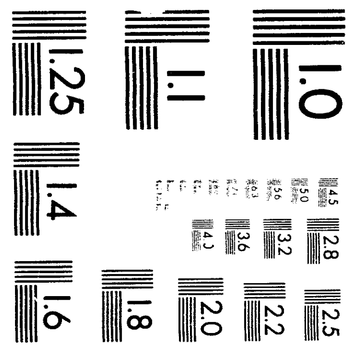

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6

1 of 1

ORNL/Sub/93-SL161

Ammunition Logistics Program

DATAMATRIX AND PDF417 DATA INTEGRITY TEST

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ABSTRACT

The Center for Automatic Identification at Ohio University conducted a test to evaluate data integrity of selected two-dimensional, high-density, high-capacity coding symbologies for use in selected automatic identification applications. The test was part of the U.S. Army's Project Manager for Ammunition Logistics Automatic Ammunition Identification Technology Project. Specific symbologies tested were Datamatrix, from International Data Matrix, Inc., and PDF417, from Symbol Technologies, Inc. As a reference, Code 39 (MIL-STD-1189) symbology was also evaluated under the same conditions.

The statistical objective of the test was to determine if Datamatrix and/or PDF417 symbologies could be expected to exhibit one error or less in two million characters scanned and decoded. The level of confidence was set to 95%.

Symbols for Datamatrix and PDF417 included 50, 100, 250, and 350 encoded characters for each of three levels or error correction, identified as low, medium, and high. Each Code 39 symbol contained 15 to 25 characters. Based on a population of 1080 symbols per symbology, sample size was calculated to be 31,438,998 characters per symbology. Actual characters scanned and decoded exceeded the calculated minimum. Each symbol was printed on 3-in.-square white paper label stock using a thermal transfer printer. Each symbol was mounted on a plastic carrier sheet on one or two surface shapes (flat or curved).

An automated test apparatus was used to assure uniformity of test conditions. The apparatus included robotic loading and unloading of carrier sheets onto scanning stations. Scanning for Datamatrix symbols was performed using fixed mounted RS-170 CCD cameras. PDF417 and Code 39 symbols were scanned using hand-held rastering visible laser scanners mounted in fixed positions and software triggered. Decoding of all symbols occurred in decoders supplied with the scanners using the respective manufacturer's proprietary decoding algorithms. Each symbol was read a total of 288 times.

Software was developed to monitor and control the test apparatus and to assure proper collection of the data. Decode data, including number of nonreads, errors, and total number of characters scanned, was collected for each symbol and was logged into three data files.

Over 94 million characters were decoded during the test. Analysis of test results indicate no errors attributable to either Datamatrix or PDF417 symbologies. Eleven errors were recorded for Code 39.

DATA MATRIX and PDF417 DATA INTEGRITY TEST

1.0 PROJECT OVERVIEW

Bar codes have been clearly established as an accurate and efficient means of identifying objects and entering data without manual keyboard entry. Popular linear bar codes such as UPC, Code 39, and Code 128 are widely used in retail, government, and industry today. The data integrity of these symbologies have been tested in previous experiments and have been shown to be very robust in their ability to be decoded with minimal substitution errors. The focus of this test was to evaluate data integrity of the relatively new two-dimensional, high density, high capacity coding symbologies for use in automatic ammunition identification applications. The specific symbologies tested were Datamatrix from International Data Matrix, Inc., Clearwater, Florida and PDF417 from Symbol Technologies, Inc., Bohemia, New York. A standard bar code symbology, Code 39 using the MIL-STD-1189 specifications, was also evaluated as a point of reference. This test was performed at the Center for Automatic Identification Education and Research in the College of Engineering and Technology at Ohio University, Athens, Ohio.

1.1 Linear Bar Codes

Code 39 and other standard bar code symbologies may be referred to as "linear" since the scan path through the symbol is a single continuous line from one end of the symbol to the other end. The length of one of these bar code symbols is a function of the minimal bar width dimension and the amount of data encoded. This becomes a problem when the desired amount of data to be encoded in a bar code symbol causes the symbol to be larger than the physical space available for the symbol. It is common to have 4 to 20 characters encoded in a linear bar code. Linear codes are often used as a "license plate" to access data from a computerized database

1.2 Two Dimensional Bar Codes

Two dimensional bar code symbologies, such as Code 16K and Code 49, have been developed to allow bar code users to encode more characters in less space. These symbologies are two dimensional because data characters are encoded in linear fashion utilizing multiple rows, thus each row carries part of the total encoded data. Each row is scanned in a linear path, but all rows must be scanned for a successful decode. Each row is uniquely identified so that the entire message can be correctly decoded even when rows are scanned in any order. Because of their arrangement of rows of encoded data, Code 16K and Code 49 are variously referred to as "multi-row", "stacked", or "two dimensional" bar code symbologies. Two-dimensional codes such as Code 16K and Code 49 can be used to encode up to 80 characters per symbol. Typical applications include 20 to 45 characters per symbol. Code 16K and Code 49 have previously been tested at Ohio University in 1991.

1.3 High Density Two Dimensional Bar Codes and Matrix Codes

The latest generation of codes allow even more information to be encoded in relatively small area. These new high density symbologies can encode up to 2000 characters per symbol. The data integrity and reliability of these high density symbologies have never previously been tested.

1.3.1 Datamatrix

Datamatrix is a two dimensional matrix code. It is a visual representation of machine executable electronic binary code. The binary code is formed as a matrix having a perimeter border and data contained therein. The border is provided with indices for indicating the density of the data contained within the matrix. The border also provides bars for indicating the size of the matrix. A scanning device utilizes the size bars and density indices to calculate the size and density of the binary code. The physical size of a Datamatrix symbol can range from .001 inch square to 14 inches square. Datamatrix symbols may encode from 1 to 2000 characters of information in any language on each symbol. The symbols may be read from any angle and decode algorithms can determine precisely the angle at which it was read. The symbology includes both error checking and error correction capability. Figure 1 is a Datamatrix symbol encoding the message "AUTOMATIC AMMUNITION IDENTIFICATION TECHNOLOGY."

Figure 1 Datamatrix Symbol

1.3.2 PDF417

PDF417 is a two dimensional bar code symbology capable of encoding up to 1800 characters per symbol. PDF417 is constructed from data units called "words," each of which is 17 modules long. Bars are made by filling in up to six consecutive modules and each unit has four separate bars and four spaces. This allows for 10,480 different possible words, far more than in standard codes that are comprised of fewer modules. In any particular application, just 929 words are used. Each word has three separate forms, as if it were English, French, and German, making a total of 2787 bar and space combinations. Each row is encoded in a different "language," to help the scanner and decoder keep track of which line is being read. Each of the 929 words also has 15 modes, 4 of which are predefined as ASCII, Alphanumeric, Mixed, and Numeric. PDF417 has both error detection and error correction. The error correction level is selectable among eight levels. There is a trade off between error correction and symbol capacity. As error correction level increases, the data capacity of the symbol decreases. Figure 2 is an example of a PDF417 symbol with the message "AUTOMATIC AMMUNITION IDENTIFICATION TECHNOLOGY."

Figure 2 PDF417 Symbol

1.3.3 Code 39 (MIL-STD-1189)

Code 39 is a linear bar code that was developed in 1975 by Dr. David Allais. It has become the most prevalent code in industrial and government applications. Code 39 was selected as the official Department of Defense (DOD) symbology in 1981. It became the official U.S. Government symbology in 1982 with the issuance of MIL-STD-1189. The name Code 39 is both a descriptor of its original character set of 39 characters (currently it has 43 characters) and the structure of the code. There are nine elements per character, three of which are wide and six of which are narrow. Each character is represented by five bars and four spaces. An optional check digit may be used for error detection. Figure 3 is a Code 39 symbol with the message "AUTOMATIC AMMUNITION IT" encoded.

Figure 3 Code 39 Symbol

2.0 PROJECT BACKGROUND

The Automatic Ammunition Identification Technologies Project (AAIT) is a multi-task development activity of the Robotics and Process Systems Division (RPSD) at the Oak Ridge National Laboratory (ORNL) for the U.S. Army's Project Manager-Ammunition Logistics (PM-AMMOLOG) at the Picatenny Arsenal, Picatenny, New Jersey. The project objectives were to evaluate compressed data symbologies and to develop systems that can reliably and automatically identify all desired rounds of Class V ammunition from the load and pack plant through all logistics nodes to the weapon system. These automatic identification technologies are expected to significantly improve the ability to track ammunition and other military assets, archive maintenance history, manage and take inventory, and accommodate automated feeding and handling of ammunition for weapons systems. The result is expected to be increased throughput capability, better inventory control, reduced human error, lower operation and support costs, and more timely resupply to various weapon systems.

Currently two general ammunition applications have been identified for high density, high capacity symbologies. The first would utilize these new symbologies as portable data files to augment existing logistics accounting systems used by ammunition supply nodes. The objective here is to implement electronic data interchange (EDI) concepts and increase automation in ammunition inventory and distribution systems. Using portable data files allows the encoding of large amounts of information in a relatively small space. These symbologies are especially useful where an external data base is not available. For example, shipments of materials could have all shipping documents encoded and attached in a durable form which could be decoded and verified at any time. Other potential applications include shipping manifests, material safety data sheets (MSDS), procedures for handling and maintenance, and inspection records. The second application would require symbols to be applied directly to artillery and armor ammunition items. The objective here is to provide machine readable information on projectiles and fuses to enable identification of these components by robotic systems designed for feeding and handling ammunition. This would improve weapon rates of fire and reduce the manpower requirements for the overall system. Additionally, projectile weight data could be encoded and used by fire control systems to perform the necessary corrections to ballistic calculations and improve weapon accuracy.

3.0 STATEMENT OF PROBLEM

The portion of the test conducted at the Center for Automatic Identification at Ohio University evaluated the data integrity of Datamatrix, PDF417, and Code 39 (MIL-STD-1189) symbologies when scanned under controlled uniform circumstances.

This study was designed to evaluate each symbology at the systems level. The system included: the symbol, reader (scanner/decoder or camera/decoder), and computer. The research made comparisons at the systems level with all system elements present.

The test measured the character substitution error rate for each symbology/system. For the purpose of this test an error was defined as decoded data which was different from the data which was encoded in the symbol.

4.0 DESIGN OF THE EXPERIMENT

A test design was prepared and strictly followed to insure that the test would be valid and conducted under known circumstances. The test design included development of the hypothesis, sample size and test conditions. The statistical objective was to design a test based on pass/fail criteria which would accept, at a 95% confidence level, a symbology with a substitution error rate of one or less in two million data characters. A given symbology would be rejected, based on statistical criteria, if there were two or more errors in two million characters. Variations due to human factors were minimized by using an automated testing device and identical external control software.

4.1 Hypothesis

The null hypothesis for the test was $H_0:\mu 1=\mu 2=\mu 3$ where:

μ = proportion (p) of errors per number of data characters attempted to be read for each symbology in the test
H_0 = the test standard (one error in 2,000,000)
$\mu 1$ = Datamatrix,
$\mu 2$ = PDF417, AND
$\mu 3$ = Code 39,

The alternative hypothesis was $H_a:\mu 1\neq\mu 2\neq\mu 3$. The confidence interval for the test was stated at 95% or an alpha error of .05 for a two tailed test. Beta error was set at .05.

4.2 Experimental Design

The experimental model for comparison is a Post Test Only Control Group design. The following figure illustrates the relationship between the items under test. R indicates randomization, X indicates the particular symbology under test, and O indicates observation or data collection

R	X1	O
R	X2	O
R	X3	O

Figure 4 Experimental Model

4.3 Calculation of Sample Size

Sample size is a direct function of the desired difference to be detected with respect to the underlying population or standard. Based on prior testing the reference standard to be used in the test was one error in 2,000,000, or in probability notation, p=np/n, p=1/2,000,000, p=.0000005. For this test, 1/2,000,000 was assumed to be a difference that was important to automatic ammunition identification technology. The intent of this study was to determine if Datamatrix and/or PDF417 meets or exceeds this standard.

A sample size was required that will accept codes with 1/2,000,000 error rate 95% of the time and accepts codes with 2/2,000,000 only 5% of the time. If either PDF417 or Datamatrix symbology had greater than one error in two million data characters scanned then it was considered as not meeting the test standard.

The appropriate reference distribution for the test was the binomial distribution. This was the appropriate distribution due to the fact that each character was measured as a success or failure. Further, the binomial was appropriate due to the size of the population of scannable characters ($N=\infty$).

4.3.1 Equations

General Form Equations

$$1 - a = \sum_{d=0}^{c} \frac{n!}{d!(n-d)!} .0000005^{d} .9999995^{n-d}$$

$$b = \sum_{d=0}^{c} \frac{n!}{d!(n-d)!} .000001^{d} .999999^{n-d}$$

Solved Equations

$$.95 = \sum_{d=0}^{22} \frac{31,438,998!}{d!(15,719,501-d)!} .0000005^{d} .9999995^{20,000,000-d}$$

$$.05 = \sum_{d=0}^{22} \frac{31,438,998!}{d!(20,000,000-d)!} .000001^{d} .999999^{20,000,000-d}$$

Sample size for testing each code is 31,438,998 characters. If the number of failures is 22 or less, then the code will be considered to have ≤ 1 error in 2,000,000 characters scanned. If a code has 23 or more errors the code will be considered to have an excessive failure rate of > 2 errors in 2,000,000 characters scanned.

4.4 Test Conditions

The test was conducted under controlled conditions. Test conditions were set by the nature of the test or the nature of the expected use of the symbologies in automatic ammunition identification projects. The test conditions consist of the symbology, symbol printing methods, the scanners and decoders to be used, and the environmental variables that was held constant or varied.

4.4.1 Symbologies

Three symbologies were tested; Datamatrix, PDF417, and Code 39 (MIL-STD 1189A).

- Datamatrix and PDF417 each utilized 3 levels of error correction; null, medium, and high.
- 360 symbols were used for each symbology
- Each symbol was read approximately 288 times.
- Each Datamatrix or PDF417 symbol contained 50, 100, 250, or 350 data characters. Code 39 symbols contained 12, 15, or 18 characters.
- Symbols were be printed on a Zebra Model 140 Thermal transfer printer on 3" inch square white paper label stock
- Code 39 symbols conformed to the MIL-STD 1189 specification.
- Each symbol was mounted on one of two different surface configurations.

The following table summarizes the test design for symbols samples tested for the Datamatrix and PDF417 symbologies:

Table 1 Number of symbols tested.

	Number of Symbols Required		
# of characters per symbol	Null Error Correction	Medium Error Correction	High Error Correction
50	200	200	200
100	100	100	100
250	40	40	40
350	20	20	20

4.4.2 Scanners and Decoders

- Scanning and decoding of PDF417 and Code 39 was done using a PDF-1000 fixed mounted, handheld moving beam, visible laser diode bar code scanners from Symbol Technologies, Inc.

- Scanning of Datamatrix was done using an RS-170 compatible CCD camera.

- Scanners were set to operate within acceptable tolerances for angles, distances, and ambient lighting conditions as defined by the manufacturers.

- Decoding of PDF417 and Datamatrix occurred in respective, separate decoders supplied with the scanners using the manufacturer's proprietary decoding algorithms.

4.4.3 Assumptions

The following assumptions were made in relation to the test design:

- Printed symbols supplied were representative of symbols encountered in Department of Defense applications.
- Automated testing equipment did not necessarily replicate physical human scanning conditions.
- The resolution of the test was a function of the detection capability or the number of errors per million characters scanned
- Lighting, temperature, voltage and other environmental effects represent normal operating conditions.

4.4.4 Fixed Factors

Certain factors remained constant during the testing process. Those factors included the test apparatus, environmental conditions, test procedure, and test personnel.

A special apparatus was constructed that allowed for standardized testing. The computer controlled apparatus was supplied with nominal 120 volt electrical current. Surge protection and line conditioning was provided.

The environmental conditions in the testing room were a function of the building capabilities. Lighting conditions were made uniform by blocking all exterior light from the room and standardizing the level of fluorescent lighting at 18.7 foot candles. Room temperature and humidity remained uniform as controlled by the building's heating and cooling system.

A standard test procedure insured uniformity of process as samples were prepared and tested. Only trained test personnel employed by the Center for Automatic Identification operated the test equipment.

4.4.5 Variable Factors

Certain factors varied during the test. The following factors should be noted:

- The surface geometry on which the labels were mounted varied as follows:

Surface	Representation
flat	package
large radius circumferential	155mm artillery shell

- The symbologies utilized were: Datamatrix, PDF417, and Code 39.
- Label quality varied as a function of normal printing variations.
- Data length was varied as indicated in Table 2 on page 13..
- Error correction level on Datamatrix and PDF417: null, medium and high
- Code 39 symbols were printed with and without a check digit.

5.0 RESOURCES

Resources used in the test included printed symbols, hardware and software. The test was monitored by personnel from the Center for Automatic Identification.

5.1 Symbols

Symbols were printed at the Center for Automatic Identification using a Zebra Model 140 thermal transfer printer. A total of 1080 symbols were printed for both Datamatrix and PDF417. Eleven hundred were printed for Code 39. Label size was approximately 3 inches square. Label stock was white paper with self adhesive backing. Data content and formats are specified in Appendix B.

5.2 Hardware

Hardware used in the test consisted of the test apparatus, the scanners and decoders, and computers. Scanners and decoders were supplied by International Datamatrix, Inc. and Symbol Technologies, Inc. The test apparatus was custom designed and built by the Center for Automatic Identification.

5.2.1 Test Apparatus

An automated test apparatus was used to insure uniformity of testing procedure. Photographs of the test apparatus and hardware are included in appendix A. The apparatus included an indexing rotary turntable containing six stations; two stations were used for scanning, one station for load/unload, and one station was used for carrier ID scanning. The carrier sheets were loaded from a magazine by a robot. The ID station used an independent, fixed mount, visible light diode scanner for ID purposes. The scanner or camera was mounted in a fixed position at each scanning station. The two scanners or cameras were clamped in place within the manufacturer's recommended operating ranges and the set-up characteristics were noted. The indexing turntable was pneumatically actuated and provided suction to secure the carriers in place.

5.2.2 Cameras, Scanners, and Decoders

Complete descriptions of the cameras, scanners, and decoders are included as Appendix C. Each scanner or camera was attached to adjustable stationary mounting brackets attached to the test apparatus. All scanners and cameras were set to read the symbols within the manufacturers' recommended operating ranges. Triggering of the scanners was performed through the computer control program

Decoders were supplied by the manufacturers. The Datamatrix decoders were only capable of decoding Datamatrix symbols. The PDF417 decoders are capable of decoding multiple bar code symbologies and were set to operate in the auto discriminating mode.

5.2.3 Carrier Sheets

Test symbols were mounted on carrier sheets. Carrier sheets were manufactured by vacuum forming from 0.040 inch white styrene plastic. The plastic carrier sheets simulated two surface geometries: flat and curved 6 inch diameter. Each test label was mounted on a carrier sheet on one of the two different shapes. Fifty percent of the symbols for each symbology were placed on the flat surface. The other half were placed on the curved surface. A picture of the carrier sheets is included in Appendix A. The plastic carrier sheets each were labeled with an ID number to identify the carrier so as to be able to store and retrieve information about the carrier and associated test symbols from the databases. USS Interleaved 2 of 5 symbology was chosen for the ID label to avoid any possible confusion with the data encoded in the test symbols.

5.2.4 Computers

The computer used for the test was an IBM compatible 386 PC, 25 MHz clock speed, 2 MB main memory, 80 MB local hard drive storage, running MS DOS version 5.0. The computer also included an 80387 floating point co-processor.

The computer also controlled the test apparatus. All processing was performed and the database was updated in real time.

5.3 Software

Several types of programs were used in the test. Control programs managed the robotic loading and unloading, rotary table indexing, and scanner activation. Data acquisition programs governed the capture and storage of the scanned data. Finally a separate program handled the identification and management of the data as either correct reads or errors. The system was programmed in Microsoft C, version 6.0. The Greenleaf Communication Library was used as a low-level serial port communications interface. Figure 5 is a schematic of the software system.

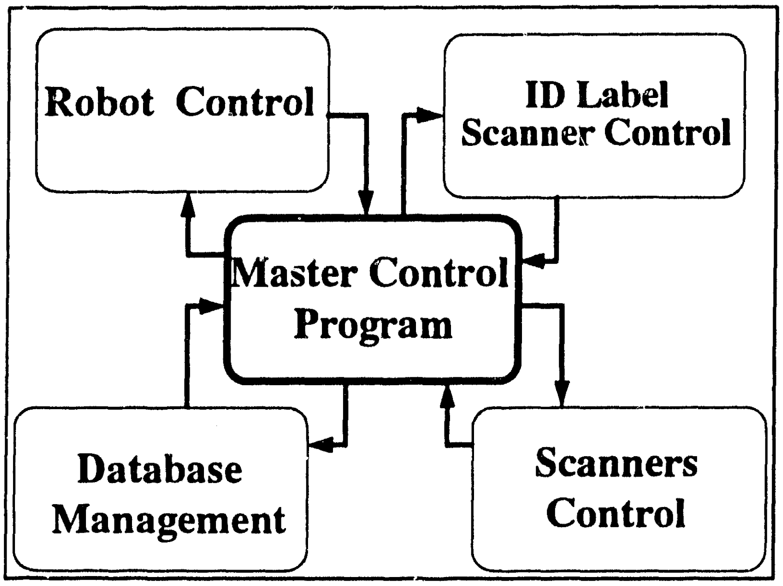


Figure 5 Software Schematic

5.3.1 Control Programs

The test device was controlled by an independent computer running custom developed software. Programmatic control of the components and functions were as follows:

- Robot - control of stepper motors for loading and unloading movements, on/off activation of vacuum gripper
- Rotary table - pneumatic rotary movement and indexing
- Scanning - trigger of scanner for reading ID tag, trigger of scanners or cameras for data capture.

5.3.2 Database Structure

The data relating to the test was divided into two categories; reference and test. The first category contained historical and background information about the labels under consideration. The second category contained information that was dynamically collected during the test procedure. Thus, the database was a relational database with two separate files. The ID number on the carrier sheets was the index item providing the relationship between the two files.

5.3.2.1 Reference Database

The reference database contained all the information that allowed for accountability and traceability of each symbol that was used in the test. The following table shows the various fields that were represented in this database.

	FIELD	COMMENTS
1.	ID Number	Identification number on the carrier sheet.
2.	Symbology	Datamatrix, PDF417, or Code 39.
3.	Characters	Number of characters encoded in the symbol.
4.	Error Correction	Datamatrix or PDF417 : High, Med, or Null
5.	Shape	Shape of the mounting surface on the carrier sheet. Flat or curved.
6.	Side length	Datamatrix only.
7.	No. Columns	PDF417 only.
8.	No. Rows	PDF417 only.
9.	Check digit	Code 39 only.
10.	Content	String of characters encoded in symbol.

5.3.3.2 Test Database

The test database was used to record all anomalies and errors during the test.

FIELD		COMMENTS
1.	ID Number	Identification number on the carrier sheet.
2.	Characters	Number of characters decoded.
3.	Error Correction	Level of error correction detected.
4.	Scanner or Camera	Camera or scanner number.
5.	Time	Records the exact time that the code was read.
6.	Date	Records the exact date that the code read.
7.	Mismatch	Number of characters mismatched.
8.	Read Data	Actual data string decoded.

6.0 METHODOLOGY

The methodology included preparation of the symbol samples, preliminary testing of components, a system check, and pilot testing prior to the actual test. Each activity tested and verified the components and operation of the system.

6.1 Symbol Preparation

Symbols were printed in the Center for Automatic Identification. All symbols were printed on a thermal transfer printer under controlled conditions. A total of 1080 symbols were printed for both Datamatrix and PDF417 symbologies; 1100 symbols were printed for Code 39. Data encoded in the symbols was alphanumeric and was randomly generated by a computer program written in C language.

Datamatrix and PDF417 symbologies had 3 different error correction levels, High, medium, and null. Code 39 symbols were printed with and without check digits. Data encoded in Datamatrix and PDF417 included 50, 100, 250, and 350 characters per symbol. Data for Code 39 included 12, 15, and 18 characters per symbol. Table 2 shows the specific formats used for each symbology.

Each test symbol was assigned a unique identification number matching that of its specific carrier sheet number for 100% traceability during the test. The labels were visually checked and then verified that they were readable and had the proper data encoded. Selected symbol samples are shown in Appendix B.

Table 2 Data count and error correction levels for printed symbols

DataMatrix Total Symbols : 1080			
Number of Characters	Error Correction Level (ECC)		
	0	50	80
50	200	200	200
100	100	100	100
250	40	40	40
350	30	30	n/a

PDF417 Total Symbols : 1080			
Number of Characters	Error Correction Level (ECC)		
	0	3	5
50	200	200	200
100	100	100	100
250	40	40	40
350	30	30	n/a

Table 2 (continued) Data count and error correction levels for printed symbols

Code 39 Total Symbols : 1100		
Number of Characters	Check Character	
	With	Without
12	220	220
15	180	180
18	150	150

Preliminary testing was done between December 1992 and mid-January 1993. As a result of the preliminary test, minor changes were made to the control software. Optimal settings within the manufacturer's stated values were determined for the scanners and cameras. Sixty to one hundred symbols were produced for each pilot test.

Two pilot tests were conducted during this period. These tests confirmed the reliability of the test apparatus, robot, scanners, decoders, control programs, reference database and dynamic test database. This test allowed for the major debugging of the control software and data acquisition software. Minor changes were made to the data acquisition and control programs. Optimal timing for the scanners was determined and changed in the control program. The number of characters read in each pilot test is included in the table 3 below.

Table 3 Characters read in the test.

	Datamatrix	PDF417	Code 39
Pilot Test 1	1,000,350	2,500,000	2,500,000
Pilot Test 2	2,500,000	2,500,000	0

6.2 Actual Test Procedure

The actual test was conducted from mid-January 1993 through April 1993. Testing was divided into three phases: Datamatrix, PDF417, and Code 39. In a typical test sequence, a batch of 60 symbols were loaded into the magazine. The host computer then initialized the robot, the index table, and it cleaned all communication buffers.

The robot picked up a symbol carrier from the top of the magazine and positioned it under the fixed ID scanner beam for symbol identification and database validation. If the symbol sample was identified as valid record in the database, the computer would indicate to the robot the next required motion to place the carrier with the proper orientation over the rotary turntable. The rotary table was indexed one location (60 degrees) which placed the sample symbol at the first scanning position. At this point, the scanning process began.

The control software automatically triggered the cameras or scanners. Datamatrix and PDF417 symbols were scanned a total of 24 times at this station. After the symbol was read 24 times, the rotary table was indexed one location. The robot picked up the next symbol sample from the top of the magazine and, after symbol identification and database validation, placed it on the next platform. Indexing the rotary table one location, placed this new symbol sample under the first scanning station. Upon completing 24 reads, the above sequence repeated placing a third symbol sample under the first scanning station. At the same time, this placed the first symbol sample under the second scanning station. At this station, the symbols were read an additional 24 times. After the symbol sample was read 24 times at the second scanning station, the rotary table indexed one location to allow the robot unload the carrier from the rotary table and dispense it to a discharge magazine. This sequence was repeated until the magazine was empty. All symbol samples were fed into the system 6 times for a total of 288 reads.

Due to the smaller amount of data encoded in each Code 39 symbols, each symbol was read a total of 164 times at each scanning station. Each symbol sample was fed 6 times in the system for a total of 1968 reads.

7.0 RESULTS

A total of 94,318,020 characters were read during the actual test. The number of characters read from Datamatrix symbols was 31,439,087 characters; 31,439,907 from PDF417; and 31,439,026 from Code 39.

An anomaly occurred and was recorded whenever the decoded data did not match the encoded data for a given symbol. All anomalies were investigated to determine their cause. Most of the anomalies were caused by communications and/or data buffering problems in the control program or ID label/symbol mismatches. If a reason could not be determined and assigned to the anomaly it was considered to be an error. A total of 417 anomalies were observed for Datamatrix, 138 for PDF417, and 435 for Code 39. Tables summarizing the anomalies and their causes are included in Appendix D. The correctable problems which caused anomalies were corrected as they were discovered.

Thirty six of the PDF417 anomalies were caused by a bug in the decode algorithm used in the PDF-1000 decoder. The problem was apparently caused by the application of the wrong decode algorithm (Codabar) to the PDF417 symbology. Upon notification of the problem, Symbol Technologies, Inc. made appropriate corrections and provided new decoder chips for the decoders. However, the test was carried to conclusion using the original decoders and no other anomalies of this nature occurred.

A separate post test was conducted in an attempt to ascertain if the problem was repeatable using the new decoders. A total of 20,005,650 characters were correctly read from the 4 symbols which had previously produced the anomaly. No further anomalies were observed during this post test. Analysis of data from this post tests strongly supports the notion that the PDF417 decode algorithm problem was truly a bug which has since been corrected.

Eleven errors were observed in the Code 39 portion of the test. A detailed analysis of the data showed that all 11 errors occurred randomly within a specific time period and on one specific symbol. The character "Z" was erroneously decoded as a "$." This same symbol was correctly read at all other times during the test.

In an additional post test, an attempt was made to replicate the errors that had been observed on that particular symbol. An additional 1,746,000 characters were read from that symbol and no anomalies were observed. The character substitution was not repeated during the post test. Detailed analysis of the data from the Code 39 portion of the test and this post test supports the notion that the character substitutions were an isolated and unexplainable occurrence.

There was a total of 11 unexplained symbology errors, all incurring in Code 39. No errors were observed in Datamatrix or PDF417. "No reads" were recorded and the numbers are summarized in Appendix D. A "no read" was not considered to be an anomaly or an error. There were no short reads or partial decodes. Table 4 shows the relevant data for the test. A listing of each error detected during the actual test is presented in Appendix E.

Table 4 Test Data

	Datamatrix	PDF417	Code 39	Total
Symbols Used	1080	1080	1100	3260
Characters Decoded	31,439.089	31,439,907	31,439,026	94,318,020
Errors Observed	0	0	11	

8.0 ANALYSIS OF DATA

The error data and associated sample sizes were analyzed in two primary ways. One method of evaluating the data was to compute chi-square values in order to determine if observed differences were statistically significant. The other method was to calculate a confidence interval for each of the bar code symbologies using the binomial distribution.

8.1 Hypothesis Test

The null hypothesis for the test was $H_0{:}\mu 1=\mu 2=\mu 3$. The alternative hypothesis was $H_a{:}\mu 1\neq\mu 2\neq\mu 3$. The confidence interval for the test was stated at 95% or an alpha error of .05 for a two tailed test. Beta error was set at .05. Based on the formulae shown in section 4.3.1 of this report, Equations Size, it was noted that if either Datamatrix or

PDF417 had less than 22 data character substitution errors out of 31,438,998 characters read the symbology could be assumed to have one error or less in two million. Errors observed in Datamatrix or PDF417 were zero, and in Code 39 eleven.

Statistical analysis included a Chi-Square test of difference to determine if the observed errors could be attributed to chance alone or were statistically significant. Chi-Square values were calculated for each symbology using the observed error rate values. Table 5 shows the computed Chi-Square values.

The computed Chi-Square values support the alternate hypothesis; i.e. symbology error rates are considered statistically different, not due to chance (χ^2=22.00033, p(1.70E-5), df=2). Stated simply, error substitution rates are not the same for all symbologies tested.

Table 5. Symbology statistical tests -- using chi-square methods

Symbology	N Number of Characters	Observed Number of Errors	Expected*	(O-E)^2/E
Datamatrix	31,439,087	0	3.66664	3.66664
PDF417	31,439,907	0	3.66673	3.66673
Code 39	31,439,026	11	3.66663	14.666696
Total	94,318,020	11	x2	22.00033
			df=2 p=	0.000017

*Assumed constant failure rate of P(e)=11/94,318,020

Conclusion: Significant difference between symbologies

8.2 Confidence Interval Analysis

A confidence interval is an estimator that expected results will be enclosed within the specified distribution a specific percentage of the time. Table 6 shows the confidence intervals at 95% that were computed from the test data for each symbology.

Table 6. Computed Confidence Intervals

Symbology	Worst Case (95%)	Best Case (95%)
Datamatrix	1 /10,494,626	1 / 612,927,799
PDF417	1 / 10,494,899	1 / 612,943,816
Code 39	1 / 1,726,706	1 / 4,540,448

The most conservative estimation of error rates is based on the data computed and based on 95% certainty. The character substitution rate for Datamatrix was computed to be no worse than one error in 10,494,626 characters scanned and decoded. Conversely, one cannot assume (with 95% certainty) that Datamatrix is much better that 1 error in

612,927,799 characters scanned and decoded. Similarly the character substitution rate for PDF417 was computed to be no worse than one error in 10,494,899 characters scanned and decoded for the worse case and 1 error in 612,943,816 characters scanned and decoded for the best case. The same statement can be made for Code 39 substituting the appropriate respective values from Table 6.

9.0 CONCLUSION

No character substitution errors were observed in the Datamatrix or PDF417 symbologies. All errors detected in this test occurred in Code 39 and were the result of character substitution errors. None of the errors were short reads. Based on the results of this test, it can be concluded that the selected bar code and matrix code symbologies are robust in their ability to be read with minimal errors. For purposes of general use Table 7 projects expected error rates for the symbologies tested.

Table 7 Generalized Error Rates

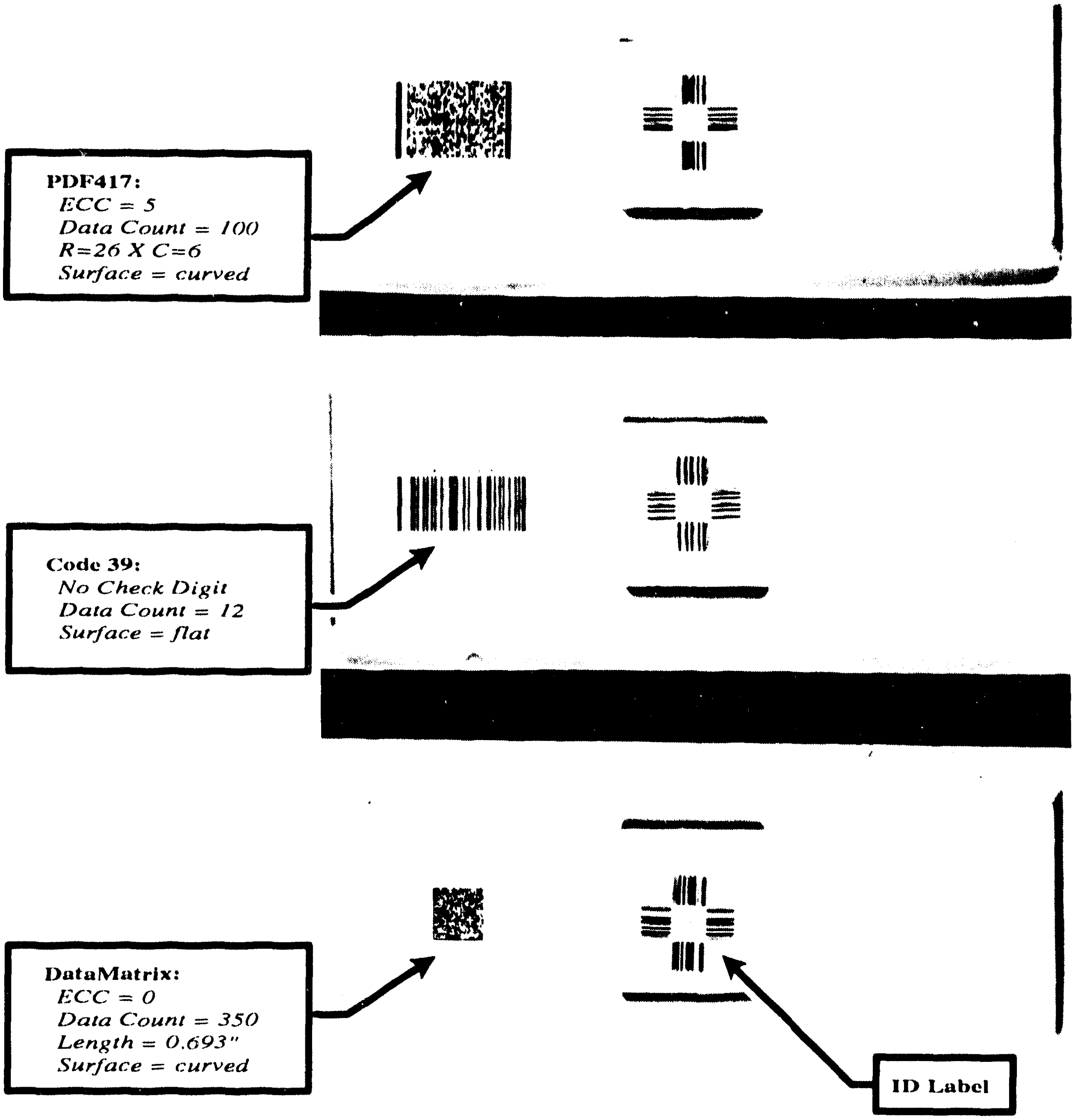
Symbology	Worst Case (95%)	Best Case (95%)
Datamatrix	1 error in 10.5 million	1 error in 613 million
PDF417	1 error in 10.5 million	1 error in 613 million
Code 39	1 error in 1.7 million	1 error in 4.5 million

10.0 SUMMARY

This test of selected coding symbologies was conducted under uniform controlled circumstances. The intent was to determine if Datamatrix and PDF417 were at least as reliable as selected symbologies which had been previously tested. The test standard was one error in two million characters. Automated scanning and decoding of approximately 1,100 symbols of each of the selected symbologies yielded a total of 94,318,020 bar code characters read. There were no observed errors for Datamatrix and PDF417 and minimal errors for the Code 39. Statistical analysis of the data indicate that users could expect error rates better than one in 10,000,000 when using Datamatrix or PDF417 symbologies to encode data and decode data.

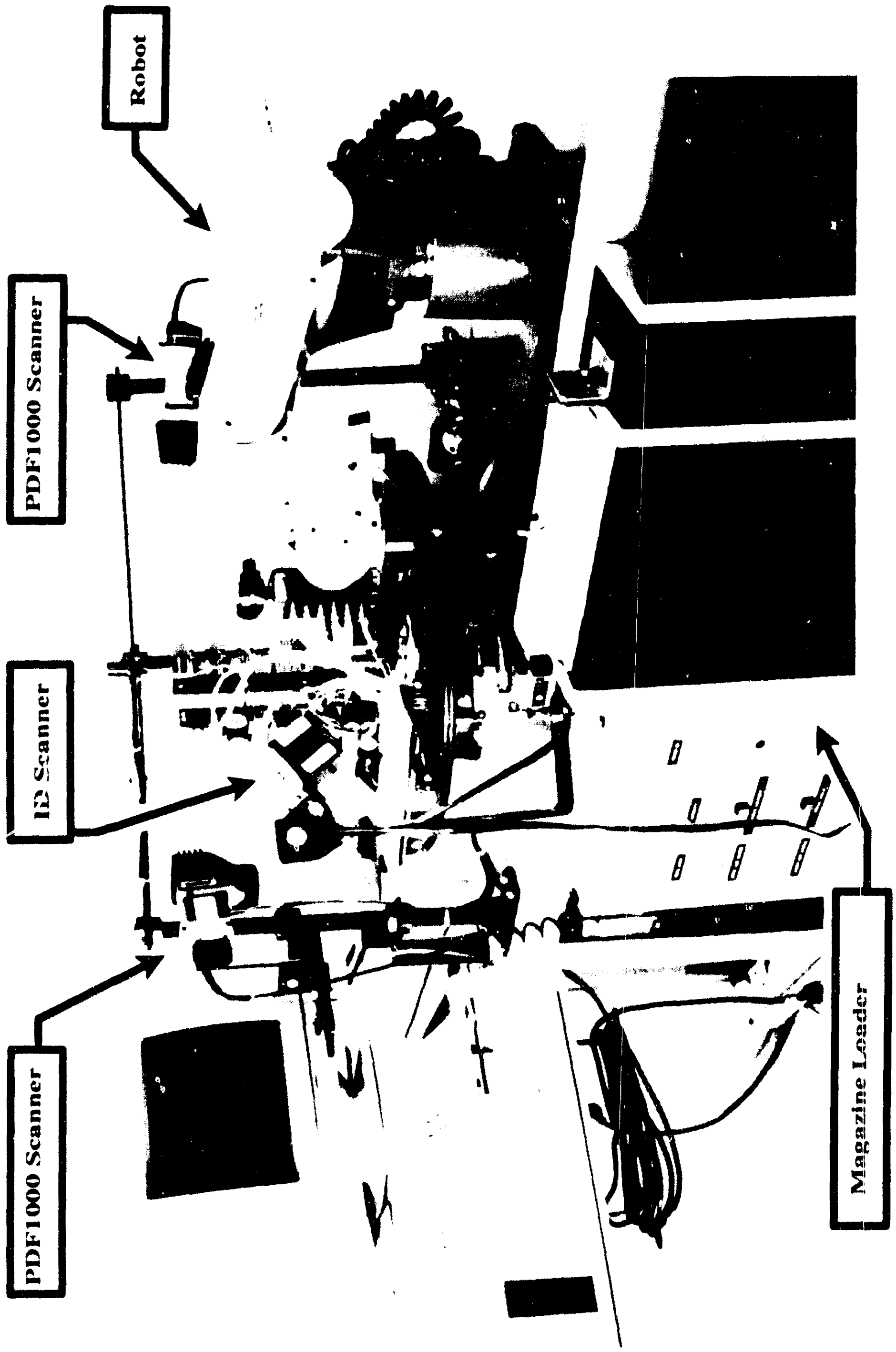
APPENDIX A

Test Apparatus

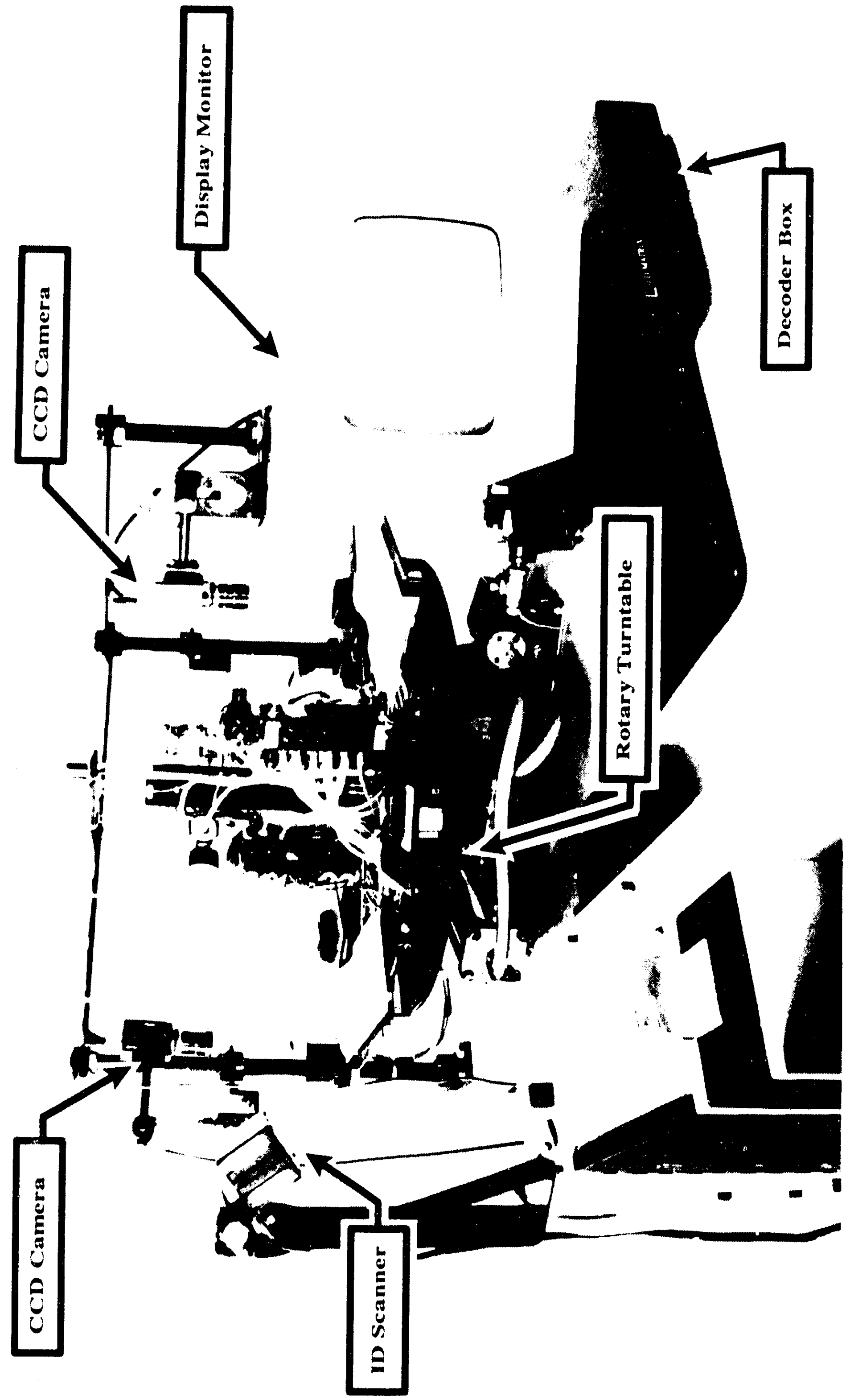


Selected Symbol Samples as Mounted on Carrier Sheets

A-1



General Arrangement of PDF417 Test Apparatus A-2



General Arrangement of Data Matrix Test Apparatus
(robot removed for clarity)

A-3

APPENDIX B

Representative Symbol Samples

Data Matrix
Representative Symbol Samples

Characters Encoded: 50
Error Correction Level: 0

Characters Encoded: 100
Error Correction Level: 0

Characters Encoded: 250
Error Correction Level: 0

Characters Encoded; 350
Error Correction Level: 0

Data Matrix
Representative Symbol Samples

Characters Encoded: 50
Error Correction Level: 50

Characters Encoded: 100
Error Correction Level: 50

Characters Encoded: 250
Error Correction Level 50

Characters Encoded; 350
Error Correction Level: 50

Data Matrix
Representative Symbol Samples

Characters Encoded: 50
Error Correction Level: 80

Characters Encoded: 100
Error Correction Level: 80

Characters Encoded: 250
Error Correction Level: 80

PDF417
Representative Symbol Samples

408 C

Characters Encoded: 50
Error Correction Level: 0

411 F

Characters Encoded: 100
Error Correction Level: 0

414 C

Characters Encoded: 250
Error Correction Level: 0

417 F

Characters Encoded; 350
Error Correction Level: 0

PDF417
Representative Symbol Samples

425 F

Characters Encoded: 50
Error Correction Level: 3

424 C

Characters Encoded: 100
Error Correction Level: 3

423 F

Characters Encoded: 250
Error Correction Level: 3

422 C

Characters Encoded; 350
Error Correction Level: 3

PDF417
Representative Symbol Samples

410 C

Characters Encoded: 50
Error Correction Level: 5

413 F

Characters Encoded: 100
Error Correction Level: 5

416 C

Characters Encoded: 250
Error Correction Level: 5

421 F

Characters Encoded; 350
Error Correction Level: 5

Code 39
Representative Symbol Samples

1128 C

8TOWHER5KFR36

Characters Encoded: 12
Check Digit: Yes

1129 F

PPW58RM2KV3C

Characters Encoded: 12
Check Digit: No

1126 C

L8WZHZ6WCV61JFZ4

Characters Encoded: 15
Check Digit: Yes

1127 F

9KKGNI1S3SCRZZD

Characters Encoded: 15
Check Digit: No

Code 39
Representative Symbol Samples

1123 F

TYEDAW0QUTUZSIBEZ46

Characters Encoded: 18
Check Digit: Yes

1124 C

520EUJL684A3MAXOSH

Characters Encoded: 18
Check Digit: No

APPENDIX C

Description of Scanners, Cameras, and Decoders

Equipment	Model	Serial Number	Date Manufactured	Tilt (degrees)	Depth of Field (cm)
CCD Camera 1	Pulnix TM-7 50 mm	003025	not available	0	61.1
CCD Camera 2	Pulnix TM-7 50 mm	003028	not available	0	61.7
DataMatrix Decoder	302-S-2F	000920046243	not available	n/a	n/a
Black/White Monitor	Sony SSM-920	131800	Nov-91	n/a	n/a
PDF1000 Scanner 1	PDF1000-1000A	A670516	Dec-92	15 back from surface	40.5
PDF1000 Scanner 2	PDF1000-1000A	A670487	Dec-92	15 back from surface	40.5
PDF1000 Decoder 1	PL-140-1000A	A452809	May-92	n/a	n/a
PDF1000 Decoder 2	PL-140-1000A	A452794	May-92	n/a	n/a

DataMatrix Decoder setup

1. Baud Rate : 9600
2. Parity : Even
3. Data bits : 7
4. Stop bits : 1
5. Full Duplex
6. Hardware_Flow_Control
7. Inter_Char_Delay : 0
8. Reader Resolution : RS170 96 bytes per line
9. Black White Threshold : 470
10. Quiet Zone : DC_43_20_17_10_2

PDF1000 Decoder setup

1. Baud Rate : 9600
2. Parity : Even
3. Data bits : 7
4. Stop bits : 1
5. Autodiscrimination : Enabled
6. Autoraster : Enabled
7. Beep after good decode : Disabled

APPENDIX D

Summarized Test Data

Summary Test Results

		DataMatrix		PDF417		Code 39		
		Characters Read	Errors	Characters Read	Errors	Characters Read	Errors	
Error Correction	None	11,664,000	0	11,664,000	0	15,822,720	0	NoCheck
	Medium	11,664,000	0	11,664,000	0	n/a	n/a	
	High	8,640,000	0	8,640,000	0	15,822,720	11	Check
Character Count								
DataMatrix	50	8,640,000	0					
	100	8,640,000	0					
	250	8,640,000	0					
	350	6,048,000	0					
PDF417	50			8,640,000	0			
	100			8,640,000	0			
	250			8,640,000	0			
	350			6,048,000	0			
Code 39	12					10,391,040	11	
	15					10,627,200	0	
	18					10,627,200	0	
Surface	Flat	15,984,000	0	15,984,000	0	15,822,720	11	
	Curved	15,984,000	0	15,984,000	0	15,822,720	0	
Camera/Scanner	1	15,984,000	0	15,984,000	0	15,822,720	11	
	2	15,984,000	0	15,984,000	0	15,822,720	0	

Observed Anomalies Classified by Variable

		DataMatrix		PDF417		Code 39		
		Characters Read	Anomalies	Characters Read	Anomalies	Characters Read	Anomalies	
Error Correction	None	11,664,000	186	11,664,000	24	15,822,720	392	NoCheck
	Medium	11,664,000	49	11,664,000	86	n/a	n/a	
	High	8,640,000	182	8,640,000	28	15,822,720	43	Check
Character Count								
DataMatrix	50	8,640,000	223		45			
	100	8,640,000	50		83			
	250	8,640,000	104		10			
	350	6,048,000	40		0			
PDF417	50			8,640,000	0			
	100			8,640,000	0			
	250			8,640,000	0			
	350			6,048,000	0			
Code 39	12					10,391,040	372	
	15					10,627,200	16	
	18					10,627,200	47	
Surface	Flat	15,984,000	253	15,984,000	116	15,822,720	391	
	Curved	15,984,000	164	15,984,000	22	15,822,720	44	
Camera/Scanner	1	15,984,000	121	15,984,000	84	15,822,720	216	
	2	15,984,000	296	15,984,000	54	15,822,720	219	

Summaries of No-reads and Anomalies by symbology, no. characters, and error correction level.

DataMatrix

No-reads	Error Correction Level		
Number of Characters	0	50	80
50	4966	1649	2916
100	1829	895	1246
250	1351	0	1878
350	2456	3362	n/a

Anomalies	Error Correction Level		
Number of Characters	0	50	80
50	97	26	100
100	25	3	22
250	40	4	60
350	24	16	0

PDF417

No-reads	Error Correction Level		
Number of Characters	0	3	5
50	443	423	148
100	520	265	314
250	1148	507	841
350	1582	467	n/a

Anomalies	Error Correction Level		
Number of Characters	0	3	5
50	10	11	24
100	4	75	4
250	10	0	0
350	0	0	0

Code 39

No-reads	Check Digit	
Number of Characters	Yes	No
12	1626	2493
15	621	859
18	1979	4088

Anomalies	Check Digit	
Number of Characters	Yes	No
12	4	368
15	16	0
18	23	24

No-reads and Anomalies by camera/scanner number and shape type

DataMatrix	
No-reads / flat	8919
No-reads / curved	13629
Anomalies / flat	164
Anomalies / curved	253
No-reads / Camera 1	10967
No-reads / Camera 2	11581
Anomalies / Camera 1	121
Anomalies / Camera 2	296

Total No-reads	22,548
Total Anomalies	417
Communication/Buffering	89
ID Label/Symbol mismatch	328

PDF417	
No-reads / flat	1559
No-reads / curved	5099
Anomalies / flat	116
Anomalies / curved	22
No-reads / Scanner 1	2149
No-reads / Scanner 2	4509
Anomalies / Scanner 1	84
Anomalies / Scanner 2	54

Total No-reads	6,658
Total Anomalies	138
Communication Problems	8
ID Label/Symbol mismatch	94
Decoding Algorithm	36

Code 39	
No-reads / flat	4720
No-reads / curved	6946
Anomalies / flat	391
Anomalies / curved	44
No-reads / Scanner 1	7998
No-reads / Scanner 2	3668
Anomalies / Scanner 1	216
Anomalies / Scanner 2	219

Total No-reads	11,666
Total Anomalies	435
Communication Problems	26
ID Label/Symbol mismatch	398
Decoding Algorithm	0
Unexplainable	11

Anomalies by explanation and camera location

DataMatrix

ID label/Symbol index mismatch		Decoding Algorithm	
Camera 1	85	Camera 1	0
Camera 2	243	Camera 2	0
Communications/Buffer		**Substitution Errors**	
Camera 1	36	Camera 1	0
Camera 2	53	Camera 2	0
		Total	**417**

PDF417

ID label/Symbol index mismatch		Decoding Algorithm	
Scanner 1	69	Scanner 1	20
Scanner 2	25	Scanner 2	16
Communications/Buffer		**Substitution Errors**	
Scanner 1	1	Scanner 1	0
Scanner 2	7	Scanner 2	0
		Total	**138**

Code 39

ID label/Symbol index mismatch		Decoding Algorithm	
Scanner 1	205	Scanner 1	0
Scanner 2	193	Scanner 2	0
Communications/Buffer		**Substitution Errors**	
Scanner 1	24	Scanner 1	11
Scanner 2	2	Scanner 2	0
		Total	**435**

Datamatrix and PDF417 Data Integrity Test: Final Results

	DATAMATRIX	PDF417	CODE 39
Pilot Test 1	1,000,350	2,500,000	2,500,000
Pilot Test 2	2,500,000	2,500,000	n/a
Test	31,439,087	31,439,907	31,439,026
Anomalies	417	138	435
Explainable	417	138	424
Post test	3,083,300	10,000,050	1,746,000
Post test	n/a	10,005,600	n/a
Anomalies	0	0	0
Explainable	n/a	n/a	n/a
Total Errors	0	0	11

APPENDIX E

Error Listing

Error Summary

Symbology	Characters Read	Anomalies	Explainable Anomalies: Misplaced Label	Communication/Buffer	Decoder	Errors
DataMatrix	31,439,087	417	366	51	0	0
PDF417	31,439,907	138	56	49	33	0
Code 39	31,439,026	435	419	5	0	11

Detailed Error Listing

The following is a list of the 11 Code 39 anomalies that were not explainable and therefore were classified as character substitution errors. All eleven errors were observed from one symbol. The original specification for the symbol is:

ID number: 307 - ***flat surface***
Number of Characters: 13
Error Correction Level : 89(indicates check character encoded)
Encoded Data: 7K179HQL3EZF3

Error Listing

ID number: 307
No. of characters: 13
Error correction level: 89
Camera no.: 1
Date:03/30/93
Time:01:06:40
No. of caharacters mismatched = 1 chars
Actual decoded data 7K179HQL3E$F3

ID number: 307
No. of characters: 13
Error correction level: 89
Camera no.: 1
Date:03/30/93
Time:01:06:46
No. of caharacters mismatched = 1 chars
Actual decoded data 7K179HQL3E$F3

ID number: 307
No. of characters: 13
Error correction level: 89
Camera no.: 1
Date:03/30/93
Time:01:06:54
No. of caharacters mismatched = 1 chars
Actual decoded data 7K179HQL3E$F3

ID number: 307
No. of characters: 13
Error correction level: 89
Camera no.: 1
Date:03/30/93
Time:01:07:14
No. of caharacters mismatched = 1 chars
Actual decoded data 7K179HQL3E$F3

ID number: 307
No. of characters: 13
Error correction level: 89
Camera no.: 1
Date:03/30/93
Time:01:07:26
No. of caharacters mismatched = 1 chars
Actual decoded data 7K179HQL3E$F3

ID number: 307
No. of characters: 13
Error correction level: 89
Camera no.: 1
Date:03/30/93
Time:01:07:44
No. of caharacters mismatched = 1 chars
Actual decoded data 7K179HQL3E$F3

ID number: 307
No. of characters: 13
Error correction level: 89
Camera no.: 1
Date:03/30/93
Time:01:07:50
No. of caharacters mismatched = 1 chars
Actual decoded data 7K179HQL3E$F3

ID number: 307
No. of characters: 13
Error correction level: 89
Camera no.: 1
Date:03/30/93
Time:01:08:17
No. of caharacters mismatched = 1 chars
Actual decoded data 7K179HQL3E$F3

ID number: 307
No. of characters: 13
Error correction level: 89
Camera no.: 1
Date:03/30/93
Time:01:08:25
No. of caharacters mismatched = 1 chars
Actual decoded data 7K179HQL3E$F3

ID number: 307
No. of characters: 13
Error correction level: 89
Camera no.: 1
Date:03/30/93
Time:01:08:54
No. of caharacters mismatched = 1 chars
Actual decoded data 7K179HQL3E$F3

Index: 307
No. of characters: 13
Error correction level: 89
Camera no.: 1
Date:03/30/93
Time:01:09:04
No. of caharacters mismatched = 1 chars
Actual decoded data 7K179HQL3E$F3

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