.

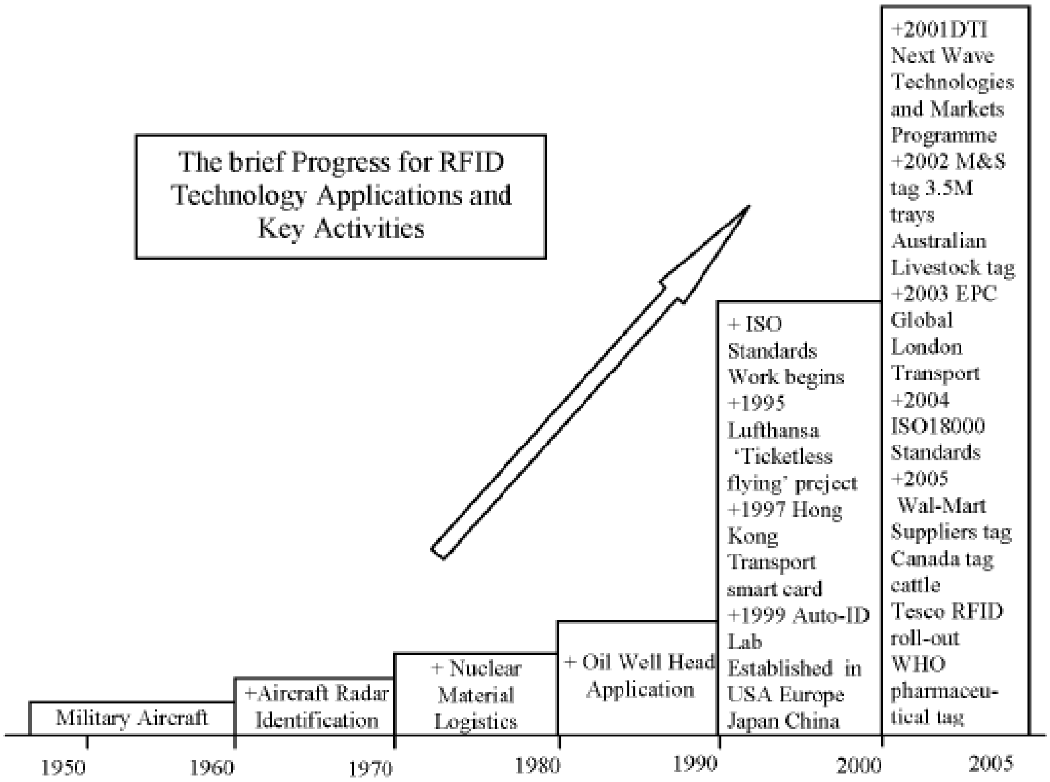


Figure 26: Brief progress for RFID technology applications and key activities [36]

3.4.1 How an RFID System Works

All RFID systems comprise of [37]:

- The RFID tag, or transponder, which is located on the object to be identified and is the data carrier in the RFID system

- The RFID reader, or transceiver, which may be able to both read data from and write data to a transponder
- The back-end database which associates records with data collected by readers

The following is the process that takes place when obtaining the information contained on the tag [38]:

- A transceiver sends the tag a signal which causes the tag to transmit its information to the transceiver
- The transceiver reads the signal
- The signal is converted into digital format
- This digital format signal is transmitted to a designated application such as an inventory management system

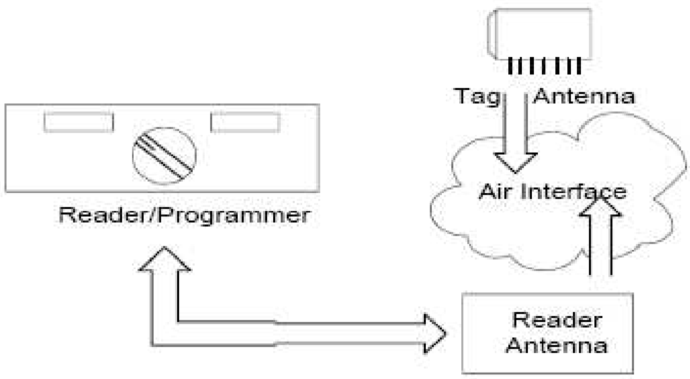


Figure 27: How an RFID system works [39]

In order to encourage the wide adoption of RFID technology in various industries, the Auto-ID centre at MIT (Massachusetts Institute of Technology) is creating an infrastructure consisting of:

- Electronic Product Code
  - A globally unique serial number similar to the Universal Product Code but used in RFID tags [30]
- Object Naming Service

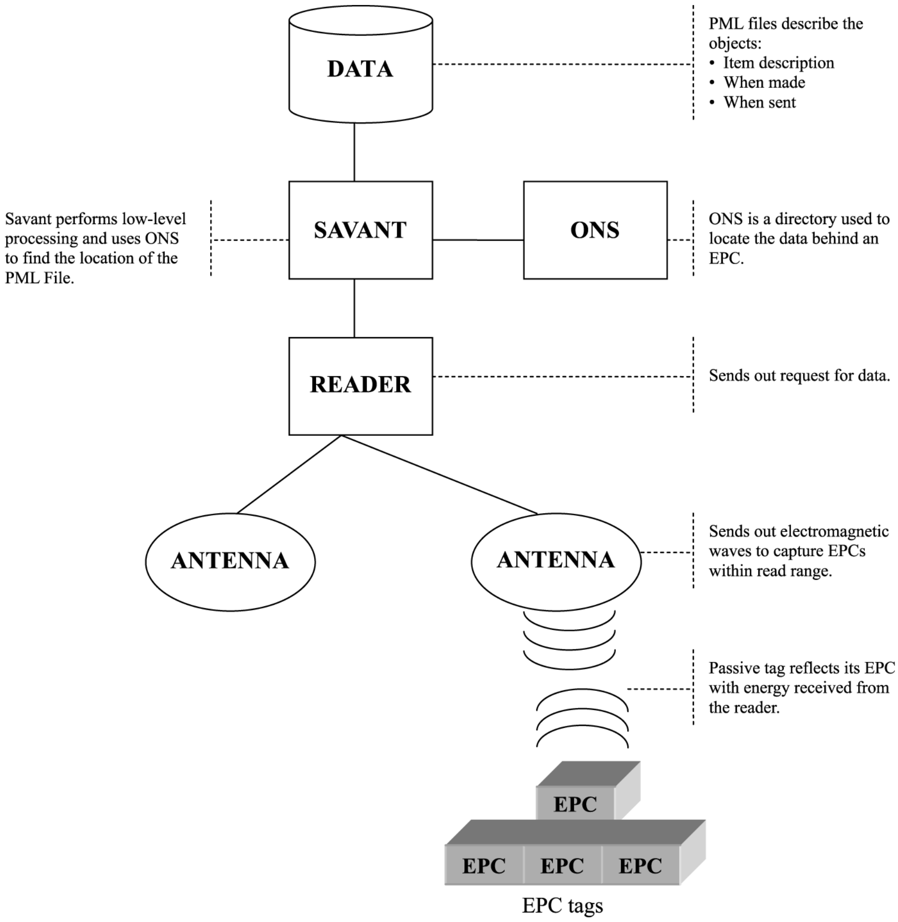
- A global lookup service similar to the Domain Name Service that translates an EPC into one or more Internet Uniform Locators or URL's where further information on the object may be found [30]

- Physical Markup Language
    - A common language used in the EPCglobal network to define data on physical objects
- Data handling middleware called Savant
    - An open source web server [37]

The Auto-ID centre created this infrastructure in an effort to standardise the way data is stored and retrieved from RFID tags therefore making RFID systems from different vendors interoperable. Interoperability of RFID systems is vital for the worldwide adoption of this technology.

The Auto-ID RFID infrastructure works as follows [30]:

- When the reader picks up a signal, Savant uses the EPC on the tag to contact the ONS (Object Naming Service)
- The ONS locates the server containing the information for the item being scanned
- This information is collected by Savant and then communicated to the databases and supply chain applications requiring the information
- The communication format for the data is Physical Markup Language (PML)



Source: (Adopted from Dinning and Schuster, 2003)

Figure 28: RFID technology infrastructure as described by the Auto-ID Centre [24]

3.4.2 RFID Tags

RFID tags are available as passive and/or active radio read/write sensor-packages with active read (and often write) capabilities in relatively large areas (like a large distribution centre warehouse, or containership), all performed automatically, supervised by computers and communicated in a wireless fashion [41]. Active tags have a battery, which runs the microchip's circuitry and broadcasts the signal to the reader. Passive tags have no battery, their power is drawn from a reader which sends out electromagnetic waves that induce a current in the tag's antenna, and powers the microchip's circuits. Passive tags have a read range of approximately 30 feet (9.144 m) whereas active tags have a read range of approximately 100 feet (30.48 m) [38].

	Passive	Active
Read range	Up to 10m	Up to 30m
Price	Cheaper	More expensive
Size	Can be as small as a grain of rice	Smallest device is about the size of a coin
Life of the tag	Indefinite if tag isn't damaged	Battery life of approximately 10 years

Table 17: Comparison of passive and active tags

The table below was compiled by EPCGlobal and gives a description of the different classes of tags and readers. EPCGlobal is a non-profit organisation that developed a RFID-network standard – EPC (Electronic Product Code) Network. It was started as a joint venture between EAN International and the Uniform Code Council (UCC).

EPC Class	Definition	Programming
Class 0	"Read only" passive tags	Programmed as part of the semiconductor manufacturing process
Class 1	"Write-Once, Read-Many" passive tags	Programmed once by the customer then locked
Class 2	Rewritable passive tags	Can be reprogrammed many times
Class 3	Semi-passive tags	
Class 4	Active tags	
Class 5	Readers	N/A

Table 18: Description of the different classes of RFID tags and readers [42]

There are four different frequency bandwidths allocated for RFID use, they are compared in Table 19.

Radio Frequency	Features	Limitations
LF (125 – 134 kHz)	• Frequency accepted worldwide • Works well near metal • In wide use today	• Limited read-range potential (impractical for some warehouse operations such as pick and pack); less than 0.5 meters
HF (13.56 MHz)	• Frequency accepted worldwide • Works well in moist environments • In wide use today	• Does not work well near metal • Limited read-range potential; less than 1 meters
UHF (860 – 960 MHz)	• Longer read-range potential ~ 3 meters • Commercial use is growing rapidly	• Detuning when tags are in close physical proximity • Does not work well in moist environments
Microwaves (2.45 GHz)	• Longer read range potential; > 3 meters with less radiated power than UHF • Fast read rates	• Complex systems development

Table 19: Comparison of different RFID frequencies [34]

The read range of the tags is directly proportional to the frequency, as the frequency increases so does the read range. Low frequency tags are best suited to access control, situations where the parts are moving slowly past the reader or a mobile reader is being used. The higher frequency tags are more suited to being used in conjunction with gate readers, when it's required to read tags from a large distance away or when it's required to read numerous tags at the same time. According to the table above, UHF tags have a read range of approximately 3 meters but this differs between suppliers, UHF tags can have a read range of approximately 7.5 meters **[76].** From here on, only three frequencies will be used as microwave tags are not in common use.

3.4.3 RFID Readers

RFID readers (or RFID interrogators) are devices that can convert the radio waves from RFID tags into a form that can be passed along to middleware software. There are 3 types of readers, stand alone, hand held or mobile. Table 20 contains information about all three of these readers. As can be seen, each has their own advantages and disadvantages. Fixed readers are suited to situations where the entities that need to read follow a fixed route past the reader i.e. a gate reader at a door or a reader on a conveyor belt. Hand held readers are suited to situations where there is a low volume throughput or the parts are already handled by workers. Mobile readers can be used in situations where it is uncertain where the object will be and allows the user a great deal of freedom to move.

Interrogator Type	**Characteristics**
Fixed Interrogators:	• Can read tags as well as write to tags, depending on the type • Can be mounted to walls, doors, or other structures • Can be integrated with stationary devices, such as conveyors, door portals, sortation systems, manufacturing lines, and others • Need an external power source • Typically can accommodate multiple antennas • Can be hard-wired or wirelessly

	connected to the local area network (LAN)
Hand-held Interrogators: Hand-held interrogators can be either *tethered* or *wireless*.	
	• Are much smaller than fixed interrogators and usually come in the shape of a gun or a tablet • Have capabilities similar to those of fixed interrogators but are much smaller • Can be used not only to read from tags but also to write to tags (some models, however, are just read-only) • Have an antenna built into the unit • Are primarily used for exception processing due to their portability and capabilities • Can be used in low-volume applications for tag data verification, case, and pallet association or tag searches • Can have both barcode and RFID functionality
Tethered interrogators	• Are tied directly into the IT infrastructure • Don't need their own power because they are typically connected to a power source through the attached tethered

	cable • Have limited mobility due to their wired connections to other devices and to their external power source
Wireless interrogators	• Are connected to the network through a wireless LAN protocol or device-specific protocols • Need a power source (battery) built into the device • Are able to achieve greater mobility due to their wireless capability
Mobile Interrogators: These interrogators can come in different forms (for instance mobile phone, PDA, or vehicle mounted).	
	• Can have PCMCIA cards to connect to laptop PCs Differ from hand-held interrogators in size and form factor • Usually are powered from their own power source (battery) or by the vehicle they are mounted on • Typically have wireless connectivity
Mobile phones and PDAs	• Are very small in size but have fairly advanced functionality • Are a proven technology • Are attractive to industrial applications
Vehicle mounted interrogators	• Are typically mounted on forklifts or clamp trucks

	• Are built to withstand environmental extremes • Are placed for minimal contact with material being handled

Table 20: Different types of RFID readers [44]

A basic reader consists of the following components [44]:

- A receiver that holds an amplifier and a demodulator
- A transmitter that holds a modulator and a power amplifier
- An oscillator
- A controller/processor
- An input/output port to an antenna

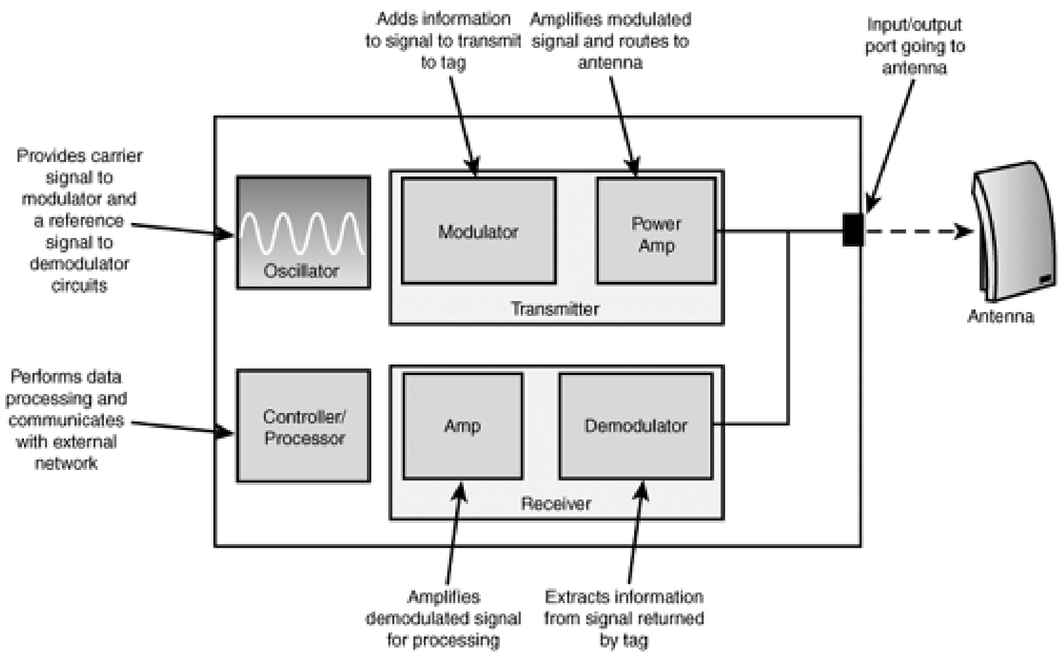


Figure 29: Components of a reader [44]

The sequence that is followed by an RFID reader when receiving a signal from a tag is as follows [44]:

- The amplifier "expands" the signal received from the tag through the interrogator's antenna for processing.
- The demodulator extracts the information from the signal.
- The controller/processor performs the data processing functions and manages the communications with the external network.

3.4.4 RFID Middleware

Middleware is the software used to manage the flow of data from readers and integrate it with back-end systems. It assists with the following [38]:

- Retrieving data from readers
- Filtering data feeds to application software
- Generating inventory movement notifications
- Monitoring tag and reader network performance
- Capturing history
- Analysing tag-read events for application tuning and optimisation

In order for a company to get the best out of its RFID system, it must also deploy RFID-enabled software. Table 21 explains different types of such software.

Type of Software	Description
Compliance Enablement	This software helps companies meet the specific RFID requirements of their customers by automating processes around tagging for customers that require it. Its functions include collecting RFID tag data in shipping, printing RFID tags or Smart Labels, creating advance ship notices (ASNs), etc.
Logistics/WMS	This software enables tracking and fulfillment processes in logistics and warehouse management software (WMS). To fully take advantage of RFID capabilities (e.g., automated RFID receiving) new work flows will need to be created in existing WMS systems.
Supply Chain Visibility	This software is an extension of warehouse management, which when combined with RFID can be used to achieve real-time visibility to goods across the supply chain, including international movements, tracking of inventory across company facilities, and during the transportation process, and as goods move among trading partners.
Asset Tracking	Asset tracking software supports tracking of a variety of fixed assets, such as trailers and reusable containers, in real time, enabling visibility of where they are now and the utilization over their life cycle (i.e., how many times has this asset been used?)
Shop Floor Control	Manufacturing and shop floor software enables raw materials, work-in-process, and finished goods inventories to be tracked in real time. Also, production related data such as lot and batch number could be written to the tags for downstream use.

Table 21: Types of RFID-enabled application software [38]

3.5 Comparison between the Traceability Systems

All the traceability systems mentioned in this chapter are capable of automatically and uniquely marking and tracking entities. In this section the type of code will be looked at instead of the marking method thus one dimensional and two dimensional barcodes will be examined instead of labels and direct part marking. This will be done to simplify the comparison and will be sufficient to compare the systems. Table 22 contains a comparison between the four methods.

System Parameters	**Barcode**		**OCR**	**RFID Systems**
	1 Dimensional	**2 Dimensional**		
Typical data quantity	1 – 100 bytes	Can be more than 7000 characters	1 – 100 bytes	16 – 64 k
Data Density	Low	Very High	Low	Very high
Machine readability	Good	Good	Good	Good
Readability by people	Limited	Impossible	Simple	Impossible
Influence of dirt/damp	Very high	Limited (due to error correction in code)	Very high	No influence
Influence of (opt.) covering	Total failure	Total failure	Total failure	No influence
Influence of direction and position	Low	Low	Low	No influence
Degradation/wear	Limited	Limited	Limited	No influence
Purchase cost (reading electronics)	Very low	Medium	Medium	Medium
Operating costs (e.g. printer)	Low	High	Low	None
Unauthorised copying/modification	Slight	Slight	Slight	Possible (Hackers)
Reading speed (including handling of data carrier)	Low	Low	Low	Very fast
Maximum distance between data carrier and reader	0 – 50 cm	0 – 50 cm	< 1 cm	0 – 30 m (depends on the type of tag – active/passive and frequency)

Table 22: Comparison of traceability methods [10]

This thesis is concerned with uniquely and automatically identifying individual entities. In order to do this one needs to ensure the technology implemented has a sufficient storage capacity. There are a few factors involved in determining the sufficient storage capacity, they are:

- Throughput
- Part life
- Whether it's for internal and/or external uses
- Whether it's desired to use a standard code e.g. EAN, EPC etc.

If, for instance, the company has a low throughput, only using the system internally and the part has a relatively short life span then one of the lower data capacity options such as one dimensional barcodes and OCR would be acceptable. If a standard code is required, then RFID or 2 D barcodes would probably be needed.

Of the four traceability methods described in Table 22, OCR is probably the least popular but it does offer the benefit of automatically reading human readable data. Most traceability systems require having human readable data as well in case there is a machine malfunction so, by having one code, valuable space is saved. As it is not widely used for traceability purposes, the technology is not readably available and is expensive.

The difference between the other options lies in:

- Data capacity
  - One dimensional barcodes and OCR have a disadvantage
- Line of sight required and distance required for a read
  - RFID has an advantage over the other 3 by not requiring line of sight and having a possibly large reading distance
- Human readable data
  - RFID does not offer this option
  - One and two dimensional barcode printing machines can print human readable data as well
  - As mentioned above, OCR already prints human readable data
- Cost of purchase and running costs
  - One dimensional barcodes have an advantage of being very cheap

- o Maintenance required for the other 3 technologies (printers etc) gives RFID the advantage when it comes to running costs

As can be seen from the brief comparison above, the choice between the different technologies is a balancing act between a number of different variables. In Chapter 6, a description will be given of a possible method to simplify this choice by inserting initial data so some of the options can be eliminated.

4. Application of Traceability Systems in Different Industries

This chapter will look at several different industry types and examine what traceability systems are chosen to be used in what areas of each industry. Discovering where the different systems are used should show in what situations the one system is better than the other.

4.1 Manufacturing Industry

A traceability system in the manufacturing industry would be required to track and trace items such as raw materials, semi-manufactured products or finished goods [26]. The purpose of the traceability system would be to track items through the factory and to determine which raw materials were incorporated in which semi-manufactured and finished production batches as well as being able to trace back exactly when, how, and by whom the part was made. Table 23 shows in what different areas an automatic, real time traceability system would be able to assist a manufacturing company. Table 23 demonstrates that a traceability system is not only useful to track and trace items but can also be incorporated into a company's current policy to assist with activities like real time production planning, ensuring maintenance schedules are up to date and capturing other valuable data.

Functional Unit	Activities	Traceability System's Impact
Product Engineering	• Process planning • Test design	• Dynamic production planning
Manufacturing	• Production planning • Scheduling • Materials management	• Tracking materials, parts or tools • Timely feedback

	• Material handling • Tooling	
Facilities	• Maintenance • Equipment installation • Utilities	• Guiding maintenance • Increasing utilities
Product Assurance	• Quality assurance	• Timely identification of wrong materials or parts
R&D	• Production development • New technology evaluation and implementation	• Accurate evaluation • Improve original design
Management Information Systems	• Data processing • Report generation	• Data captured accurately and timely • Timely feedback
Procurement	• Vendor certification • Purchasing	• Materials or spare parts can be traced
Inventory	• Raw materials • Finished products • Work-in-process • Pipeline inventories management	• Visibility • Shrinking volume
Human Resources	• Wage administration • Employee protection	• Labour cost reduction • Increased security

Table 23: Advantages of using a traceability system in a manufacturing enterprise [36]

Figure 30 was originally used as a framework for an RFID based manufacturing system but the same principles would apply to a DPM based manufacturing system [36]. The main purpose of the figure is to explain how a traceability system is able to support production planning dynamically in the manufacturing industry by using real time data to link the information and material flow. This is done by the readers (connected to the information flow) collecting data from the tags (which move with the material flow).

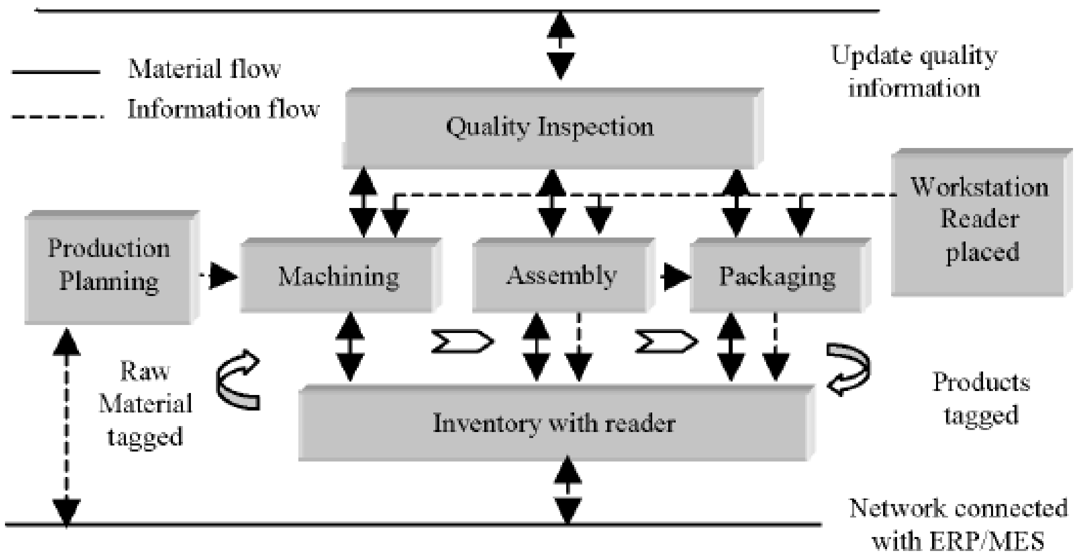


Figure 30: A framework for an automatic identification manufacturing system [36]

Recently there has been a global trend towards the use of RFID and DPM technologies. In the next couple of sections projects where companies have implemented these type of systems will be discussed.

4.1.1 RFID in the Manufacturing Industry

In 2006 Boeing announced that it will use RFID tags on significant parts of its 787 Dreamliner airplanes. Boeing suppliers will be required to apply RFID tags to life-limited parts, on-board emergency equipment and line replaceable units (LRUs) for the 787. Along with their unique codes, the tags will contain installation, inspection and maintenance data which will facilitate the tracking, repair and eventual replacement of parts. The tags that are used have to be passive tags so they don't interfere with flight operations. There are promising signs for the future of RFID in this industry. This is evident by the new joint venture between Boeing, Airbus and Sopheon PLC, a product-life-cycle management vendor. This partnership suggests that vendors see potential life-cycle applications for RFID [46].

Another example of the application of RFID technology in the manufacturing industry is the Ford Motor Company. They used RFID technology at their car and truck facility in Cuautitlan, Mexico. They encoded what needed to be done at each station on the tag. This eliminated the workers first having to go through the paperwork and manually updating it which resulted in a large time saving [47]. Ford Motor Company mainly uses DPM technology and more information regarding their system is available in the next section.

Below are just a few reasons why RFID systems are popular in the manufacturing industry [41]:

- Close to real time inventory control
- Part numbers can be cross referenced to minimise inventory
- Work in progress inventory can be significantly reduced since parts and their locations can be automatically traced
- Identifying parts for statistical process control data collection and then testing correct correlation within the batch or product family
- Assistance in kitting parts and assemblies
- Automated part tracking throughout the cell, the factory and the global supply chain becomes a reality
- Global stock forward positioning becomes real-time traceable
- Supplier relationship management becomes real-time automated too, on a global basis

- Strategically placed readers can ensure the correct part is worked on at the correct time by the correct worker using the correct tool
- Information regarding what processes (and in what order) a particular part needs to undergo can be stored on the tag and this can be verified at reading stations located at the different workstations

4.1.2 DPM in the Manufacturing Industry

Direct Part Marking is widely used throughout the manufacturing industry especially when the parts are extremely small as the codes used can be extremely small. One such manufacturing sector is the production of electronic components.

EbV Elektronik, a German electronic circuit board manufacturer successfully implemented a traceability system based on DPM. The production line at the plant is fully automated and produces boards in both high volumes and small batches. The production line needs to run at a fast pace and there is no room for unnecessary downtime. They therefore required an effective code reading system that could guarantee 100% identification. Every board and component used in the production is laser marked on the line with a matrix code unique to that part. 42 sensors are located throughout the plant that verify and read the marked codes. The path of each part through the production line is carefully monitored and this data is stored in case there is a problem found with the part. Since EbV started this traceability initiative, the company has become highly rated for the quality of its products and services and has gained ISO 9001 certification [10].

Another manufacturing firm that successfully implemented an RFID system is BMW. BMW implemented new software at the end of 2004 at its Hams Hall plant in the UK which enables them to “track and trace” engines and develop a complete manufacturing process and component genealogy [48]. They became the first automotive plant in the UK to use data matrix technology in production. The Hams Hall plant produces four cylinder engines which are used in BMW’s 1 series and 3 series cars. When they planned the implementation, they saw their biggest advantage being that it would limit recalls to a few engines instead of a more blanket recall, which would result in huge cost saving for the company. They also wanted to reduce plant-wide production errors from 1600 to below 1000 ppm (parts per million) [48].

In phase 1 of the implementation, cylinder blocks, cylinder heads and crankshafts received 2D matrix encryption. This cost somewhere in the region of 180 000 Euros [48]. They planned on increasing the number of parts that would be marked and some suppliers' components already have the data matrix mark when they arrive at the factory.

Figure 31: Data matrix encryption on a BMW cylinder head together with the ten-digit, ten-year unique code [48]

BMW went through similar steps as described in Chapter 3 concerning Direct Part Marking. They had to decide on type of mark, readers, verifiers etc. They chose a ten digit date-based algorithm which provides a 10 year unique code. This code is stored in the 2D data matrix and is also written so it can be manually read. An example of this code can be seen in the above figure. The code is 5424135748. The first digit (5) represents the day of the week with Sunday being one, therefore this part was made on a Thursday. The next two digits represent the week number (42). The 4 represents the year i.e. 2004. The remaining digits (135748) represent hours, minutes and seconds.

They made use of rapid indent (dot peen) and laser marking machines supplied by Technifor Ltd of Leamington Spa and 2D data matrix readers and verifiers from RVSI in

Nashua, New Hampshire, USA. They went through a process of deciding the best location for the mark on each type of part. The factors they considered important for mark placement were [48]:

- Coolant retention
- Reading access
- Surface texture
- Possibility of future physical damage

Phase 2 was the introduction of XFactory which cost about 80 000 Euros. XFactory is now known as Tecnomatix Production Management [42]. It is designed to track all aspects of discrete manufacturing production -- maintaining historically accurate records as well as real-time information of the production process, defect tracking, and complete product genealogy. It is able to deliver knowledge and control of product manufacturing, which result in [42]:

- Reduced work in progress
- Lower cost of errors
- Lower cost of compliance with government regulations
- Limits the amount of rework.

As mentioned in the previous section Ford Motor Company is a big supporter of the use of DPM. Figure 1 in Chapter 2 shows Ford’s vision of involving their entire supply chain in the traceability project. The two main drivers for their DPM project were improving the quality of their finished products and stopping large recalls [49]. Through the project they realised that the traceability would help support flexible manufacturing. Ford assembles multiple products on the same line and some of these are virtually indistinguishable to the naked eye. In the past, Ford used coloured dots or labels on these components. DPM has reduced the errors encountered during this process [49].

4.2 Food Industry

In 2002 EU Regulation 178 was written to ensure the safety and traceability of food. In essence, all operators in the food industry will have to ensure that [50]:

- Only safe food is placed on the market
- Presentation, labelling, packaging etc. do not mislead consumers
- Food complies with applicable legislation
- Traceability systems are in place
- The relevant authorities are informed where they consider that a product is not in compliance with food safety requirements

This regulation and others like it where put in place to, among other reasons [51]:

- Stop the spread of diseases such as mad cow disease and improve meat safety
- Track food transportation systems to reduce the risk of tampering
- Help provide customers with information on a variety of food attributes including country of origin, animal welfare, and genetic engineering

Traceability systems used in the food industry are a lot less complex than those used in the manufacturing industry due to:

- Packaging, crates or containers are marked instead of individual entities
- The general shape, size and material of the marked object (usually a square or rectangle) are similar even in different sectors of the food industry

As mentioned above, it is rare that the individual entity is marked in the food industry. For this reason, labels are the more likely method that is used for traceability purposes. The type of code printed on the label will depend on the user's requirements.

4.3 Retail Industry

In the middle of 2004, one of the world's biggest retail outlets, Wal-Mart issued a mandate to their top 100 suppliers. All shipping crates and pallets were required to be equipped with RFID tags. This was arguably the beginning of the boom in the RFID industry. Mostly smart labels are used to enable the rest of the supply chain to continue using their identification numbers and traceability technology (one or two dimensional barcodes or human readable data). They are continually trying to increase the number of suppliers using RFID tags and in January 2008 they issued a statement that all 15 000 suppliers need to use RFID tags and each pallet received after 30 January 2008 without a tag will result in a $2 fine [28].

Marks and Spencer, a British retail outlet, uses 13.56MHz RFID tags embedded in over 4 million plastic trays it uses to move fresh foods from 115 suppliers through 6 distribution centres to its stores. They claim to be achieving a reading accuracy of 99.98%. Ian Mumby, the head of supply chain logistics at M&S says that although most people think the benefits of RFID are around cost reduction and speed, to them the main benefit is control. Sending the right product in the right quantity to the right depot at the right time is far more important to them. Marks and Spencer is also using RFID tags on clothing to speed up stock counting and make sure items are back on the shelf as quickly as possible. This is achieved by stock taking being done by an employee who walks around with an RFID reader and is able to scan products without even needing line of sight [34].

Table 24 shows what is thought to be the future adoption of RFID technology in the retail industry. As can be seen, mass use of this technology in the retail industry is only expected after 2012.

	2003-5	**2006-7**	**2008-11**	**2012+**
When	Explorer	Early adopter	Fast follower	Mass use
Who	M&S, Metro, Tesco, Target, Wal-Mart	Leading US and European retailers & manufacturers	Main brand and private label manufacturers	Mass retailers, mass manufacturers
Where	DC to stores	Multiple DCs and stores, selected in-store	Upstream supply chain, mass in-store	Upstream supply chain, mass in-store
What	Pallet, case and tray	Selected items	Broad range of items	Mass items
Why	Inventory visibility	Loss prevention, reusable assets	End to end supply chain	Reverse logistics

Table 24: RFID adoption in the retail industry [34]

4.4 Health Care/Pharmaceutical Industry

The most necessary health care area to have a traceability system in place would be the tracing of surgical instruments in hospitals. The reasons for tracking are to improve the management of these items in terms of usage and cost-effectiveness of different suppliers. There is also an interest in relating instruments to particular surgical interventions where resistant contaminants may be encountered. Due to the variety of shapes, sizes and colours of the instruments needed to be marked, DPM is normally used, in particular DPM marked using dot peen marking (laser marking made the instruments liable to rust) and with DMT dot code (most easily readable code using dot peen marking) [21].

Although DPM is the most popular method, RFID tags are also used in this industry. Cardinal Health Inc., the leading supplier of products and services supporting the healthcare industry, is placing RFID tags on surgical medical products to ensure that no items are left inside the patient during surgery. In November 2004, USA pharmaceutical company Purdue Pharma began applying read-only tags to every 100-tablet bottle of OxyContin to be shipped to Wal-Mart and drug wholesaler HD Smith. This tagging was done in an effort to meet Wal-Mart's RFID mandate and to combat the growing market for counterfeit and stolen drugs [37].

4.5 Defence Industry

The United States of America's Department of Defence (DoD) realised the great need for automatic and unique identification of valuable assets. A policy was issued on the 29th of July 2003 by the DoD which stated that UID (Unique Identification) is required for all solicitations starting from 01/01/04 [22]. Other items that need a UID are [52]:

- All delivered items where unit acquisition cost is $ 5000 or more
- Items less than $ 5000 when identified by the requiring activity as serially managed, mission essential, or controlled inventory
- Items less than $ 5000 when the requiring activity determines that permanent identification is required
- Regardless of value,
    - Any DoD serially managed subassembly, component, or part embedded within a delivered item
    - The parent item that contains the embedded subassembly, component or part

According to the Department of Defence, UID is a program that will enable easy access to information about DoD possessions that will make acquisition, repair and deployment of items faster and more efficient [22, 52]. Below is a list of the perceived benefits [22]:

- Item visibility regardless of platform or "owner"
- Lower item management costs
- Item data necessary for top-level logistics and engineering analysis

- Accurate sources for property and equipment valuation and accountability
- Improved access to historical data for use during systems design and throughout the life of an item
- Better item intelligence for warfighters for operational planning
- Reduced workforce burden through increased productivity and efficiency
- Improved inventory accuracy

The basic idea behind IUID (Item Unique Identification) is to permanently mark a part so it can be uniquely identified throughout its lifecycle. The data elements that are encoded into the permanent code are [52]:

- IUID Type
- Concatenated Unique Item Identifier

In order to determine the IUID type the following elements may be required [52]:

- Issuing agency code
- Enterprise identification number
- Original part, lot or batch number
- Current part number
- Serial number
- Item description
- Unit of measure

The DoD decided on mainly using data matrix code applied by a DPM technology (mostly laser marking). An example of a UID code and what the encoded number means can be found in Appendix B.

4.6 Conclusion

The situations described above all require unique identification of individual parts yet the situations are all very different. Each industry and situations within each industry type have their own set of specifications which dictate what type of system is able to be used. This is precisely the basis behind the development of the model described in Chapter 6. There are a lot of variables involved when choosing a traceability system and these need to be taken into account very early in the planning process. Below is a summary of generally in which industry each identification technology is used.

Labels are generally used in situations where the marked entities aren't exposed to extreme conditions and aren't expensive (e.g. the food industry).This is not to say labels are not used in manufacturing and other industries. The examples used in this chapter (especially for the manufacturing industry) are mostly of entities whose cost or application warrants the use of RFID tags or DPM. DPM is usually chosen above RFID when the entities are small (e.g. circuit boards) or are exposed to conditions such as heat or forces which would be harmful to RFID tags (e.g. engines). RFID tags are used in situations where a longer reading range is required (e.g. Marks and Spencer) or when the ability of the tag to store information that can be used later in the supply chain is required (e.g. Ford). Both RFID tags (Wal-Mart) and DPM (U.S.A DoD) are required by regulations in different industries. Other industries, like the food industry, don't stipulate the type of traceability system required but do require complete traceability.

5. Case Studies

This chapter contains a summary of the case studies conducted at AAT Composites and Aerosud. The purpose of these studies was to both gather information for this thesis and to assist the company. The case study reports prepared for the use of the companies are available in Appendices C and D. The background information on the companies was gathered directly from the company concerned and from their websites.

5.1 AAT Composites

This case study was conducted from the 14th of February 2007 to the 27th of June 2007 under the supervision of Igor Zelewitz, an Industrial Engineer in charge of production planning.

5.1.1 Background Information

Aerodyne Technology and later Aerodyne Aviation Technology, the forerunners of AAT Composites, was founded near Cape Town, South Africa, in 1983. It established itself as a leader in the design and manufacture of innovative high performance products using 0Advanced Composite Materials and became well known in the Aerospace and Sport markets for products that range from bicycles to primary structures for supersonic aircraft.

During the 1990's Aerodyne was restructured into a group of 4 companies with a view to improving focus on a diversified product and market range. One of these 4 companies grew into AAT Composites, which specializes in the design and manufacture of composite parts for aircraft interior structures, mainly related to seating.

5.1.2 Objectives

The objectives for this study were to get a better understanding of the practical implications of implementing a traceability system as well as gather information regarding the different available technologies and look for possible areas of improvement.

5.1.3 Results

While conducting this study it was discovered (see Aerosud conclusion) that the two main options for a cradle to grave traceability system were DPM and RFID. Even after choosing one of these options, there are a lot of decisions to be made regarding the type of marking system to be used and certain marking systems do not work well under certain conditions. This case study showed that there is a big need for a model to simplify the process of choosing a suitable system for a particular application. This was investigated and will be explained further in Chapter 6. Valuable time was wasted on this project doing tests on technologies that could have been eliminated at the start of the project.

5.1.4 Conclusion

Practical information regarding the use of traceability systems in a manufacturing environment was obtained. This information gave the thesis a new direction from just looking at improving current traceability methods to developing a model that would assist in choosing a suitable traceability system.

5.2 Aerosud

This case study was conducted from the 9th of June 2008 till the 13th of June 2008 under the supervision of Wouter Gerber.

5.2.1 Background Information

Aerosud was formed in 1990 by the then key designers of the South African Rooivalk Combat Support Helicopter, together with similar leaders from the Cheetah fighter program (Mirage III upgrade) and the Product Support Environment. Towards 1995 Aerosud embarked on diversification into the commercial aviation market with the design of galleys and other interior systems. Aerosud is today an internationally recognised supplier for interior systems. In the year 2000 Aerosud embarked upon major expansion of its production capacity. From its new premises near Pretoria it now manufactures around 2000 parts and assemblies a day and supplies these to the assembly lines of Airbus, Boeing, BAE Systems, Augusta Westland Helicopters and Spirit AeroSystems. Today, deeply involved in both Civil and Military Aviation Engineering projects, their activities cover design, development, prototyping, manufacture and in service support.

5.2.2 Objectives

The main objective was to identify all extra variables (other than those obtained through research) that need to be considered when implementing a traceability system in a manufacturing company.

A secondary objective of this case study was to use the theoretical knowledge gained to analyse Aerosud’s current traceability system and note areas where new technology could make a difference.

5.2.3 Results

Apart from identifying variables the batching process used by Aerosud was noted and slightly changed the approach of this thesis. Prior to this case study it was assumed that the only two technologies available to uniquely identify parts from cradle to grave are RFID and DPM due to the ability of these technologies to store large amounts of data for long periods of time. This case study showed other possibilities. The batching principle implemented by Aerosud works well due to the fact that the batched parts stay together at all times. This results in the possibility of using one number to identify numerous parts. This batching policy would only work for internal traceability purposes though as once the parts leave the factory they are split up. Therefore, if the parts are only required to be traced within the factory and are batched together, other technologies that are capable of storing less data can be used.

A lot of the same variables that were encountered in the research study were noticed as well as a few extra ones. Some of the extra variables that were discovered during this case study (and the one conducted at AAT) are:

- Chemicals
    - During the treatment process, parts are exposed to a number of chemicals that would be harmful to RFID tags
- Regulations
    - Airline regulations encountered that prohibit the use of active RFID tags and markings on some parts made aware the possibility of other regulations about traceability systems
- Internal or External traceability and the possibility of batching
    - This would affect the number of unique identifiers required
- Cost
    - This was mainly seen to be an issue at AAT and a maximum limit needs to be set out at the start of the project to eliminate unsuitable systems

A more detailed discussion of these variables is available in Chapter 6.

5.2.4 Conclusion

From both perspectives, this study was a success. Aerosud was able to identify areas where their traceability system could be improved and extra variables were discovered to be used for the decision making program. The possible solutions recommended to Aerosud will require further investigation and refining to ensure they would work in their environment.

A further description of the newly discovered variables and how they impact the thesis can be found in Chapter 6.

6. The Decision Making Model

This chapter contains information on the Decision Making Model that was designed. The model is available on a CD inside the back cover of this thesis. All the information involved in developing the model is explained and the workings of the model described. There are 11 traceability systems that will need to be decided between. These systems are explained in greater detail in Chapter 4 and are:

- Labels
    - One dimensional barcodes
    - Two dimensional barcodes
    - Smart Labels
- OCR
- DPM
    - Ink jet marking
    - Laser marking
    - Dot peen
    - Electro chemical etching
- RFID
    - Low frequency
    - High frequency
    - Ultra high frequency

6.1 Objective

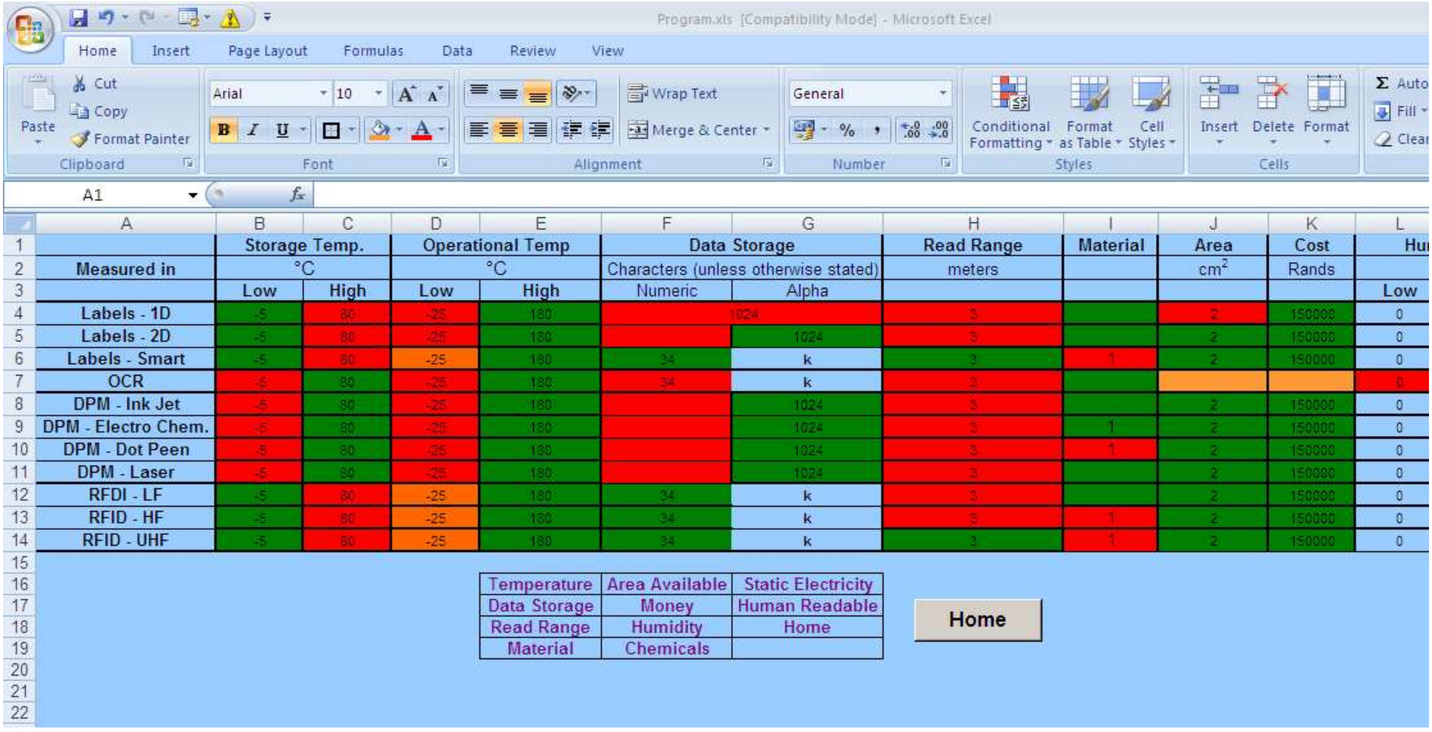
The purpose of the model is to simplify the decision making process of choosing between different traceability systems. It is intended that the model help save time and money by eliminating possible choices early on in the process. The objective is therefore to create a simple, easy to use model capable of eliminating traceability choices by balancing the user's requirements with conditions surrounding the entities that are to be marked and read. The people targeted to use this program are not familiar with traceability technology and are implementing their first fully automatic and unique identification system.

6.2 How the Program Works

The program was created using Excel. Excel was chosen for its popularity and for its usability. The program works by asking the user a number of questions regarding certain pre-determined variables (see 6.3) and, from the users' answers, grading the different traceability methods. The grades for the traceability method can either be:

- Not suitable
- Warning: Problems will be encountered but can be overcome
- Suitable

These grades are represented in the results sheet by a red, orange and green filled in cell respectively, which can be seen in the figure below. From this results sheet, the user can easily identify problem areas and either eliminate that traceability system as an option or take the necessary steps to rectify the problem. For example, in Figure 32, the read range required can only be satisfied by two technologies, smart labels and UHF RFID tags.



	Storage Temp.		Operational Temp		Data Storage		Read Range	Material	Area	Cost	Hu
Measured in	°C		°C		Characters (unless otherwise stated)		meters		cm^2	Rands	
	Low	High	Low	High	Numeric	Alpha					Low
Labels - 1D	-5	80	-25	180	1024		3		2	150000	0
Labels - 2D	-5	80	-25	180		1024	3		2	150000	0
Labels - Smart	-5	80	-25	180	34	k	3	1	2	150000	0
OCR	-5	80	-25	180	34	k	3				0
DPM - Ink Jet	-5	80	-25	180		1024	3		2	150000	0
DPM - Electro Chem.	-5	80	-25	180		1024	3	1	2	150000	0
DPM - Dot Peen	-5	80	-25	180		1024	3	1	2	150000	0
DPM - Laser	-5	80	-25	180		1024	3		2	150000	0
RFDI - LF	-5	80	-25	180	34	k	3		2	150000	0
RFID - HF	-5	80	-25	180	34	k	3	1	2	150000	0
RFID - UHF	-5	80	-25	180	34	k	3	1	2	150000	0

Temperature	Area Available	Static Electricity
Data Storage	Money	Human Readable
Read Range	Humidity	Home
Material	Chemicals	

Figure 32: Results table from the program

A list of the variables that were used and conditions that the different systems can operate in can be found in Section 6.3. The operating conditions for the different systems were determined through a literature study but, due to the dynamic aspect of modern day technology, these conditions can be edited in the program. The variables are either requirements of the user or general environmental conditions. Either way they should be known or easy to determine thus the questionnaire shouldn't take long to fill out. A more detailed description and instructions how to use the program are given in Appendix E.

6.3 Variables

The variables were investigated through a combination of literature research and case studies conducted and the data was gathered by examining articles and looking through specification sheets of various suppliers and obtaining a general consensus.

6.3.1 Temperature

There are two aspects to this variable, operational temperature and extreme temperature. Operational temperature is the temperature range in which the technology still works i.e. the code is able to be read and processed. Extreme temperature is the temperature range which the technology can withstand and still be operational. It is also known as the storage temperature. The extreme temperature range only influences RFID tags although, for all the technologies, the storage temperature of the reader must be looked at.

RFID

All three types of RFID tags have similar temperature specifications. These specifications differ more between suppliers than between the types of tag. Approximate values were obtained by looking at a few specification sheets obtained from suppliers web pages. An approximate storage (extreme) temperature range is between - 40 ℃ and 125 ℃ and an operating temperature range betwe en – 25 ℃ and 85 ℃ [55, 56, 57]. There are however high temperature RFID tags which are encased in a housing to protect the tag's chip and antenna. According to the World Intellectual Property Organisation, high temperature tags are defined as tags which have a storage temperature range of -40 ℃ and 300 ℃ and an opera ting temperature range of -20 ℃ and 200 ℃ [58]. The results sheet will not take hi gh temperature tags into account as it changes the size of the tag but, this should not be forgotten by the user as a possibility

DPM

All four DPM marking methods have the same temperature characteristics. Temperature only has an effect on the operation of the DPM reader rather than on the mark itself (i.e. the storage temperature). Therefore, the specifications of the readers were looked at to determine the temperature restrictions. From these specifications an operating temperature range of -5 ℃ to 50 ℃ was determined [59, 60, 61].

Labels

There are extreme temperature labels available that can withstand temperatures as low as -104 ℃ and as high as 1952 ℃ [66]. That is the storage temperature range for the one dimensional and two dimensional barcode labels. The one dimensional and two dimensional labels have the same specifications as the DPM above thus the operating temperature range is -5 ℃ to 50 ℃. The smart labe l will have the same temperature specifications as the RFID tag. The storage temperature range of the smart label is therefore between -40 ℃ and 300 ℃ and an operatin g temperature range of between -20 ℃ and 200 ℃.

OCR

Storage temperature is not a problem for OCR marks. Operating temperature is the only problem and the range is between 0 ℃ and 50 ℃ [63 , 64, 65].

Traceability System	Storage Temperature (℃)	Operat ing Temperature (℃)
Labels – 1D	-104 to 1952	-5 to 50
Labels – 2D	- 104 to 1952	-5 to 50
Labels – Smart Labels	-40 to 125	-25 to 85
OCR	N/A	0 to 50
DPM – Ink Jet marking	N/A	-5 to 50
DPM – Electro chemical etching	N/A	-5 to 50
DPM – Dot peen	N/A	-5 to 50
DPM – Laser marking	N/A	-5 to 50
RFID – LF	-40 to 125	-25 to 85
RFID – HF	-40 to 125	-25 to 85
RFID – UHF	-40 to 125	-25 to 85

Table 25: Traceability systems and temperature

6.3.2 Data Storage

Data storage regards the amount of data needed to be stored in the code to fulfil the user’s requirements. The requirements could be for only storing a unique code or to include other additional data. To ensure a unique code the user needs to look at a number of factors including:

- The throughput of the company
- Part life and
- Whether the part needs to be externally traceable as well

Once these factors have been considered the user will be able to determine the data storage space required of the traceability technology.

RFID

Of the four available traceability methods, RFID tags have the greatest storage capacity. They offer the ability of storing extra data and writing additional information on the tag. This additional information could always be made available through a back end database but, by writing it on the tag, the information becomes available to customers who don't have access to the database. The storage capacity of an RFID tag is between 16 and 64 k [10] although, 128 and 256 k tags are going to be available in the near future. For this study, the maximum storage capacity of an RFID tag is assumed to be 64 k

DPM

The storage capacity of 2D codes is not measured in kilobits but rather in the number of characters that can be stored. As mentioned in Table 2 in Chapter 3, the largest storage capacity for a commonly used two dimensional code is 7366 numeric characters or 4464 alphanumeric characters (QR code).

Labels

The data storage capacity of the three types of labels is very different. The data storage capacity of a one dimensional barcode is directly related to the data density of the code and the space that is available. The data density that will be used as the standard for this program will be that of Code 93, 13.9 characters per inch (5.47 characters per cm) [72] (this can always be changed by using the edit function in the program). The storage capacity of the two dimensional barcode is the same as mentioned above (7366 numeric and 4464 alphanumeric characters). The storage capacity of the smart label is between 16 and 64 k.

OCR

As mentioned in Chapter 3, the storage space of an OCR mark is 100 bytes or 0.78125 k [10].

Traceability System	Data Storage
Labels – 1D	Variable (5.47 characters per cm)
Labels – 2D	7366 numeric and 4464 alphanumeric
Labels – Smart Labels	16 to 64 k
OCR	0.78125 k
DPM – Ink Jet marking	7366 numeric and 4464 alphanumeric
DPM – Electro chemical etching	7366 numeric and 4464 alphanumeric
DPM – Dot peen	7366 numeric and 4464 alphanumeric
DPM – Laser marking	7366 numeric and 4464 alphanumeric
RFID – LF	16 to 64 k
RFID – HF	16 to 64 k
RFID – UHF	16 to 64 k

Table 26: Traceability systems and data storage

6.3.3 Read Range

Read range refers to the maximum distance between the reader and the mark/tag while still able to obtain a successful read.

RFID

The three types of RFID tags offer very different read range capabilities. As with most of the variables, the read range differs between suppliers and a general answer will be used. Low frequency tags have the shortest maximum read range of approximately 0.5 meters [34]. High Frequency tags have a maximum read range of approximately 1 meter [34]. Ultra high frequency tags have a maximum read range of approximately 7.5 meters [43]. The large read range capability of UHF tags offers the benefit of using gate readers which automatically read tags as they pass through.

DPM

As mentioned in Table 22 in Chapter 3, the maximum read range of a two dimensional reader is 50 cm.

Labels

The maximum read range of one dimensional barcodes is 50 cm [10]. For smart labels the maximum read range of RFID tags (UHF) will be used, thus, as stated above, smart labels have a maximum read range of approximately 7.5 meters. The two dimensional barcode labels have the same read range as the DPM (50cm).

OCR

OCR readers need to be less than 1cm away to read the mark [10].

Traceability System	Read Range (meters)
Labels – 1D	0.5
Labels – 2D	0.5
Labels – Smart Labels	7.5
OCR	0.01
DPM – Ink Jet marking	0.5
DPM – Electro chemical etching	0.5
DPM – Dot peen	0.5
DPM – Laser marking	0.5
RFID – LF	0.5
RFID – HF	1
RFID – UHF	7.5

Table 27: Traceability systems and read range

6.3.4 Material

The type of material the marked entity is made of not only affects the marking process but the reading process as well. For RFID tags, certain materials that are near the reader or in between the reader and the tag can affect the reading distance so this also needs to be considered. The program will either fill the material cell in the results sheet with green or red. If the cell is filled in red it is up to the user to determine what material is the problem.

RFID

The different RFID tag frequencies are affected by different types of material. The material affects the reading process by either reducing the read range or creating a situation where a read is not possible. Low frequency tags are not affected by material. High frequency tags can penetrate through most materials but are affected by metal. Ultra high frequency tags are affected both by metal and water [43].

DPM

The type of material the entity is made of affects the marking process. The different marking methods are affected by different types of material. The table below has a quick summary of what types of material the different marking methods can mark.

	Metal	**Plastic**	**Glass**	**Wood**
Dot Peen	Yes	Yes	No	Yes
Electro Chemical Etching	Yes	No	No	No
Ink Jet	Yes	Yes	Yes	Yes
Laser	Yes	Yes	Yes	Yes

Table 28: DPM marking methods and material

Electro Chemical Etching can only mark conductive metals such as aluminium, stainless steel and carbide [67]. There are some contradictions regarding the ability of a dot peen marker to mark plastic parts. According to Gibson Engineering it is not possible for a dot peen marker to mark plastic parts [7] but, according to Columbia Marking Tools it is [68]. For this program it is assumed plastic can be marked by dot peen markers.

Labels

Due to the numerous methods of applying labels they are virtually compatible with any material. The only problem would be with the reading of the smart labels. The tag frequencies and their corresponding problems with materials can be found above. Seeing as though this program doesn't distinguish between tag frequencies for smart labels, there will be an red block if there is any problem, and it is up to the user to check which frequency type would give the problem.

OCR

OCR marks are generally printed on by ink printers and, as mentioned under the DPM heading, ink printers can be used on all the main types of materials.

Traceability System	Material
Labels – 1D	N/A
Labels – 2D	N/A
Labels – Smart Labels	Metal, Water
OCR	N/A
DPM – Ink Jet marking	N/A
DPM – Electro chemical etching	Any material other than conductive metals
DPM – Dot peen	Glass
DPM – Laser marking	N/A
RFID – LF	N/A
RFID – HF	Metal
RFID – UHF	Metal, Water

Table 29: Traceability systems and materials that affect them

6.3.5 Physical area required

This variable is concerned with whether the mark will fit on the required entity. To determine this, the user has to know where on the part he/she wants the mark. As far as possible it should be attempted to place the tag/mark on a flat surface and in a position where it is easily accessible by the reader.

RFID

For RFID tags the shape of the antenna is related to the frequency. Low and high frequency tags usually have coiled shaped antennas and high frequency tags have long antennas shaped liked old television antennas [43]. This results in the different frequencies having different tag sizes. As antenna size is directly proportional to the maximum reading distance, the estimate in this program is not accurate. It will need to be determined by the user which is more important, read range or space on the part. Once one of these has been chosen, expectations for the other variable will have to be adapted accordingly. RFID tags can be as small as a grain of rice but this would be impractically for the manufacturing environment therefore average tag sizes were obtained and are listed below [74, 75, 76]:

- LF = 0.0089 cm^2
- HF = 0.013 cm^2
- UHF = 0.045 cm^2

DPM

The size of the mark depends entirely on what code is selected and how much data is stored in this code. For this program, the benchmark that will be used is 500 characters stored in the most popular code (data matrix) and, as mentioned in Chapter 3.3.2, it is possible to store 500 characters in an 0.05 $inch^2$ area (500 characters in 0.322581 cm squared area) of a data matrix code. If the user wants to change the benchmark he/she can by using the edit function. Attention needs to be taken that the code used for the variable Physical area available (data matrix) and the code used for the variable Data storage (QR code) is different. They both have similar characteristics but QR code is capable of storing more data and data matrix code is denser. Therefore, QR code was used for the data storage variable and data matrix code for the area variable.

Labels

The size of labels varies considerably depending on the information they contain. For this study it will be assumed that the minimum amount of data is contained on the label. This assumption can be changed at a later stage using the edit function. An important consideration for labels is the blank space that is located around the mark. This is usually directly related to the size of the mark and the level of error correction required (for 2D codes).

Earlier it was stated that 1D barcodes have a data density of 5.47 characters per cm. The height of a 1D barcode has no affect on the data storage capacity but does affect the redundancy of the code, a barcode height of 3 cm will be assumed with a storage capacity of 18 characters. The area required to store this code will be 9.87 cm^2. The assumption of the height of the code has a great affect on the answer this can therefore be changed by the user depending on the importance of redundancy.

Above it was stated that the area required for a data matrix to store 500 characters is 0.323 cm^2. This along with a rough estimate of blank space required results in the approximate size of the 2D barcode label to be 0.4 cm^2. For smart labels, the worst case scenario will be assumed (UHF tag). Very little blank space is required for smart labels therefore, an approximate area of 0.05 cm^2 will be necessary.

OCR

Exact values regarding the data density of Optical Character Recognition marks are difficult to come by. The marks will be required to be fairly large as it is human readable. An orange filled cell will always appear on the results sheet so as if OCR is one of the final choices, further experiments will need to be conducted regarding the space required on the part for the mark.

Traceability System	**Area Required (cm^2)**
Labels – 1D	9.87
Labels – 2D	0.4
Labels – Smart Labels	0.05
OCR	N/A
DPM – Ink Jet marking	0.323
DPM – Electro chemical etching	0.323
DPM – Dot peen	0.323
DPM – Laser marking	0.323
RFID – LF	0.0089
RFID – HF	0.013
RFID – UHF	0.045

Table 30: Traceability systems and area required

6.3.6 Cost

This variable concerns the costs associated with an initial pilot project. The number of required marked parts, readers, cost of the software and the maximum budget allowed for the project has to be manually entered. The price of the software will be manually entered as it varies too much from situation to situation depending on its outputs. An estimate can be obtained from a supplier once he/she knows the user's requirements.

RFID

The costs associated with RFID tags are the tags themselves and the readers. Therefore, the number of marked parts and reading stations are important and care should be taken to ensure an accurate estimate of these factors is made. A price sheet was obtained from Walter Muller of Clyde Technologies on the 11th of November 2008 and a summary is below:

LF: Tag = R12.93

Reader = R 2327.95

HF: Tag = R 15.18

Reader = R 991.25

UHF: Tag = R 12.15

Reader = R 25 479.43

DPM

Prices for Direct Part Marking machines were obtained from a U.S.A DoD specifications sheet [33]. An exchange rate of $1 = R10 is assumed.

Ink jet marker: R 100 000 for the machine + R 5 per mark

Electro chemical etching: R 20 000 for the machine + R 5 per mark

Dot peen: R 100 000 for the machine + R 1 per mark

Laser marking: R 150 000 for the machine + R 3 per mark

The cost of two dimensional barcode scanners is approximately R 5000 [84, 85].

Labels

When looking at the price of label printers, it needs to be kept in mind that there are additional costs involved for the ink and ribbon used for each label. Industrial sized label printers generally are capable of printing one dimensional and two dimensional barcodes. It is possible to just install a one dimensional barcode maker on a desktop computer and print labels through a standard printer but for this study it is assumed that the labels will be printed in large quantities and will require a reliable dedicated printer. Therefore, the price of the one and two dimensional barcode label printers is the same, R2500 [77, 78]. The cost of the ribbon and ink for the labels is approximately 25 cents [79]. The cost of smart label printers is quite high, therefore the price used was for a simple smart label printer, R 20 000 [80, 81]. The cost per label is presumed to be about the same but with the added cost of an RFID tag at approximately R 12.

The cost of a one dimensional barcode reader is approximately R 500. As mentioned above the cost of two dimensional barcode scanners is approximately R 5000 and it will be assumed HF tags are in the smart labels and the readers cost approximately R 991.25.

OCR

Optical Character Recognition technology is mainly used for documents than for traceability purposes and so the price of OCR traceability products is very high. It is for this reason that cost is not going to be considered for OCR. If OCR turns out to be the user's choice as a traceability system, suppliers should be contacted for bulk discount quotes. As previously, the OCR cost cell will be filled with orange.

Traceability System	**Costs (Rands)**	
	Marking machine/Tag	**Reader**
Labels – 1D	2500 + 0.25 per label	500
Labels – 2D	2500 + 0.25 per label	5000
Labels – Smart Labels	20 000 + 12.25 per mark	991.25
OCR	N/A	N/A
DPM – Ink Jet marking	100 000 + 5 per mark	5000
DPM – Electro chemical etching	20 000 + 5 per mark	5000
DPM – Dot peen	100 000 + 1 per mark	5000
DPM – Laser marking	150 000 + 3 per mark	5000
RFID – LF	12.93	2327.95
RFID – HF	15.18	991.25
RFID – UHF	12.15	25 479.43

Table 31: Traceability systems and initial investment required

6.3.7 Humidity

The ranges for humidity were very similar for all the technologies. As with temperature, there were slight differences between suppliers but nothing too large. All the technologies were able to work between 5 and 95% [60, 61, 70, 55] and only OCR was able to work outside this range (between 0 and 95%) [72, 73].

Traceability System	Humidity (%)
Labels – 1D	5 to 95
Labels – 2D	5 to 95
Labels – Smart Labels	5 to 95
OCR	0 to 95
DPM – Ink Jet marking	5 to 95
DPM – Electro chemical etching	5 to 95
DPM – Dot peen	5 to 95
DPM – Laser marking	5 to 95
RFID – LF	5 to 95
RFID – HF	5 to 95
RFID – UHF	5 to 95

Table 32: Traceability systems and humidity

6.3.8 Chemicals

Most technologies will be affected by chemicals in a certain way. Chemicals can erode and degrade a mark or could permanently damage an RFID tag, RFID tags are generally susceptible to aggressive chemicals like acid . The list of possible harmful chemicals is too great to write down .This variable is therefore just a simple yes/no question asking the user if the entity that is marked is exposed to any possible harmful chemicals. If the user is doubtful whether or not a chemical is harmful, experiments need to be conducted to determine exactly what chemicals affect which marking method in what way.

6.3.9 Static Electricity

Static electricity is present in most factories. It mostly has an effect on RFID tags and is more prominent with smart labels as the paper rubbing against other objects can create static charges. It is generally accepted that if an RFID tag is exposed to static electricity levels of greater than 500 volts, the tag will be damaged and the data lost [53, 54].

	Static Electricity (volts)
Labels – 1D	N/A
Labels – 2D	N/A
Labels – Smart Labels	N/A
OCR	N/A
DPM – Ink Jet marking	N/A
DPM – Electro chemical etching	N/A
DPM – Dot peen	N/A
DPM – Laser marking	N/A
RFID – LF	500
RFID – HF	500
RFID – UHF	500

Table 33: Traceability systems and effect of static electricity

6.3.10 Human readable data

Human readable data is an important fail safe measure for a traceability system. If the encrypted mark/code fails, the human readable data can be used to manually track and trace the part. Human readable data is possible to be marked using all technologies except RFID tags. If human readable data is required, extra space would need to be allowed for when considering some of the other variables.

	Human Readable Data
Labels – 1D	Yes
Labels – 2D	Yes
Labels – Smart Labels	Yes
OCR	Yes
DPM – Ink Jet marking	Yes
DPM – Electro chemical etching	Yes
DPM – Dot peen	Yes
DPM – Laser marking	Yes
RFID – LF	No
RFID – HF	No
RFID – UHF	No

Table 34: Traceability systems and human readable data

6.4 Test of the Decision Making Model

To validate the accuracy of The Decision Making Model three tests were conducted. The objective of these tests was to show the purpose of the Decision Making Model and to demonstrate how a solution is obtained from the results sheet. Two of the tests were conducted using assumed values for certain industry types and the third used data gathered at AAT Composites. The industry types were chosen to show two completely different situations and how the Decision Making Model would handle such situations. There is an example of where the Decision Making Model can't offer a solution but from the results page a hybrid option can easily be seen.

For the first two tests, the value obtained for the budget needs to be explained. Two values are assumed, the cost of the software package and the budget for the project. While working at AAT Composites two quotes were obtained for their software system, R 300 000 and R 500 000. It is from these two quotes that the estimate of the cost of the other software packages is based. The R 500 000 software package was capable of ensuring traceability throughout the supply chain and had all the required features whereas the R 300 000 package had less features.

When estimating the budget of the project, AAT's budget of approximately R 750 000 was taken into account. This was adapted to the other two situations taking the size of the company and the expected financial benefits into account.

6.4.1 Test 1 – Packaging Industry

The values of the variables for this test simulate the typical conditions found in the packaging industry, in particular the high-speed packaging of non-metal (specifically plastic) parts into cardboard boxes, which are then stacked onto pallets. This test was chosen to demonstrate a traceability project that requires a large read range with little environmental obstacles. A few areas that should be taken note of:

- The parts are not exposed to any extreme environmental conditions
- The boxes and not the individual products are to be marked
    - Batching is possible in this case due to all the parts in a particular box originating from the same raw material and following exactly the same production path
- Large reading ranges are required so as the entire pallet can be read at the same time by using gate readers
- The number of boxes required to be marked is approximately 10 000 per a month
- Traceability is required from when the part is packed into the box till the part is removed from the box
    - It is for this reason that the data storage size is comparatively small – the life of the unique traceability number is not greater than 6 months
- There are a number of aspects that need to be looked at with regard to the budget
    - In the first year approximately 120 000 parts need to be marked
    - The software package required will be fairly simple. The parts are only traceable for 6 months and very little data besides the location of the part needs to be recorded. A budget of R 75 000 will be assumed for the software package.

- o The benefits offered from such a traceability system are not largely financially beneficial therefore, the budget cannot be particularly large. A budget of R 500 000 for the first year will be used

Variable	Value	
Storage Temperature (℃)	15 to 35	
Operational Temperature(℃)	15 to 35	
Data Storage	2 k	25 numeric
Read Range (meters)	3	
Material	Plastic, cardboard	
Physical Area Available (cm^2)	20	
Budget (Rands)	500 000	
Humidity (%)	30 to 80	
Harmful Chemicals	No	
Static Electricity (Volts)	Negligible	
Human Readable Data	Yes	

Table 35: Variable values for Test 1

The figure below shows the result sheet after the data has been entered in the Decision Making Model.

	Storage Temp.		Operational Temp		Data Storage		Read Range	Material	Area	Cost	Humidity		Chemicals	Static Electricity	Human Readable
Measured in	°C		°C		Characters (unless otherwise stated)		meters		cm^2	Rands	%			Volts	
	Low	High	Low	High	Numeric	Alpha					Low	High			
Labels - 1D	15	35	15	35	25		3		20	111500	30	80	No		Yes
Labels - 2D	15	35	15	35		25	3		20	147500	30	80	No		Yes
Labels - Smart	15	35	15	35	2	k	3	0	20	1572930	30	80	No		Yes
OCR	15	35	15	35	2	k	3				30	80	No		Yes
DPM - Ink Jet	15	35	15	35		25	3		20	815000	30	80	No		Yes
DPM - Electro Chem.	15	35	15	35		25	3	0	20	735000	30	80	No		Yes
DPM - Dot Peen	15	35	15	35		25	3	0	20	335000	30	80			Yes
DPM - Laser	15	35	15	35		25	3		20	625000	30	80			Yes
RFDI - LF	15	35	15	35	2	k	3		20	1645223.6	30	80	No	0	Yes
RFID - HF	15	35	15	35	2	k	3	0	20	1904530	30	80	No	0	Yes
RFID - UHF	15	35	15	35	2	k	3	0	20	1736835.4	30	80	No	0	Yes

Figure 33: Result sheet for Test 1

The results sheet shows that there is no obvious solution for this problem. The only two technologies (Smart labels and UHF RFID) that satisfy the read range requirements do not fall within the budget for this project. There is however a possibility of combining technologies to solve the problem. It is possible to apply one dimensional labels to the boxes and permanent RFID tags (UHF) to the pallets. When the boxes are loaded onto the pallets they are scanned and linked to the unique ID of the pallet's tag. When the pallet containing all the boxes passes through a gate reader, the back-end system will register that all the individual boxes passed through that reading station. The cost of the software package will be slightly increased but due to the system mainly using 1D labels, the project will still fall within the budget.

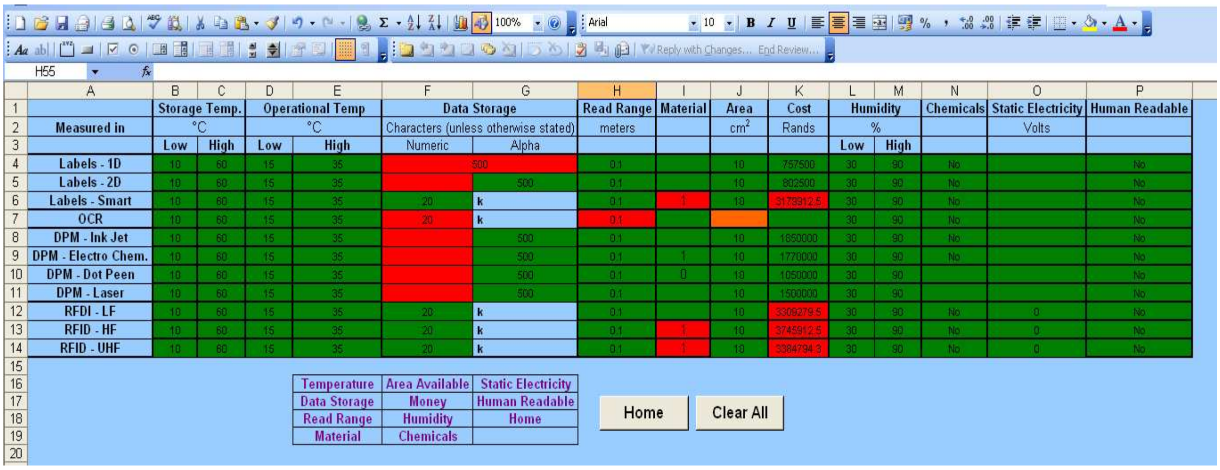
6.4.2 Test 2 – Automotive Parts Manufacturer

The values of the variables for this test simulate those of an automotive parts manufacturer. This test was chosen to demonstrate a situation where a company has a large amount of metal parts and a big budget. These are a few areas that should be taken note of:

- The parts and some of the environment are made of metal
- A long read range is not required as the parts are mostly handled by the workers
- The parts vary greatly in shape and size
    - A smallest physical area available of 10 cm^2 will be assumed
- The budget related issues
    - The number of parts that are required to be marked is approximately 200 000 in the first year
    - The software program required is quite complicated as it needs to track and trace the parts throughout their entire life and this company makes far more parts than AAT, therefore R 700 000 will be budgeted for the software package
    - This system would offer great benefits with regard to the recall of parts, production planning and addressing sources of quality problems therefore the budget for this project is assumed to be approximately R 2 000 000.

Variable	Value	
Storage Temperature (℃)	10 to 60	
Operational Temperature(℃)	15 to 35	
Data Storage	20k	500 alphanumeric
Read Range (meters)	0.1	
Material	Metal	
Physical Area Available (cm^2)	10	
Budget (Rands)	2 000 000	
Humidity (%)	30 to 90	
Harmful Chemicals	No	
Static Electricity (Volts)	Negligible	
Human Readable Data	No	

Table 36: Variable values for Test 2



	Storage Temp.		Operational Temp		Data Storage		Read Range	Material	Area	Cost	Humidity		Chemicals	Static Electricity	Human Readable
Measured in	°C		°C		Characters (unless otherwise stated)		meters		cm^2	Rands	%			Volts	
	Low	High	Low	High	Numeric	Alpha					Low	High			
Labels - 1D	10	60	15	35	500		0.1		10	757500	30	90	No		No
Labels - 2D	10	60	15	35		500	0.1		10	802500	30	90	No		No
Labels - Smart	10	60	15	35	20	k	0.1	1	10	3173912.5	30	90	No		No
OCR	10	60	15	35	20	k	0.1				30	90	No		No
DPM - Ink Jet	10	60	15	35		500	0.1		10	1850000	30	90	No		No
DPM - Electro Chem.	10	60	15	35		500	0.1	1	10	1770000	30	90	No		No
DPM - Dot Peen	10	60	15	35		500	0.1	0	10	1050000	30	90			No
DPM - Laser	10	60	15	35		500	0.1		10	1500000	30	90			No
RFDI - LF	10	60	15	35	20	k	0.1		10	3309279.5	30	90	No	0	No
RFID - HF	10	60	15	35	20	k	0.1	1	10	3745912.5	30	90	No	0	No
RFID - UHF	10	60	15	35	20	k	0.1	1	10	3384794.3	30	90	No	0	No

Figure 34: Result sheet for Test 2

From the above results sheet it is quite obvious that two dimensional barcodes (whether labels or DPM) are the best option. RFID falls outside the budget range and OCR and 1D labels don't have enough storage capacity. It is now the user's choice which marking process to use.

6.4.3 Test 3 – AAT Composites

Data used for this test was gathered during a case study at AAT Composites. A detailed evaluation of this case study can be found in Appendix C. The environmental conditions in this scenario are extreme, a few areas that should be noted:

- The parts are inserted into an autoclave and exposed to an average temperature of 180 ℃ for approximately 2 hours
- The parts are mostly handled by the workers, so a large read range is not required
- Some of the parts have traces of carbon in them
- The physical area available on the smallest parts is not very large
  - The smallest area available to place a mark is approximately 5 cm^2
- Aspects related to the budget
  - From the obtained quotations, the cheapest quote of R 300 000 will be used
  - The benefits from such a system were seen as aiding with production planning and offering a real time location of all parts to aid with a theft problem. The loses were large but the company is quite small therefore an approximate budget of R 750 000 was assigned to this project
- Approximately 10 000 parts are produced a month and thus 120 000 parts would need to be marked in the first year

Variable	Value	
Storage Temperature (℃)	10 to 180	
Operational Temperature(℃)	15 to 35	
Data Storage	10 k	30 alphanumeric
Read Range (meters)	0.1	
Material	Metal	
Physical Area Available (cm²)	5	
Budget (Rands)	750 000	
Humidity (%)	10 to 90	
Harmful Chemicals	No	
Static Electricity (Volts)	Negligible	
Human Readable Data	No	

Table 37: Variable values for Test 3

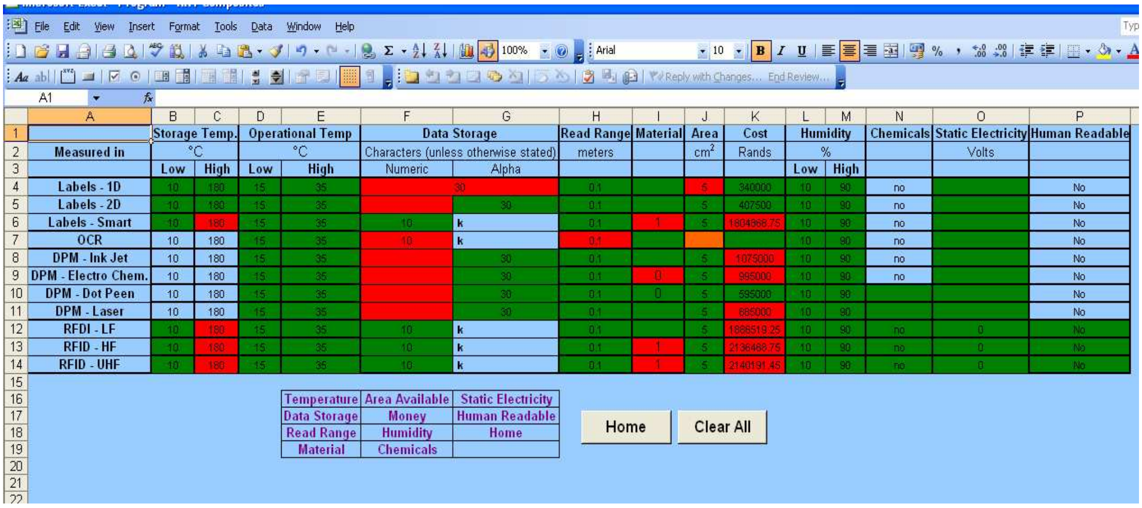


Figure 35: Result sheet for Test 3

The report sheet above shows that the only valid options would be dot peen marking and 2D barcode labels. When the project was conducted these options were eliminated as the managers wanted to use UHF RFID tags due to the large read range capability but only LF tags worked due to the carbon content in the parts. By the time this was realised, the project was already too far along in the RFID direction to look at other options.

Quotations for the required software package were only obtained at the end of the project, this proved to be a lot greater than expected and resulted in the proposed traceability system exceeding the budget. That was why this particular project was cancelled. The Decision Making Model ensures all possible variables are obtained before any systems are even considered and avoids late project cancellations for reasons that could have been determined at the beginning of the project.

6.5 Conclusion

There were a few problems obtaining data for OCR systems and this is seen as an indication of their popularity. They are in use but mainly for date stamps in the food industry and to print Vehicle Identification Numbers (VIN) in the motor industry. Little attention was paid to this technology due to its limited uses in the area of research but further investigations are required to obtain the necessary data.

For all other technologies data was collected but, due to the possibility of the improvement of the technologies, these need to be continuously updated. Most of the data was collected from specification sheets of suppliers as it is difficult to give the technologies as a whole general specifications. Numerous specification sheets were looked at and, in most cases, an average answer was determined. Although there were a few difficulties in obtaining accurate data, the model developed satisfies the requirements. It is very straightforward to use and provides the user with a set of results that are easily analysed. The edit function will ensure the program stays up to date and specific suppliers' data can also be used if required.

In the three tests conducted, the Decision Making Model successfully narrowed down the choice of traceability system to a manageable number. All three tests resulted in a viable traceability option being chosen and the last test demonstrated why the AAT Composite project failed. The three examples that were used varied largely in conditions while still examining common factors that would be found in general manufacturing environments. The tests confirm that The Decision Making Model is capable of achieving what was required, simplifying the process of choosing a suitable traceability system for use in a manufacturing environment.

7. Conclusion

This thesis provides a thorough and in-depth literature study on current traceability methods, their use in different industries and benefits they offer as well as the creation of a new model to assist in choosing a suitable traceability system.

It was shown that there are many aspects within a business where an automatic unique identification system could be beneficial, from the general use for recall applications to supplying real-time information to assist with production planning.

The traceability systems examined a range from simple systems that are widely used (1D barcode labels) to systems that are at the pinnacle of technological developments (DPM and RFID). Each has its own set of advantages and industry sectors where it is applied.

These systems are used in a variety of industries all around the world. Organisations such as Wal-Mart and the U.S DoD have issued mandates to all their suppliers for RFID tags (Wal-Mart and the U.S DoD) and DPM (U.S DoD) to appear on certain parts.

The case studies that were conducted guided the path of this thesis. The AAT case study showed the need for a model to assist the user when selecting a suitable traceability system. The Aerosud case study highlighted some areas of concern when implementing traceability systems in a typical manufacturing environment.

The Decision Making Model explained in Chapter 6 has the potential to save a company an abundance of time and resources when deciding on a traceability system. It highlights possible areas of concern, which can be addressed early on in the process and eliminates unnecessary time spent on investigating systems which are not suitable to the particular situation. There is still a possibility for the program to expand and the editing function allows for this.

Future work in this field needs to be done to keep the Decision Making model up to date. This includes updating the existing data and investigating alternative traceability methods. More research and experiments will be required to ensure the data that the technologies are measured against are accurate.

Currently most companies mark parts by batches and not individually due to the costs associated with unique marking. It is the opinion of the author that adoption of unique identification methods is going to increase due to:

- The lowering costs of the technology
- Pressure exerted by big companies (e.g. Wal-Mart, U.S.A DoD)
- Increasing uses and benefits associated with the technologies

As adoption increases, product prices will decrease and benefits will increase. The prices will decrease due to mass production and the benefits will increase due to an improved interoperability and exchange of data between different companies throughout the supply chain. The current economic crisis will certainly have an effect on the implementation of these systems as companies will be wary of the financial investment required without being able to accurately quantify the benefits.

The objectives set out in Chapter 1 were met. Knowledge was gained regarding different types of traceability systems and their use in different industries. This information was used along with that gathered through case studies to develop a model capable of assisting users to evaluate and select the most suitable traceability system for their application in the early stages of the investment planning process.

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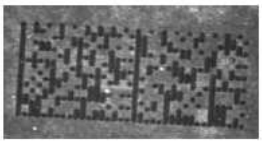
A

Appendix A DPM Marking Methods on Different Materials

Marking Method	Description	Advantages & Disadvantages
Ink Jet on substrate 	Contrast levels vary widely, round element shape ***Application:*** - Post-packaging - Warehousing - Automotive	***Advantage:*** *- Low-entry cost* *- High speed* *- Easy to read if contrast is good* ***Disadvantage:*** *- Not considered permanent by some industry standards* *- Dot registration can vary* *- Higher cost consumables* *- Mark quality dependant on surface cleanliness* *- Difficult to read if contrast poor*
Pre-printed packaging 	Typically high contrast, square element shape ***Application:*** - Product labeling - Product packaging - Document processing	***Advantage:*** *- Economical* *- High speed* *- Good contrast* *- Easy to read* ***Disadvantage:*** *- Less flexibility*
Thermal transfer label stock 	High contrast, typically black on white label stock Square element shape ***Application:*** - Product labeling - Packaging - WIP tracking, various industries	***Advantage:*** - High contrast - Low-entry cost - Easy to read ***Disadvantage:*** - Not permanent - Higher cost: consumables
Laser etch on silk screen 	High contrast, square & round element shape ***Application:*** - Electronics	***Advantage:*** - Good contrast - No consumables - Permanent ***Disadvantage:*** - Displaces surface - Process creates debris
Ink Jet on plastic 	High or low contrast, round element shape ***Application:*** - Bio-science - Pharmaceuticals - Packaging	***Advantage:*** - Limited damage to surface ***Disadvantage:*** - Higher cost consumables - Not permanent - Bleeding can affect mark quality

Marking Method	Description	Advantages & Disadvantages
Thermal print on foil packaging 	*Typically good contrast, square element shape* *Application:* *- Pharmaceutical Packaging*	***Advantage:*** *- Economical* *Disadvantage:* *- Reflective nature of marking method may require additional lighting* *- Deformation of surface may affect readability of code*
Ink jet on glass 	*Good contrast, round element shape* ***Application:*** *- Pharmaceutical Packaging* *- Clinical R&D* *- Electronics*	***Advantage:*** *- High contrast* *- Low entry cost* *- Limited damage to surface* ***Disadvantage:*** *- Not permanent* *- Bleeding can affect mark quality*
Laser etch on metal 	*Low contrast, square element shape* ***Application:*** *- Electronics* *- Automotive* *- Aerospace* *- DOD* *- Medical device*	***Advantage:*** *- Permanent* *- No consumables* *- High quality mark* ***Disadvantage:*** *- Process creates debris* *- Affects surface of substrate*
Laser etch on glass epoxy 	*Medium contrast, square element shape* ***Application:*** *- Electronics*	***Advantage:*** *- Permanent* *- No consumables* *- High quality mark* ***Disadvantage:*** *- Process creates debris* *- Lack of contrast; difficult to read* *- Affects surface of substrate*
Laser etch on rubber 	Very low contrast, square or round element shape ***Application:*** - Automotive	***Advantage:*** - Permanent - No consumables ***Disadvantage:*** - Process creates debris - Affects surface of substrate
Chem etch on metal 	Typically medium contrast, square element shape ***Application:*** - Electronics - Semiconductor - DOD - Aerospace - Medical device	***Advantage:*** - Permanent - High quality mark - No debris from process ***Disadvantage:*** - Potentially toxic material bi-product - Low-volume use only - Potentially complex process

Marking Method	Description	Advantages & Disadvantages
Chem etch on silicon 	Typically medium contrast, square element shape ***Application:*** - Semiconductor	***Advantage:*** - Permanent - High quality mark - No debris from process ***Disadvantage:*** - Potentially toxic material bi-product - Potentially complex process
Dot peen on smooth, highly reflective metal 	Low contrast, dependant on difference in depth to create light and dark elements. Round or square element shape, dependant on shape of stylus ***Application:*** - Automotive - Aerospace - DOD	***Advantage:*** - Permanent - No consumables ***Disadvantage:*** - Alters surface - Low contrast mark - More difficult to read - Inconsistent depth will create smaller elements - Background noise
Dot peen on textured metal 	Low contrast, dependant on difference in depth to create light and dark elements. Round or square element shape, dependant on shape of stylus ***Application:*** - Automotive - Aerospace - DOD	***Advantage:*** - Permanent - No consumables ***Disadvantage:*** - Alters surface - Low contrast mark - Very difficult to read, due to high degree of surface noise created by texture

B

Appendix B Explanation of Data Matrix Code

For the UID: D0CVA5786950

<u>What you see:</u>

<u>What the Reader sees:</u>

[)>$^{R}{}_{S}$DD$^{G}{}_{S}$MFR 0CVA5 $^{G}{}_{S}$SER 786950 $^{R}{}_{S}$ $^{E}O_{T}$

<u>Where:</u>

[)> = A three-character compliance indicator in the message header

$^{R}{}_{S}$ = A Format Trailer Character to indicate the fourth character of the message header

[)>$^{R}{}_{S}$ = The message header

DD = A special DoD-specific format header, which indicates Text Element Identifiers (TEIs) are being used in the collaborative solution

$^{G}{}_{S}$ = A Data Element Separator used between data fields

MFR = TEI for Manufacturer Commercial and Government Entity (CAGE) code

0CVA5 = CAGE Code

$^{G}{}_{S}$ = A Data Element Separator used between data fields

SER = TEI for Serial Number within the Enterprise Identifier

786950 = Serial Number within Enterprise Identifier

$^{R}{}_{S}$ = A Format Trailer Character to indicate the end of a data format envelope

$^{E}O_{T}$ = A Message Trailer which identifies the end of the message within the data stream

C

Appendix C AAT Composites Case Study

1. Introduction

This is the final report for the AAT traceability solution project. The project started on the 14th of February 2007 and ended on the 27th of June 2007. The expected outcome of the project is a traceability system capable of real time tracking of parts within AAT's factory.

The report consists of recommendations what system to use, requirements for the different components of the system and the proposed new production flow. Further details regarding the technology investigated and the experiments that were conducted can be found in earlier reports.

2. The Choice of the Traceability System

AAT required a traceability system that provided a real time tracking solution to assist with production planning. Two options were compared:

- Direct part marking and
- RFID

They both offer a real time tracking solution but due to:

- Lower initial costs
- Less disruption to the current production process and
- Larger reading range, an RFID system was decided on.

3. Tag

The tag is the guiding force when choosing an RFID solution as this determines what frequency will be used, the rest of the components all rely on this decision. In order to determine what type of tag should be used, a list of requirements was drawn up in Table 1.

Class of Tag	Class 0 or Class 1
Read Range	As long as it's readable through the material
Frequency	LF, HF, UHF
Data	Unique ID is sufficient
Anti Collision	Yes
Temperature	180°C for 120 minutes
Pressure	6 bar
Read Rate	> 25 tags per second

Table 1: AAT requirements

After an extensive research study on types of tags, it was discovered that the laundry industry was the closest in terms of temperature and pressure constraints to the AAT environment. Therefore, all three frequency band laundry tags were investigated.

2.1 HF Laundry Tag

The high frequency laundry tag was the first that was investigated. It was supplied by Clyde Technologies, a local agent for Assa Abloy Identification Technologies (AAITG). It is a round tag approximately 16 mm in diameter and 3 mm thick. It operates at 13.56 MHz. According to its data sheet, it satisfies both the temperature and pressure constraints and, as mentioned previously, it is mainly used in the laundry industry. To test whether the tag does indeed satisfy the AAT requirements an experiment was conducted.

2.1.1 Tag Experiment

The experiment involved making 9 lay-ups and inserting them in the autoclave to test whether they would be able to handle the extreme temperature and pressure conditions. An attempt to measure the temperature at which the tags can be read was also made.

Three types of materials and two types of cores were used for the test. The following is a list of the materials and cores used:

- Glass Phenolic Pre-preg SL246/00 (2240)
  - with nomex core
  - with rohacell core
  - no core
- EPO UD CST 270/635 FT102 40% (2662)
  - with nomex core
  - with rohacell core
  - no core
- EPO PR FB1377 200/1270 12k FT1021 (12k Weave) (2664)
  - with nomex core
  - with rohacell core
  - no core

All the lay-ups were arranged as follows: 1 layer of material, the tag, the core (if present), and 4 layers of material.

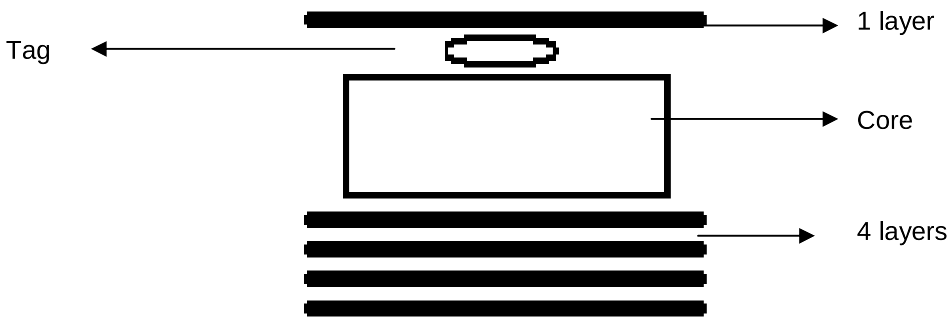


Figure 1: The test lay-up

The mock lay-ups were treated like all other parts and were wrapped in plastic and vacuumed prior to being inserted in the autoclave. They were in the autoclave for 75 minutes. When they were removed, an attempt was made to measure the temperature of the parts, this was a difficult task as the thermometer used took a long time to get up to the actual measurement and by the time it did the parts had cooled down.

The desired results were not obtained. As mentioned, the thermometer gave an inaccurate answer, the highest temperature read was 50 ℃ and this is known to be incorrect. When removed only one of the tags was able to be read, the SL 246 with a rohacell core and in this lay-up the tag had shifted out of the core. After 10 minutes of cooling down the other two tags that were inserted into the SL 246 parts (with nomex and with no core) were read. A tag from the UD 270 with rohacell core was removed to investigate whether the tag was damaged but a read on that tag was obtained. All the parts were badly deformed with the tag extruding from the part in most cases, this could possibly be countered by creating an indent in the core into which the tag can be perfectly placed (this was done for the test but not very accurately).

Three of these tags were also put through a press moulding test. The test was successful in the sense that the tags weren't damaged but as with the previous experiment, reads were only obtained through the SL 246 material.

2.1.2 Results

Both tests were not successful. It was discovered that the material, carbon, interfered with the frequency and thus high frequency tags cannot be used.

2.2 LF Laundry Tag

The next type of tag tested was a low frequency laundry tag. These tags were also obtained from Clyde Technologies. They are almost identical to the high frequency tags except the LF tag operates at 125 kHz and is 12.4 mm in diameter and 2 mm thick.

2.2.1 Tag Experiment

The exact same experiment as conducted on the HF tags was used for the LF tags. The tags were inserted into the autoclave for 75 minutes but, due to problems with the reader software, an attempt was only made 5 days later to read them.

Upon inspection it was obvious that the distortion of the material caused by these tags seems to be a lot less than that of the HF tags. The reader used for this experiment was a short distance reader and the read range was tested using a spare tag. All 9 lay-ups were read on both sides and the reading distance was not greatly affected by the material. This experiment was a complete success.

2.2.2 Results

Due to the resounding success of the experiment, this tag is a definite possibility to use.

2.3 UHF Laundry Tag

The ultra high frequency tags will be supplied by Trolley Scan. The tags are 160 mm long thin pieces of wire and can be seen in the picture below.

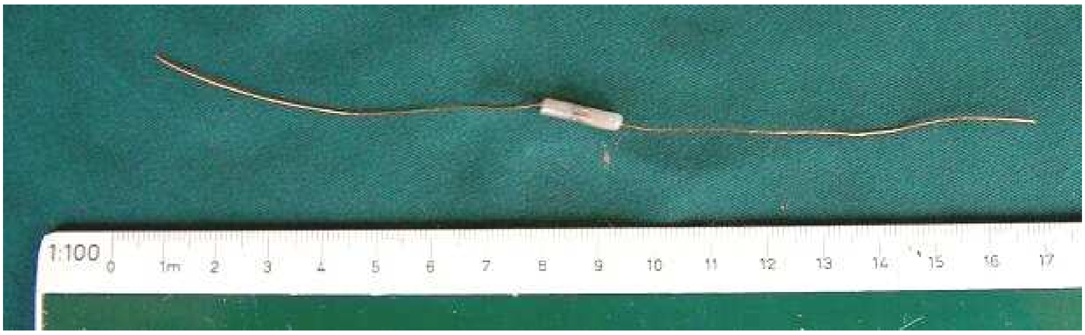


Figure 2: The UHF laundry tag

Trolley Scan have their own designated test centre in Kengray so they will send the tags to Strand, AAT is responsible for putting the tags in the part and sending it back to Kengray where the tests will be conducted. If these tags work they will offer advantages such as larger read ranges therefore, gate readers can be employed throughout the factory.

Before these tags can be recommended for use it must first be determined if they can fit into all the parts and what effects bending the antennae has on the readability of the tag. A similar experiment to the previous two should be conducted and, due to the seemingly exposed antenna, new press moulding tests must be done.

3. Reader

The amount of readers required with read range distances in brackets are:

- 1 short distance reader (5 cm)
- 9 medium distance readers (30 – 60 cm)
- 5 gate readers (60 – 100 cm)
- 11 employee tag readers (contact)

3.1 LF Reader

Low Frequency RFID technology is generally a short distance technology and this is not ideal for AAT. AAT would like the option of having gate readers and being able to perform medium to long distance scans. There is a Spanish company, Kimaldi, who Clyde Technolgies contacted on behalf of AAT and they offer medium distance LF readers. They claim to be able to achieve read ranges of up to 90 cm. This is in ideal conditions but if reads of about 70 cm are possible, gate readers can be installed in the factory. Kimaldi does a lot of work with AAITG so their readers should be compatible with the LF tag that has been tested. The readers should cost less than R 10 000 each.

3.2 UHF Reader

If the UHF tag from Trolley Scan is decided upon, the reader can also be provided by Trolley Scan. They offer complete systems consisting of tags, readers and software.

3.3 Recommendations

Further experiments have to be conducted with these readers in the factory to test if the AAT environment affects the signal between the reader and tags. It will also need to be determined if the reader/tag combination will be able to achieve the desired read rates.

4. Software

Two companies, In2one and Stowe Holdings were contacted as possible software suppliers. Clyde Technologies recommended Stowe Holdings and an Afritag representative recommended In2one. If the Trolley Scan UHF tag is used then their software program can also be used.

Another option would be to develop the software system internally but this causes additional difficulties due to the lack of experience the programmers have in designing such systems

If the type of system described in this report is required, it might be time consuming and difficult to write such a software program internally. It will probably be better to entrust this job to a company with experience in this field. Both software companies from whom quotes were obtained are reputed companies with experience in the RFID software field. When deciding on which company to use, their products should be closely compared and costs should not be the only deciding factor. It may be the case that the cheaper option doesn't fulfil all the requirements and ends up costing more in the long run.

5. Proposed Facility Layout

The proposed layout of the facility and the production flow will be explained by defining the different reading stations that should be present and explaining the material flow through these stations.

5.1 Station 1

Station 1 will be located in a room allocated for the use of receiving the tags. The person operating this station is responsible for coupling the tags and the routing labels together, both physically and on the database. The work order number can either be manually entered or there is the option of sticking a bar code on the routing label and scanning it in. This should be a new job description and a new employee who is fully computer literate should be hired. No employee scan is required as it should always be the same person working here.

IN Process	The tag is assigned to a W.O child part number
OUT Process	The tag is scanned in at Station 2
Responsible person	New Employee
Workstation required	Yes – To assign the tag to the part number on the database
Type of readers required	Medium range reader

Table 2: Station 1 requirements

The data sent to the software program will be:

- Tag ID
- Part number
- Work order number
- Date and time
- Employee ID

5.2 Station 2

Station 2 will be located in the kit cutting room near the kit assembly shelf. A work order hyperkit bag will contain numerous tags, each for a different kit in the hyperkit. Once a hyperkit is assembled, the bag is scanned. Prior to release, it must be determined if the correct number of tags are present. This could be incorporated into an existing employee's job description but, if it is found to be too much work, a new employee can be hired.

IN Process	Scanned in when tag and kit are inserted into the hyperkit bag and put on the kit cutting shelf
OUT Process	When received by Station 3
Responsible person	Kit Cutting Supervisor
Workstation required	No, but some sort of visual aid needs is required to determine the amount of tags in the bag
Type of readers required	Medium range reader and Employee tag reader

Table 3: Station 2 requirements

The data sent to the software program will be:

- Tag ID
- Employee ID
- Date and time
- Number of tags in a bag – this can be used to cross check if the correct number of tags were read

5.3 Station 3

Station 3 will be located in the moulding room in front of the chute. When a part is scanned here, the responsibility for the part has been handed over from kit cutting to moulding. This person is responsible for receiving the kits and ensuring they are moulded in the correct order. This will be done by the moulding foreman and he/she needs to be computer literate.

IN Process	1. A WO from kit cutting is received by moulding 2. A part requiring rework is received 3. Second step mouldings are received
OUT Process	1. The tag is scanned in at Station 4 2. The tag is scanned in at Station 7
Responsible person	Moulding Foreman
Workstation required	No
Type of readers required	Medium range reader and Employee tag reader

Table 4: Station 3 requirements

The data sent to the software program will be:

- Tag ID
- Employee ID
- Date and time

5.4 Station 4

This station will also be located in the moulding room. When a moulder gets the kit from the shelf, they have to scan the part. Once the lay-up procedure is complete, they have to scan the part again. This way, process times for the lay-up procedure will be easy to determine. Another way of achieving the second scan is if a signal can be sent to the software program when the vacuum is attached and released. There should be a function built into the software that ensures the worker is using the correct tool for the job. When the part is scanned for the second time, the responsibility for the part is handed over to the curing attendant.

IN Process	Moulder scans tag when he/she takes the kit off the shelf
OUT Process	1. Tag is scanned at this station when moulder is finished 2. Kit rejected (NCR # required and detail logged) – sent back to kit cutting for rework
Responsible person	Moulder responsible for the part
Workstation required	No
Type of readers required	Medium range reader and Employee tag reader

Table 5: Station 4 requirements

The data sent to the software program will be:

- Tag ID
- Employee ID
- Date and time
- Tool ID

5.5 Station 5

Station 5 will be a gate reader located at the ‘out” door of the moulding room. As a part leaves the moulding room it is automatically scanned. Some kind of error prevention system (lights, sounds) needs to be implemented to ensure the part is read.

IN Process	Scanned when part moves through gate
OUT Process	Scanned when part moves through the gate (in and out process is the same)
Responsible person	Curing attendant or the press supervisor
Workstation required	No
Type of readers required	Long range gate reader

Table 6: Station 5 requirements

The data sent to the software program will be:

- Tag ID
- Employee ID
- Date and time

5.6 Station 6

This station will be located somewhere near the autoclaves. The part should be carried from moulding to this station by the autoclave attendant. When he/she arrives here they should scan the part in. They will receive notification on their workstation when the parts are ready and how many parts are waiting to be cured. This should allow them to be able to better plan their curing cycles.

IN Process	When part is scanned through the gate reader at station 5
OUT Process	1. Scanned in at Station 8 2. Scanned in at Station 10
Responsible person	Autoclave attendant
Workstation required	Yes
Type of readers required	Medium range reader and Employee tag reader

Table 7: Station 6 requirements

The data sent to the software program will be:

- Tag ID
- Employee ID
- Date and time
- Tool ID (Autoclave/Oven ID)

5.7 Station 7

This station will be located near the press machines. The press supervisor is responsible for getting the kits from the shelf in the moulding room. He will receive a notification on his workstation when kits are ready for him to pick up. When he walks through the gate reader at the moulding door, the part becomes his responsibility. When work commences, the employee designated to work on the part should scan his employee tag and the parts tag at this station, this shall be repeated once the job is completed

IN Process	Scanned out of station 5
OUT Process	1. Scanned in at Station 8 2. Scanned in at Station 10
Responsible person	Press supervisor
Workstation required	Yes
Type of readers required	Medium range reader and Employee tag reader

Table 8: Station 7 requirements

The data sent to the software program will be:

- Tag ID
- Employee ID
- Date and time

5.8 Station 8

Station 8 will be a gate reader located at the Trimming room door. Tags are scanned when they arrive and when they leave. It must be ensured that the gate reader only reads the doorway area and not parts inside or outside the room. When at this station, the part is the responsibility of all the workers working in this room. Parts that arrive at this station come from curing.

IN Process	Scanned when part moves through gate
OUT Process	Scanned when part moves through the gate (in and out process is the same)
Responsible person	Workers in the trimming room
Workstation required	No
Type of readers required	Long range gate reader and Employee tag reader that grants access to the trimming room

Table 9: Station 8 requirements

The data sent to the software program will be:

- Tag ID
- Employee ID
- Date and time

5.9 Station 9

Station 9 will be a gate reader at the Routing room door. Scans will be scanned in and out of the station through the gate reader. Again, it must be ensured that the gate reader only reads the doorway area and not parts inside or outside the room. When at this station, the part is the responsibility of all the workers working in this room. Parts that arrive at this station come from trimming.

IN Process	Scanned when part moves through gate
OUT Process	Scanned when part moves through the gate (in and out process is the same)
Responsible person	Workers in the routing room
Workstation required	No
Type of readers required	Long range gate reader and Employee tag reader that grants access to the routing room

Table 10: Station 9 requirements

The data sent to the software program will be:

- Tag ID
- Employee ID
- Date and time

5.10 Station 10

Station 10 will be located at moulding quality control. As parts arrive there, they are scanned in. This can be done by the people already working at this station. The person responsible for this station will be required to rate the mouldings, this can either be done using a number or colour rating system. The software program will then be able to link this rating with the particular employee who was responsible for the moulding. At this station parts can be rejected or sent for rework. The software program will be able to handle such cases. Parts arrive at this station from curing, trimming or routing.

IN Process	Part scanned in when they arrive at this station
OUT Process	1. Part is accepted and scanned at this station 2. Part requires rework and sent back to moulding 3. Part is rejected and scrapped (part must also be scrapped on the database)
Responsible person	QC workers
Workstation required	Yes – to rate parts and when a part is scanned, a picture of what it should look like will appear on screen
Type of readers required	Medium range reader and Long range gate reader and an Employee tag reader

Table 11: Station 10 requirements

The data sent by this station to the software program will be:

- Tag ID
- Employee ID
- Date and time
- Part rating
- If rework required or scrapped
    - Reason
    - Next destination

5.11 Station 11

Station 11 will also be located at moulding Q.C. The parts in this station are the responsibility of the finishing foreman. When they come to pick up parts they scan their employee and part tag. The reader at this station should be a close proximity reader so as the other parts on the shelf don't affect the scanning process. The parts that are scanned in at this station are classed as being busy with their finishing process.

IN Process	Parts scanned in when foreman takes part to finishing
OUT Process	1. Scanned in at Station 12 2. Scanned in at Station 13
Responsible person	Finishing foreman
Workstation required	No
Type of readers required	Short range reader and an Employee tag reader

Table 12: Station 11 requirements

The data sent to the software program will be:

- Tag ID
- Employee ID
- Date and time

5.12 Station 12

Station 12 will be located somewhere central to the paint loop. The painting foreman is responsible for parts in this loop. The part and employee tags are scanned in when the part arrives.

IN Process	Scanned in when part arrives at this station
OUT Process	1. Back to Station 11 2. Scanned in at Station 13
Responsible person	Painting foreman
Workstation required	No
Type of readers required	Medium range reader and an employee tag reader

Table 13: Station 12 requirements

The data sent to the software program will be:

- Tag ID
- Employee ID – person manning this station
- Employee ID – person responsible for the part
- Date and time

5.13 Station 13

Station 13 should be located at quality assurance. The part is scanned as it arrives at this station. This will be done by the people already working there. Parts can be sent for rework or can be scrapped and this must be included in the program. All the information gathered by the QA workers should be inserted into the database. This will make it easier to notice negative trends.

IN Process	Scanned in when part arrives at this station
OUT Process	1. Part is accepted and scanned in at Station 15 2. Part requires rework and sent to Station 14
Responsible person	QA workers
Workstation required	Yes
Type of readers required	Medium range reader and an employee tag reader

Table 14: Station 13 requirements

The data sent to the software program will be:

- Tag ID
- Employee ID
- If rework required or scrapped
    - Reason
    - Next destination

5.14 Station 14

Station 14 will be located at Finishing Quarantine. When parts arrive here they are scanned into the system. The parts are examined and their next station decided upon. The workers currently working at this area are responsible for the station.

IN Process	Scanned in when part arrives at this station
OUT Process	1. Requires rework and sent back to Station 11 2. Requires moulding rework and sent back to Station 10 3. Part is rejected and is scrapped
Responsible person	Finishing Quarantine workers
Workstation required	No
Type of readers required	Medium range reader and an employee tag reader

Table 15: Station 14 requirements

The data sent from this station to the software program will be:

- Tag ID
- Employee ID
- Date and time
- If require rework or scrapped
  - Reason
  - Next destination

5.15 Station 15

Station 15 will be located at the despatch area. When a part is scanned at this station it will be a signal that the part has left the system. This will be a new job description, this person will have more responsibility than just scanning the parts in. He/she will also be responsible for ensuring parts are finished in time as well as have access to the database and if a part takes to long in the system they will initiate an investigation.

IN Process	Parts are scanned in as they arrive at this station
OUT Process	Once parts are scanned in here they are already out of the system
Responsible person	Despatch workers
Workstation required	Yes
Type of readers required	Medium range reader and an employee tag reader

Table 16: Station 15 requirements

6. Conclusion

Suitable options for tags, readers and software were found. The proposed new layout for the factory and the benefits that this system could offer satisfy the requirements that were set out at the beginning of the project.

After completion of this stage of the project it was cancelled due to financial reasons. The company rather went forward with their plans of implementing an ERP system and put the traceability project on hold. The initial costs associated with doing trials and implementing a traceability system are great and very difficult to reclaim within 3 years. Initial quotations received for the software package alone exceeded R 500 000. This is the reason why cost was included as a variable in the Decision Making Model.

D

Appendix D Aerosud Case Study

1. Introduction

A case study was conducted at Aerosud from the 9th of June till the 13th of June 2008. The purpose of the project was twofold:

- To acquire data to study traceability systems in a manufacturing environment and
- To assist Aerosud by analysing their current traceability system and looking for areas where this system can be improved

The study was conducted by inspecting three of Aerosud's production lines and interviewing other relevant role players. The three lines that were inspected were the Sheet Metal, A 400 and Galley lines and these were toured under the supervision of Heinrich Torlage, Jeff Esterhuizen and Ryan Brameld respectively. The main goal of these tours was to analyse the current method of traceability and to identify any factors that might influence what type of traceability system can be used. Other people who assisted in the study were Andre Visagie (with process flow diagrams), Werner Els (traceability of raw materials and other items in stores), and Kotie Nigrini (Syspro).

2. Description of the Current Process

This chapter will describe how the current traceability system operates. Firstly, how the items in inventory are traced then the three lines mentioned above will be described. This chapter just describes the current process flow and traceability system. Suggestions for improvements are given in Chapter 3.

2.1 Inventory: Receiving and Storage

When the items are received from suppliers, a Receiving Inspection Sheet (RIS) is manually filled out. On this sheet, a sequential batch number is given to the item which is linked to the suppliers number for this item so traceability back to the supplier is possible. Quality then checks the item to ensure it is up to standard. If the part is accepted a Goods Receiving Note is issued (GRN) and from this a label is electronically printed from Datascope and applied to the item. If the item is perishable, information regarding its use by date, inspection date etc. is printed on the label and recorded in Syspro.

The item is then taken to stores where it can be broken up into smaller batches. If this is the case, each individual batch receives the same sticker that was issued to the large batch. The stock then gets put in a bin according to the stock code. If a bin doesn't already exist the storeman can create one. The storeman gets a weekly print out from Syspro with information regarding the perishable items. It is his job to ensure these items are either used by their expiry date or disposed of.

Items are pulled from stores either by a PPS or a stores requisition. When this is done, the batch number of the item issued by stores is linked to the batch number of the part on Syspro. Sub assemblies are also in stores and are released in the same way.

2.2 Sheet Metal Line

The material is taken from stores to routing where nests are cut and all the PPS of a particular nest are put into a single packet. The batch number of the cut part is also transferred to the offcut. A tag engraved with the lot number is attached to one of the parts. A lot number is used to describe a set of the same type of part. When the parts are too big to be put in a packet they are grouped together and identified by the engraved tag. This engraved number is then used to link the parts to their PPS. The lot is then taken with its PPS to be deburred. Once deburred , the lot is attached to a single jig and inserted into the oven for heat treatment, this heat treatment is done at approximately 470℃ for 60 minutes depending on the part. The parts are taken off the jig and individually bent and pressed and taken for chemical treatment, each lot is given an individual rack it is hung from and dipped into the chemicals. The parts are then prepared for the painting process and masking tape is applied to areas not requiring paint. Primer is applied and once dry the top coat is painted. The parts are then sent for marking, depending on the customer's requirements, type of material and whether paint is applied or not, they are either marked with an ink jet printer or with a dot marker. The condition of the part is then tested and the part is sent for final inspection. When the part is sent to final inspection, it is ensured that the mark on the part corresponds to the PPS and the PPS archived. Each worker has an unique stamp which they use to stamp the PPS once they have completed their designated job.

2.3 A 400 line

There are four types of materials used in this assembly process namely aluminium, open weave, fabric and plastic. The materials are drawn from stores and nests are then planned and cut for all the materials except plastic. When the aluminium is cut the lot number is transferred to the material by engraving it on a tag and attaching it to one of the parts of the batch. The material batch number is then written on the off cut and a new label with the material's information is issued to the off cut. In the case of the open weave and the fabric, the lot number is transferred to the part by writing it on masking tape and sticking it on the part. Like with aluminium, the material batch number is then written on the off cut and a new sticker is issued. After cutting the aluminium, open weave and fabric go to geometry inspection. The aluminium parts are then taken to chemical treatment before they are painted, the open weave parts are sent straight to painting and the fabric parts are cured with the plastic to make window funnels or assembled to make other parts. After painting, the aluminium and open weave parts are taken to paint inspection and then to final assembly.

The plastic is taken straight from its storage shelf to be formed. This process is done at approximately 180℃. From here the part is taken fo r trimming and de-burring. They are then taken for geometry inspection where after some parts go to painting and others go to be assembled to make trim frames. After painting, the parts go to paint inspection and then to final assembly. In final assembly the aluminium, open weave, fabric and plastic parts are assembled along with capping, ferrules bond gaskets and other hardware to make the final part. The final part is sent to be wrapped and packed and stored in the finished goods store where it is separated from its PPS for the first time since the start of production. The PPS is scanned into the archive. The parts are checked by quality control and sent to dispatch.

2.4 Galley Line

Like the other lines, the Galley line begins with the cutting of the material. The material is cut to size and the batch number is written on masking tape and attached to each part. The worker is again responsible for transferring the material batch number on to the off cut. The cut parts are then sent to bonding where they are left on a shelf until they are required. The different parts used to make up the galley are logged in the PPS and the galley is identified by its PPS for the rest of the process. The parts are then bonded together and the masking tape is removed. From bonding some of the galleys go to assembly while others first go to painting and then to assembly. They are then taken to install their electricity and plumbing systems. From here they go to final assembly and to inspection.

3. Areas of Possible Improvement

This chapter highlights areas where improvements are possible. Firstly, general improvements will be described. These are changes that would affect all the processes analysed, followed by the other, more specific improvements.

3.1 General

3.1.1 The Material Cutting Process

When materials are received, the batch number is only placed once on the piece of material. When this piece is cut it is up to the worker to ensure the correct batch number is marked on the parts and the offcut, so new labels can be issued. The cutting process should be automated so that, when a nest is cut, it registers how many parts were cut and how much material is left over and prints a corresponding number of new labels. This will be done by putting a bar code scanner next to the cutting machines. Prior to the start of the cutting process the worker must scan the batch number and the PPS number. This will send the nest profile to the cutting machine and print out the corresponding number of labels once cutting has finished. A fail safe will be built in so that the cutting machine won't work unless the label has been scanned. If this is done it will eliminate human error when the cutting operator writes the batch number down and ensure every part is directly linked to a batch of material. Another solution to this problem would be to attach a number of labels to the material when it arrives so it is almost guaranteed that a label will be present on an off cut.

3.1.2 RFID on the Process Planning Sheet

This solution is more a method of tracking the parts than tracing the parts. A good traceability system offers both tracking and tracing capabilities, this system will use the same method to trace the parts (the PPS) but the method of tracking would be greatly improved. It works on the basis that the PPS are all kept at a given location in a particular work cell and, the part and the PPS are always at the same work cell. If the PPS are not currently kept in a designated area, one shall be allocated at every work cell for them. It will work by applying a smart label to a packet of PPS. A smart label is a label that contains an RFID tag. This label would contain a medium to long distance RFID tag (HF or UHF) whose ID is linked via the back end database to all the PPS' in the packet. RFID readers will be placed at predetermined work cells or at every work cell. The RFID reader will then read tags and thus all the PPS at a given cell, automatically updating the database. This system will eliminate workers walking around with readers scanning all the PPS numbers and perhaps missing a few. It also offers a real time up to the date view of where every PPS in the factory is (and hopefully the corresponding part). The cost of the labels will be recovered by the salary currently paid to the workers scanning the PPS sheets. The benefits above the current system will also result in saving money. These labels can be easily reusable as the unique ID on the tag stays the same, the PPS it is linked to is just changed on the database. More sturdy, long lasting holders can be used to hold the PPS as these can also be reused so that the RFID tag does not need to be removed every time it goes through the system.

3.1.3 Identification of Batches

After the analysis of the three lines, it was seen that, in most cases, the batch number used to identify a batch of the same parts seems to be sufficient. This is the case as the parts are cut from the same material and worked on as batches by the same employees under the same conditions. The area that can be improved is using a better method of identifying the batches through the system. A machine readable identifier for the batches will greatly improve the current system. This identifier can be applied to a part in a number of different ways. The methods that were looked at for this study were labels, Direct Part Marking (DPM) and Radio Frequency Identification (RFID) tags. Direct part marking can be done using one of four methods, dot peen marking, laser marking, ink jet marking and electro chemical etching. The particular method used per line is described in the corresponding section.

Apart from the marking method, the system will generally work the same on all the lines. This is how:

- The worker scans the PPS and a code is automatically printed on the part or, on a label or tag which is applied to the part (like the current system, it will only be applied to one of the parts in a batch)
- Every employee is given a card or sheet with their employee number written as a barcode
- When a batch arrives at a new work cell the employee will scan their employee number, the PPS and the tag
    - If the tag and PPS don't correspond, it won't allow the employee to proceed
- The program will then display the name of the part, a description (batch size etc,) and a picture of the part to ensure the worker is working on the right part
- When an employee is finished working with a part they will then scan the part out
- All the information on the PPS regarding the items required for the assembly can be electronically stored
    - When a part is scanned into a particular station a message can be sent to stores regarding the items that part requires so stores can gather the required components. When the worker goes to pick up the additional

parts, he scans his PPS and the storeman can immediately give him/her the components he/she requires

When something out of the ordinary occurs it would trigger a red flag. This will result in the system stopping the production and/or notifying the relevant people of a particular event. Depending on the urgency of the problem, it is possible to make these notifications via email or sms. The following are examples of what can be regarded as red flag events:

- The PPS and the barcode don't correspond
- A part is in a particular station for too long
- A part is not registered at being at any station for too long
  - It is in between stations
- A part is not following its predetermined process flow and is at an incorrect station
- An unauthorised worker is handling a part

The system will offer a number of benefits including:

- An almost real time view of the shop floor enabling the user to identify the exact location of individual batches
- A part has a responsible person at all times so parts can't go missing and if they do there will someone to blame and a point to start the investigation
- By seeing how long parts are at particular stations, supply chain management becomes easier and bottlenecks are rapidly identified
- Quality of the parts will improve through the rapid identification of responsible workers and other problem areas
- The back end system will have the process flow of every batch so the program can determine whether the part is at the right station or not

- When quality scans the part they can give the part a grade and this can be attributed to particular workers and used for incentives
- When the part is scanned at quality, a picture of the part can appear on their workstation giving them all the dimensions and areas to look at for that particular part
- It will eliminate most of the paper work required
  - o Only the higher assembly PPS will follow the part around, the rest of the information can be made available electronically
- If a particular part needs to be hurried through the system, it can be given preference at all the work cells and the workers there can be notified through their workstation
- It will simplify the process of linking added parts to the main part (can be done by scanning the items and linking them on the database)

3.2 Inventory: Receiving and Storage

The handling of the perishable items seems to be the biggest problem area in this department. Currently, the data regarding perishable items is printed from Syspro by the storeman and checked by him weekly, this should continue to be done but in addition to this an alert should be written into Syspro that sends him an email of all the items that need to be used. Another possible solution would be for Syspro to tell the storeman exactly what batch number of the item he must issue for a particular job. This will work on a FIFO system that is overridden by items which imminent expiry dates. It will not allow the storeman to issue an item if it is not the one recommended for use by the program (an override will be needed for extreme circumstances). By doing this it will ensure items are not left at the bottom of a pile and never used.

Another issue is the persishing of items while they are on the production floor. This is more of a problem for items like paint and glue that aren't completely used immediately after being drawn from stores. What will happen is that when an item is released by stores it stays on the system until it is returned either empty or not. If it is not empty it is put back on the shelf for future use. If it is empty, the item is scanned, shown on the system to be finished and disposed of. This will allow the storeman to see items that are in use on the production floor that are near to or past their expiry date. His/her system will also be able to tell him/her at exactly what workstation the item is at and he/she will be able to warn this person.

3.3 Sheet Metal Line

In this line the batches are currently identified by a tag which is attached to one of the parts and engraved with the lot number. Due to the exposure of these parts to the chemical treatment process, labels would not be suitable. RFID tags would also not be suitable as the chemical process would require the tag to be protected by a casing and this will prove difficult to attach to the part. The casing will also not be able to protect the tag from the extreme temperatures (470 ℃ for 60 mi nutes).

Direct Part Marking could prove to be a viable option but due to customer's standards the mark can't be directly printed on the part. The tag that is currently engraved with the lot number should be engraved with a barcode (either 1D or 2D) of the lot number, this would eliminate human error when reading the tag. Ink jet marking will not be viable as the mark would be removed in the chemical surface treatment process. Electro Chemical etching will probably also be removed during the chemical process. Laser and dot peen marking seem to be the best options and price wise dot marking would be the best option.

3.4 A 400 Line

Four different types of material are used in this assembly as explained in the sections below

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3.4.1 Aluminium Parts

The aluminium parts will work like the parts in the sheet metal line.

3.4.2 Open Weave Parts

No direct markings would be possible with this type of material, labels will rather be used. Smart labels can be applied to each part that will contain the batch number. Ink jet printed labels, similar to the ones currently used, can be applied to the open weave part. Depending on the chosen technology, these codes can be either one or two dimensional. It would be necessary to put the ink jet label in an area of the part that does not get painted. This is not as necessary for the RFID label as it is possible to be read through the paint. The cost of applying smart labels to each part will be way too large therefore, the ink jet printed labels will be used.

3.4.3 Fabric Parts

Like with the open weave parts, smart labels can be applied to a part but, like mentioned before, this will probably prove to be too expensive. If allowed by the client, the bar code (1D or 2D) can be printed directly on the fabric using an ink jet printer. If this is not possible or viable, a label like the one explained for the open weave part can be used. The costs and benefits of printing directly on the part or using labels should be investigated further.

3.4.4 Plastic Parts

Due to the temperatures the part is exposed to during the forming process, an RFID tag will have to be placed in a casing if it is to be used. The casing is generally bulky but it can be attempted to place it under the top layer of glass, similar to where the identification page is currently placed. DPM will be difficult to achieve on these parts as the mark would be distorted during the forming process. Applying the mark to a label will also not be viable as it would disintegrate during the forming process. The part will have to be scanned prior to entering the forming process, a new label printed and this stuck on the part once the forming process is completed. If total traceability is to be achieved, the process of applying the new label after forming has to be strictly controlled.

3.5 Galley Line

Assuming the process recommended for the cutting process is used, the parts will be labelled when they go from cutting to bonding. At the bonding process these parts will be scanned, linked via the back end database to the PPS and the labels removed. This will simplify and remove human intervention from this process. When the galley is bonded, all the parts used to make up the galley can now be represented by one number and so the galley needs to be marked. This can either be done by physically marking the galley or marking the trolley that it now moves through the system on (according to the future state model). It is highly recommended that the galley moves through the system on this trolley, not only for traceability purposes but also to simplify moving the galley from station to station.

3.5.1 Marking the Galley

If the galley is to be physically marked, there are a number of options which will now be explained. The galley itself can be marked which could either be done with an ink jet printer or electro chemical etching (laser and dot peen would damage the surface of the part). This mark will just be the PPS number in bar code form and will be located in a non visible but easily accessible location (so it will be easy for the worker to scan and won't be an issue for the client). This way whenever the galley enters or exits a particular work station it can be scanned and any extras applied to the part (e.g. paint, screws etc.) can be more easily linked to that particular PPS number. If required, the mark will be put in an area where it can be removed without causing too much physical damage to the part. A label can also be used with a bar code on but again it will need to be removed when the galley leaves the system.

An RFID tag can also be applied to the part. The benefits offered by this over the barcode markings would be that it doesn't need to be accessible to the worker, it can be read from as far away as 10 meters. The problem with RFID tags is that they are a lot more expensive but they can be removed from the part in final inspection and reused, the tag ID will just be re-assigned to a new PPS number in the database.

3.5.2 Marking the Trolley

The trolleys are reusable items so it would work out cheaper to mark these. From what can be understood, the future state of the galley line will involve the galley moving from station to station on a trolley it is put on after bonding. If this is the case the trolley can be marked, either using DPM or RFID tags.

If DPM is used, the mark will have to be applied directly to the trolley as, due to the long life of the trolley in the factory, a label would be damaged. The method of marking can be decided on after it is determined where on the trolley the mark should go and what material the mark would be applied to. The benefits of using DPM would be that it is cheaper and the mark could be a one dimensional bar code (which is a technology already used in the factory).

RFID tags could also be put on the trolleys. They could even be attached underneath the trolley so they are not susceptible to damage. The benefits of using RFID will be that line of sight is not required and the reader could read the tag on its own (the reader can be set to continuous read so it's not up to the worker to scan the tag).

No matter what method is used to mark the trolley, the system would work like this:

- Each trolley would be uniquely marked
- The individually cut parts are marked after cutting, as explained earlier, with a label printed during the cutting process
- When the parts are bonded together they are scanned and linked to the PPS number on the database
- After bonding a galley is assigned to a trolley by scanning the unique mark on the trolley and the galley's PPS number
    - From here on the galley will be identified by the trolley number
- When the trolley mark is scanned, the information required by the current work cell for the connected galley will appear on the workstation (i.e. the information currently on the PPS)

- When the galley is removed from the trolley, the connection between the two is broken and the trolley is returned to its storage area ready to be used again

4. Conclusion

As mentioned at the beginning of this report, there were two main goals when the project started namely, gathering information for study purposes and assisting Aerosud by improving their current traceability system. With regard to the data gathered for study purposes, the goal was to acquire information about how Aerosud uses their traceability system and to investigate the variables that influence the choice of traceability system. This part of the project was successful as a number of new variables were discovered and knowledge on how the traceability system works was gained from numerous sources.

With regard to assisting Aerosud with their traceability system, the success of the study will be decided by the management of Aerosud. A number of possible solutions were identified and theoretically, they should offer major benefits. These solutions could either be used on their own or in conjunction with each other. If all the suggested solutions are implemented it should provide Aerosud with a traceability system capable of real time tracking of parts and assemblies through the system as well as providing them with cradle to grave information on all items in the system.

E

Appendix E The Decision Making Model

1. Introduction

The Decision Making Model was programmed in 2008 using Microsoft Excel. It is used to assist in the decision making process of choosing a suitable traceability system. It works by asking the user questions regarding certain variables that are present in most manufacturing environments and which influence the workings of the different traceability systems as well as allowing the user to set up his/her own set of requirements for the future system. The Decision Making Model is available on the back cover of this thesis. Below is an explanation of how the program works.

2. Operation of the Model

The program compares 11 different traceability options using 10 variables. A detailed explanation of the traceability systems is available in Chapter 3 and a description of the variables is in Chapter 6.

When starting the program, the user has four options:

- To go to the instructions page
- To start using the program
- To go to the edit page
- To go to the previous set of results

Prior to starting the program the user needs to ensure that Macros are enabled in Excel. In the following sections brief descriptions of the above choices are given.

2.1 Instructions Page

The instructions page is intended for first time users and is just a brief explanation of the program, how it works and how the user can edit it. Figure 1 is a screen shot of the instructions page.

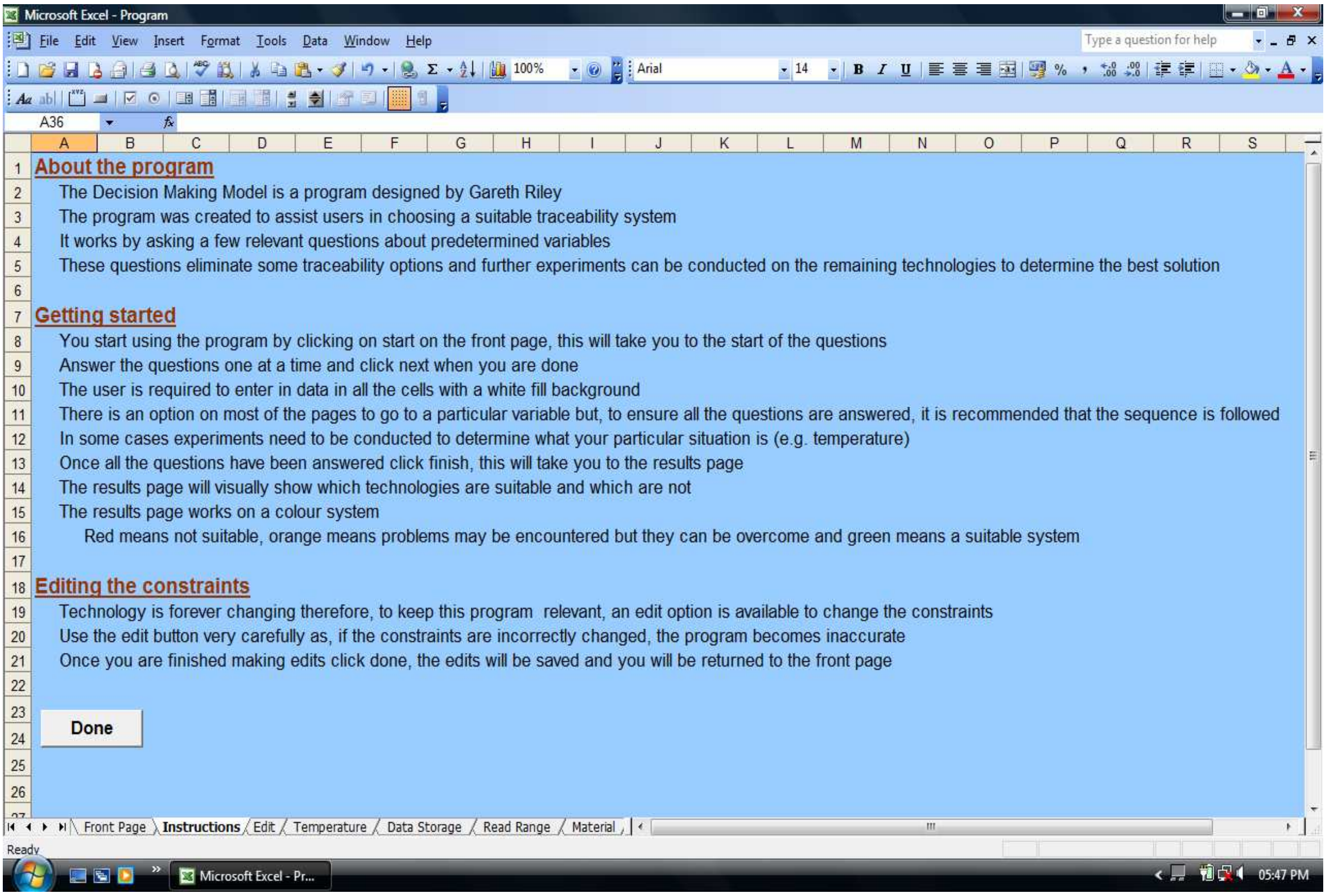


Figure1: Screen shot of the instruction page

2.2 Start Using the Program

Once "start" has been clicked, the program takes the user to the first variable (temperature). It is recommended that before the user clicks "start" to click "clear all" to ensure all the data entered is new data. It is possible for the user to jump between variables (see navigation table in Figure 2) but, to guarantee that all the questions are answered, the sequence should be followed and the user should just click "next" on all the pages. Some of the questions might require experiments to be conducted to ensure accurate results but the answers should be mostly information that is readily available. The user is required to fill in all the areas where there is no background fill and the cell is surrounded by a solid border. This can be seen in Figure 2. When the user has finished answering all the questions, the program takes the user to the results page which is described in Section 2.4.

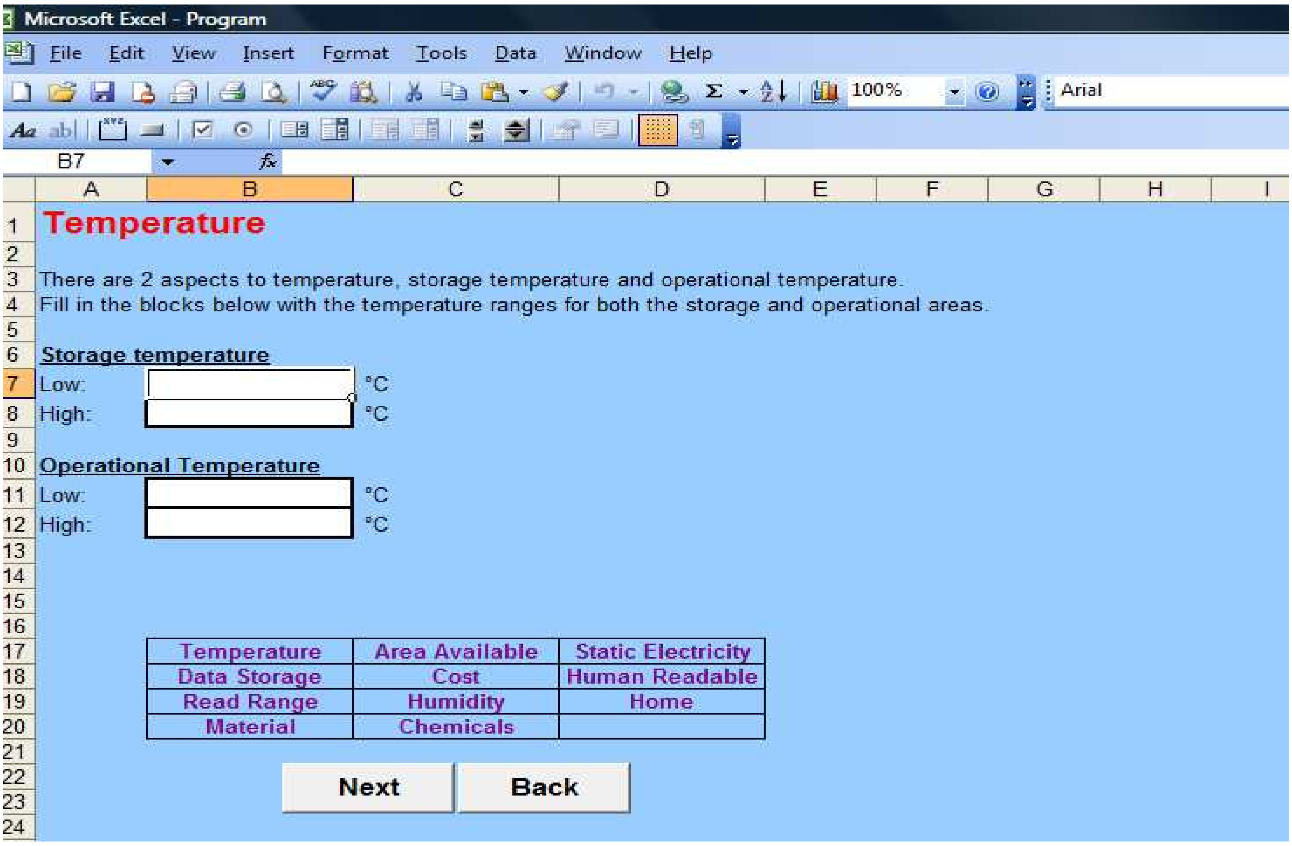
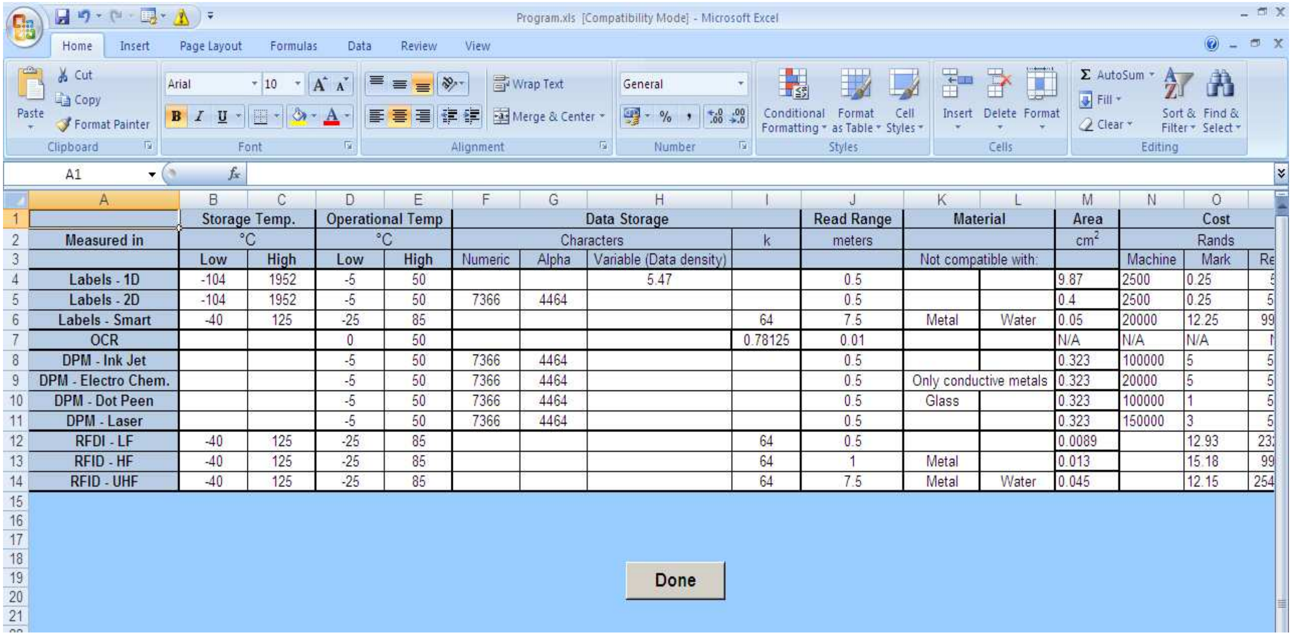


Figure 2: The Temperature question page

2.3 The Edit Page

It is necessary to make this program dynamic and flexible as the technology used for traceability systems is constantly improving. This edit page needs to be used carefully as if incorrect changes are made, the program is rendered inaccurate. The only variable that can't be edited by just entering data in the table is material, this is due to the complex nature of the code that controls the results table. A screen shot of the edit page is shown in Figure 3.



Measured in	Storage Temp. °C Low	Storage Temp. °C High	Operational Temp °C Low	Operational Temp °C High	Data Storage Characters Numeric	Data Storage Characters Alpha	Data Storage Characters Variable (Data density)	Data Storage k	Read Range meters	Material Not compatible with:		Area cm²	Cost Rands Machine	Cost Rands Mark	Re
Labels - 1D	-104	1952	-5	50			5.47		0.5			9.87	2500	0.25	5
Labels - 2D	-104	1952	-5	50	7366	4464			0.5			0.4	2500	0.25	5
Labels - Smart	-40	125	-25	85				64	7.5	Metal	Water	0.05	20000	12.25	99
OCR			0	50				0.78125	0.01			N/A	N/A	N/A	N
DPM - Ink Jet			-5	50	7366	4464			0.5			0.323	100000	5	5
DPM - Electro Chem.			-5	50	7366	4464			0.5	Only conductive metals		0.323	20000	5	5
DPM - Dot Peen			-5	50	7366	4464			0.5	Glass		0.323	100000	1	5
DPM - Laser			-5	50	7366	4464			0.5			0.323	150000	3	5
RFDI - LF	-40	125	-25	85				64	0.5			0.0089		12.93	23
RFID - HF	-40	125	-25	85				64	1	Metal		0.013		15.18	99
RFID - UHF	-40	125	-25	85				64	7.5	Metal	Water	0.045		12.15	254

Figure 3: The Edit Page

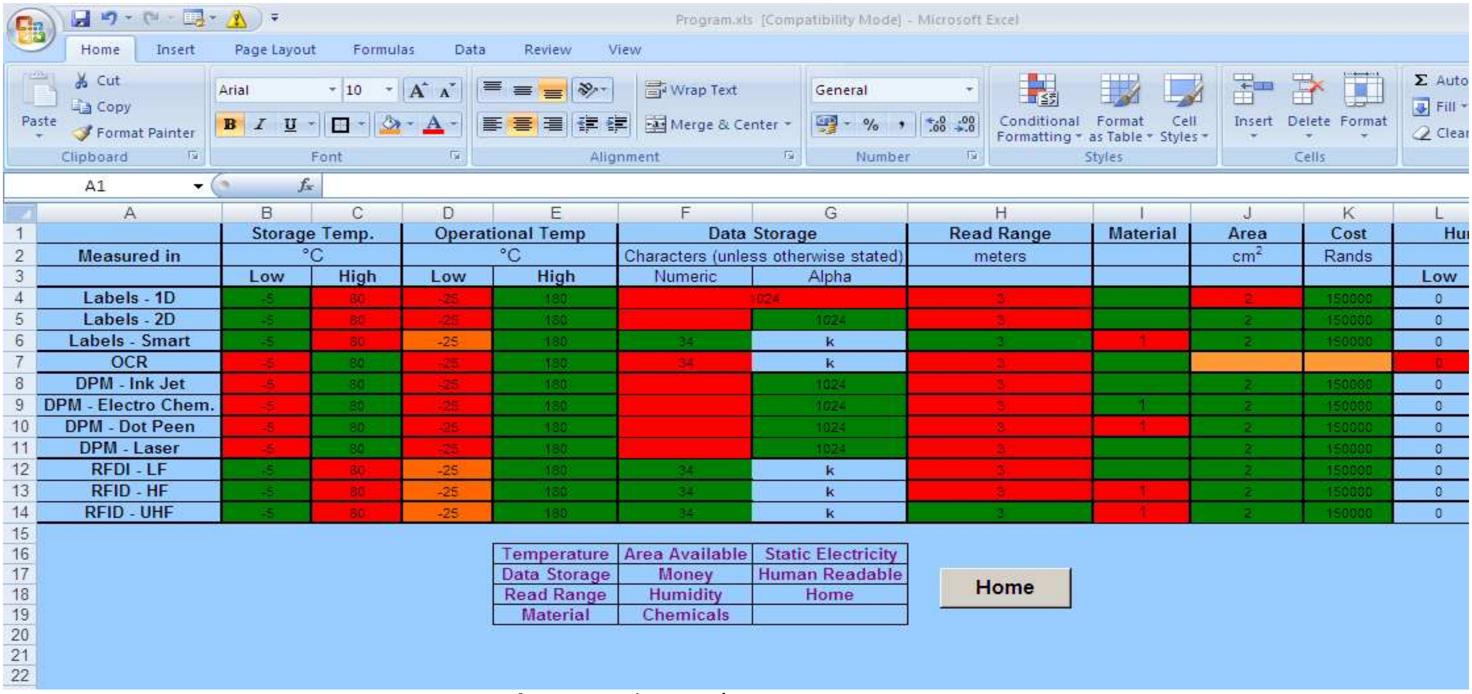
2.4 The Results Page

The results page is a visual summary of the comparison between the variables and the traceability options using the answers to the questions asked regarding the variables. A colour code system is used to enable simple recognition of possible problem areas:

Red	Particular traceability system is not suitable for use
Orange	Problems might be encountered but either something can be done about it or further experiments are needed
Green	Traceability system is suitable for use

Table 1: Key for the colour code system

If data is left out on the varibles page, an error message will appear in the affected cells. The user should then return to the specific page and make the necessary changes.



	Storage Temp.		Operational Temp		Data Storage		Read Range	Material	Area	Cost	Hu
Measured in	°C		°C		Characters (unless otherwise stated)		meters		cm²	Rands	
	Low	High	Low	High	Numeric	Alpha					Low
Labels - 1D	-5	80	-25	180	1024		3		2	150000	0
Labels - 2D	-5	80	-25	180		1024	3		2	150000	0
Labels - Smart	-5	80	-25	180	34	k	3	1	2	150000	0
OCR	-5	80	-25	180	34	k	3				0
DPM - Ink Jet	-5	80	-25	180		1024	3		2	150000	0
DPM - Electro Chem.	-5	80	-25	180		1024	3	1	2	150000	0
DPM - Dot Peen	-5	80	-25	180		1024	3	1	2	150000	0
DPM - Laser	-5	80	-25	180		1024	3		2	150000	0
RFDI - LF	-5	80	-25	180	34	k	3		2	150000	0
RFID - HF	-5	80	-25	180	34	k	3	1	2	150000	0
RFID - UHF	-5	80	-25	180	34	k	3	1	2	150000	0

Temperature	Area Available	Static Electricity
Data Storage	Money	Human Readable
Read Range	Humidity	Home
Material	Chemicals	

Figure 4: The results page

3. Conclusion

This program is designed to be easy to understand and to be used by people not familiar with the industry. The results page is set up in such a way that all the answers are visually available. It is possible to make the program more specific and technical but that would have made the it more complicated to use and the results achieved would have been similar. The edit function allows any future users of the program to keep it up to date and possibly add any future technologies to it.