



Technical Bulletin #4 Encryption Guidelines and Algorithms for State Use

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This technical bulletin supplements information in Appendices A and B to 45 CFR 1355 on assigning record numbers to detailed foster care and adoption data submitted to the Administration for Children and Families (ACF). This bulletin provides States with guidance in encrypting record numbers in the State data file submissions.

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I. GENERAL INFORMATION

A. Background

To protect confidentiality when reporting detailed data to AFCARS, States are required to assign a sequential number or a unique number which follows the child as long as he or she is in foster care and use a sequential or encrypted record number for reporting adoptions.² This record number (foster care data element #4 and adoption data element #5) must be a twelve digit number that cannot be linked to the child except at the State or local level. For purposes of the Federal child and family services reviews and the title IV-E foster care eligibility reviews³, States must be able to identify the case file for a specific record for up to three years after the end of the report period.

States may:

- generate a **sequential** record number for each child in the submission. The sequencing must begin with '000000000001' having each additional record incremented by 1. Since children may be represented by different sequential numbers for different reporting periods, States must maintain cross reference files for each bi-annual submission to cross walk assigned sequential numbers back to the appropriate case files; or,
- **encrypt** the case number for each child in the submission by applying a mathematical formula to the child's case number. States can match the encrypted case number to the original case number by applying the reverse mathematical formula. Confidentiality is maintained by using a mathematical formula that can be identified only by the State transferring data.

While States may use either sequential numbering or encrypting, ACF encourages States to use encryption. Using this method makes it easier for States to cross reference files for the identification of case record numbers at a later date. Also, States are encouraged to use the same case record number for a child each time the child enters and exits foster care, or receives services. This, combined with the use of the same "key", allows the State and ACF to develop cohort information and an annual database by matching records submitted for each of the report periods in a fiscal year. This is especially important in regard to the new child and family services review and the statewide assessment. The statewide assessment includes AFCARS data from the three most recent and available Federal Fiscal Years.

This bulletin provides information on encrypting case numbers. For information regarding the use of the AFCARS Encryption/Decryption Utility supplied by ACF for State use, see *Technical Bulletin #5, AFCARS Encryption/Decryption Utility: C Version 2.0*.

States may either use the methods outlined in this document to encrypt record numbers or may develop their own algorithms. However, all methods must adhere to the following guidelines:

² See 45 CFR 1355, Appendix A Section II.I.D. and Appendix B, Section II.I.C.

³ See 45 CFR 1355.31-37, and 1356.71.

Guidelines

- Each AFCARS record number must be unique.
- The method selected must give the same result every time the procedure is executed. In other words, a client ID must always yield the same encrypted AFCARS record number after processing.
- To enhance security, the encryption method should apply a minimum of two different algorithms to the record numbers.
- Federal auditing standards require that the States be able to reverse the process and determine the original client ID for any AFCARS record number. The State must maintain any algorithms, tables, and keys used to generate the unique ID. Avoid functions and algorithms that, when reversed, can return more than one value. For example:
 - functions such as $x=y^2$ should be used with care as the inverse (the $\sqrt{\quad}$) can yield two results. For example, $\sqrt{4} = 2$ or -2 . (In this the user may want to specify $|\sqrt{\quad}|$.)
 - avoid algorithms that involve rounding since the result of two different operations may be rounded to the same number. For example:
 - 8888/47 = 189.106 :rounded to 189
 - 8889/47 = 189.127 :rounded to 189
- The method of encryption must be kept secure by the State. Only authorized personnel should have access to it.
- The AFCARS record number, as cited in *Technical Bulletin #2, AFCARS File Format*, must be right justified and padded with zeros to fill out the 12 character field.
- Every character in the State client ID should be transformed.
- Any of the characters in the ASCII character set may be used except:
 - control characters (ASCII codes 0 through 31). Control characters are excluded to prevent errors during ACF processing and parsing of the file.
 - ASCII characters 35 (#), 36 (\$), 37 (%), and 64 (@). These characters are reserved as file identifiers, as indicated in the revised *Technical Bulletin #2, AFCARS File Format*.
- Each encrypted number must be scanned to ensure that the ASCII control characters (0-31) and ASCII characters 35, 36, 37, and 64 are not being used.

Instructions and Methods

AFCARS record numbers may be encrypted using a variety of methods. In the following three sections, we will introduce algorithms States may select from to encrypt record numbers:

- Substitution
- Transposition
- Bit-level operations

II. SUBSTITUTION METHOD

A. Introduction

In this method of encryption, each digit in the ID is replaced by another digit generated through an algorithm. To see how this type of encryption is accomplished, consider the following number line:

$$\begin{array}{c}
 0 \ 1 \ 2 \ 3 \ 4 \ 5 \ 6 \ 7 \ 8 \ 9 \\
 L \longleftarrow \hspace{10em} \longrightarrow R
 \end{array}$$

A very simple encryption is accomplished by substituting each digit with the digit found 4 positions to the left on the number line. If the count of 4 extends beyond the number line, circle around and continue counting. By applying this rule, 1234 becomes 7890. *Please note that this example is for illustration purposes only. It is not sufficiently complex for encrypting the State client ID.*

The following substitution models (sections II.B.-II.F.) are appropriate for encrypting State client IDs. However, if one of these substitution methods is chosen, the State should develop its own rules for substituting one digit for another. Please do not use the examples given as the substitution scheme for State encryption rules.

B. Unique digit substitution

Apply a different substitution rule for each digit. For example, 1234 is encrypted as 6493 using the number line and the following table of rules:

$$\begin{array}{c}
 0 \ 1 \ 2 \ 3 \ 4 \ 5 \ 6 \ 7 \ 8 \ 9 \\
 L \longleftarrow \hspace{10em} \longrightarrow R
 \end{array}$$

1 st digit left:	5 positions
2 nd digit right:	2 positions
3 rd digit right:	6 positions
4 th digit left:	1 position

- On the number line, locate 1 and move five positions to the left to get 6.
 On the number line, locate 2 and move two positions to the right to get 4.
 On the number line, locate 3 and move six positions to the right to get 9.
 On the number line, locate 4 and move one position to the left to get 3.

C. Variable length substitution

If the client ID length is variable, different rules can be applied based on the number of digits in the ID. For example, if the State's client ID can vary from 6 to 9 digits, the following table of rules could be applied:

Number of digits in State ID	Shifting Pattern
6	1 st digit right: 3 positions 2 nd digit right: 5 positions 3 rd digit left: 3 positions 4 th digit right: 7 positions 5 th digit left: 1 position 6 th digit left: 4 positions
7	1 st digit left: 6 positions 2 nd digit right: 4 positions 3 rd digit left: 2 positions 4 th digit left: 8 positions 5 th digit left: 3 positions 6 th digit left: 9 positions 7 th digit left: 2 positions
8	1 st digit right: 1 position 2 nd digit left: 3 positions 3 rd digit left: 2 positions 4 th digit right: 4 positions 5 th digit left: 8 positions 6 th digit right: 9 positions 7 th digit left: 3 positions 8 th digit right: 9 positions
9	1 st digit left: 7 positions 2 nd digit left: 4 positions 3 rd digit left: 2 positions 4 th digit right: 9 positions 5 th digit left: 9 positions 6 th digit left: 2 positions 7 th digit right: 4 positions 8 th digit left: 5 positions 9 th digit right: 9 positions

D. Substitution with shuffled digits

Use a number line with shuffled digits. For example, 1234 is encrypted as 6361 using the following number line and table of rules:

6 9 2 8 3 1 4 0 5 7
L <-----> R

1 st digit left:	5 positions
2 nd digit right:	2 positions
3 rd digit right:	6 positions
4 th digit left:	1 position

- On the number line, locate 1 and move five positions to the left to get 6.
- On the number line, locate 2 and move two positions to the right to get 3.
- On the number line, locate 3 and move six positions to the right to get 6.
- On the number line, locate 4 and move one position to the left to get 1.

E. Substitution with an alphanumeric line

Increase the substitution possibilities by using a line that includes both the alphabet as well as digits. 1234 is encrypted as I4PI using the following alphanumeric line and table of rules:

A B C D E F G H I J K L 0 1 2 3 4 5 6 7 8 9 M N O P Q R S T U V W X Y Z
L <-----> R

1 st digit left:	5 positions
2 nd digit right:	2 positions
3 rd digit right:	10 positions
4 th digit left:	8 positions

- On the number line, locate 1 and move five positions to the left to get I.
- On the number line, locate 2 and move two positions to the right to get 4.
- On the number line, locate 3 and move six positions to the right to get P.
- On the number line, locate 4 and move one position to the left to get I.

F. Key-driven substitution

A key can be used to drive the substitution algorithm. The key determines the number of positions to shift the characters of the ID. The selected key should be as long as the longest ID that exists. Each character of the key will correspond to one character of the ID.

The following example uses an algorithm that shifts every digit X positions to the right, where X is the alphabetic position of the corresponding letter of the key (i.e. A = 1, B = 2, C = 3, D = 4, E = 5, etc.). If the number 123456789 is to be encrypted and the key is TRANSFORM, the resulting ID is YX4UBOZDZ using the alphanumeric line and table shown below:

A B C D E F G H I J K L 0 1 2 3 4 5 6 7 8 9 M N O P Q R S T U V W X Y Z
 L <-----> R

A=1	N=14
B=2	O=15
C=3	P=16
D=4	Q=17
E=5	R=18
F=6	S=19
G=7	T=20
H=8	U=21
I=9	V=22
J=10	W=23
K=11	X=24
L=12	Y=25
M=13	Z=26

- On the number, locate 1 and move (T= 20) positions to the right to get Y.
- On the number, locate 2 and move (R= 18) positions to the right to get X.
- On the number, locate 3 and move (A= 1) position to the right to get 4.
- On the number, locate 4 and move (N= 14) positions to the right to get U.
- On the number, locate 5 and move (S= 19) positions to the right to get B.
- On the number, locate 6 and move (F= 6) positions to the right to get O.
- On the number, locate 7 and move (O= 15) positions to the right to get Z.
- On the number, locate 8 and move (R= 18) positions to the right to get D.
- On the number, locate 9 and move (M= 13) positions to the right to get Z.

III. TRANSPOSITION METHOD

A. Introduction

In this method of encryption, the positioning of the digits is changed. For example, 1234567 becomes 7234561 if the first and last digits are transposed. *Please note that this example is for illustration purposes only. It is not sufficiently complex for encrypting the State client ID.*

The following models (sections III.B. - III.C.) are appropriate for encrypting State client IDs.

B. Transposition of digit pairs

Transpose all digits in the ID. For example, 1234567 becomes 4657321, by applying the following rules:

Transpose the 1st and 7th digits
 Transpose the 2nd and 6th digits
 Transpose the 3rd and 5th digits
 Transpose the 1st and 4th digits

In the first transposition, 1 and 7 are switched to produce the number: 7234561.

In the second transposition, 2 and 6 are switched to produce the number: 7634521.

In the third transposition, 3 and 5 are switched to produce the number: 7654321.

In the fourth transposition, 7 and 4 are switched to produce the number: 4657321.

C. Transposition with shuffled digits

Rather than follow a straight transposition scheme, shuffle all digits. For example, 1234567 becomes 4715326 when applying the following rules:

1st digit to 3rd position
 2nd digit to 6th position
 3rd digit to 5th position
 4th digit to 1st position
 5th digit to 4th position
 6th digit to 7th position
 7th digit to 2nd position

In the first transposition, 1 will be in the third position: -- 1 - - - - .

In the second transposition, 2 will be in the sixth position: -- 1 - - 2 - .

In the third transposition, 3 will be in the fifth position: -- 1 - 3 2 - .

In the fourth transposition, 4 will be in the first position: 4 - 1 - 3 2 - .

In the fifth transposition, 5 will be in the fourth position: 4 - 1 5 3 2 - .

In the sixth transposition, 6 will be in the seventh position: 4 - 1 5 3 2 6 .

In the seventh transposition, 7 will be in the second position: 4 7 1 5 3 2 6 .

IV. BIT-LEVEL OPERATIONS

A. Introduction

State Case ID's can be encrypted by transforming the characters at the bit level to other characters in the ASCII data set. However, it is important to remember that ASCII control characters (0-31) and characters 35, 36, 37, and 64 must not be used. Inserting ASCII control characters into the AFCARS submission file will cause a file format error; the State file will not be processed and will fail the Data Compliance Utility.

Three methods of bit manipulation are left shifts, logical nots (binary complements), and exclusive or (XOR). Left shifts describe the procedure of re-positioning bits within a character. Logical nots describe an operation in which each bit is replaced with its complement. XOR describes an operation that involves comparing binary representations of two characters and producing another binary representation according to a set of comparison rules. Each bit-level operation is described below in greater detail. The following models (subsections IV.B. - IV.E.) are appropriate for encrypting State client IDs.

B. Left Shifts

This method has two types. Each involves three steps:

1. Truncate (delete) the left most bit.
2. Move the remaining bits over 1 position to the left.
3. Fill the empty right position with a 0, or
4. Fill the empty right position with a 1.

B.1 Left Shift 1 Position

In this example, the left most bit is truncated, all of the remaining 0's and 1's are moved one position to the left, and the empty position filled with a 0:

Left Shift 1 position (<<1)			
	Binary Representation	ASCII number	ASCII Character
Original Character	00110011	51	3
Converted Character	01100110	102	f

B.2 Left Shift 1 Position plus 1

In this example, the left most bit is truncated, all of the remaining 0's and 1's are moved one position to the left, and the empty position filled with a 1:

Left Shift 1 position and adding 1 ($\ll 1$) + 1			
	Binary Representation	ASCII number	ASCII Character
Original Number	00110011	51	3
Converted Character	01100111	103	g

C. Logical Nots (Binary Complements)

In this method, each bit is replaced with its complement (opposite value). Every 0 is replaced with a 1, every 1 is replaced with a 0. The following table illustrates this method:

Logical Not (\sim)			
	Binary Representation	ASCII number	ASCII Character
Original Number	00110011	51	3
Converted Character	11001100	204	□

D. XOR Method

In this method, compare the binary representation of the original character and the binary representation of the key on a bit by bit basis. If both bits are the same (both 0 or both 1), the result is zero. If both bits are different, the result is one. The following table illustrates this method:

Exclusive or (XOR) method			
	Binary Representation	ASCII number	ASCII Character
Original Number	00110011	51	3
XOR Key	10000000	128	Ç
Final Conversion	10110011	179	

E. Combinations of left shifting and logical nots

Bits can be further manipulated by sequentially applying two operations to a character. The following four tables illustrate some possible combinations:

E.1 Left Shift 1 Position followed by a Logical Not

In this method, the left most bit is truncated, all of the remaining 0's and 1's are moved one position to the left, and a 0 is added to the right side. Next, each bit is replaced with its complement to get the final conversion shown below.

Left Shift 1 position (<<1) and a Logical Not (~)			
	Binary Representation	ASCII number	ASCII Character
Original Number	00110011	51	3
Initial Conversion	01100110	102	f
Final Conversion	10011001	153	Ö

E.2 Logical Not followed by a left shift one position

In this method, each bit is replaced with its complement. Next, the left most bit is truncated and all of the remaining 0's and 1's are moved one position to the left. A zero is added on the right side to get the final conversion shown below.

Logical Not (~) followed by a left shift 1 position (<<1)			
	Binary Representation	ASCII number	ASCII Character
Original Number	00110011	51	3
Initial Conversion	11001100	204	□
Final Conversion	10011000	152	ÿ

E.3 Left Shift 1 Position plus followed by a Logical Not

In this method, the left most bit is truncated, all of the remaining 0's and 1's are moved one position to the left, and a 1 is added on the right side. Next, each bit is replaced with its complement to get the final conversion shown below.

Left Shift 1 position and adding 1 (<<1) + 1 and a Logical Not (~)			
	Binary Representation	ASCII number	ASCII Character
Original Number	00110011	51	3
Initial Conversion	01100111	103	g
Final Conversion	10011000	152	ÿ

E.4 Logical Not followed by a Left Shift 1 Position plus 1

In this method, each bit is replaced with its complement. Next, truncate the left most bit, all of the remaining 0's and 1's are moved one position to the left, and a 1 is added on the right side to get the final conversion shown below.

Logical Not (~) followed by a left shift 1 position and add 1 (<<1)+1			
	Binary Representation	ASCII number	ASCII Character
Original Number	00110011	51	3
Initial Conversion	11001100	204	□
Final Conversion	10011001	153	Ö

V. COMBINING ALGORITHMS

A. Introduction

States can devise an encryption method that employs a minimum of two algorithms. Combining methods can help create more complex encryption algorithms to ensure more secure State client IDs.

B. Substitution with Transposition

One possible combination is to apply substitution with shuffled digits to a State client ID followed by transposition of digit pairs.

In the first method, 1234 is encrypted as 9715 using the following number line and table of rules:

9 0 8 2 3 6 7 4 1 5
L <-----> R

1 st digit left:	8 positions
2 nd digit right:	3 positions
3 rd digit right:	4 positions
4 th digit left:	8 positions

- On the number line, locate 1 and move eight positions to the left to get 9.
- On the number line, locate 2 and move three positions to the right to get 7.
- On the number line, locate 3 and move four positions to the right to get 1.
- On the number line, locate 4 and move eight positions to the left to get 5.

Next, transpose all digits in the ID. 9715 becomes 1597 by applying the following table of rules:

Transpose the 1 st and 4 th digits
Transpose the 2 nd and 3 rd digits
Transpose the 3 rd and 4 th digits
Transpose the 1 st and 2 nd digits

- In the first transposition, 9 and 5 are switched to produce the number 5719.
- In the second transposition, 7 and 1 are switched to produce the number 5179.
- In the third transposition, 7 and 9 are switched to produce the number 5197.
- In the fourth transposition, 5 and 1 are switched to produce the number 1597.

C. Bit Level Operations with Transposition

The following algorithm was developed to be used by States to create encrypted AFCARS record numbers and will ensure that none of the restricted ASCII codes (characters 0-31, 35, 36, 37, and 64) occur in the resulting encrypted numbers. It uses the operations described below and assumes that State case IDs are composed of upper and lower case alphabetic characters (ASCII characters 41-90 and 97-122), digits 0-9 (ASCII characters 48-57), and dashes (ASCII character 45).

1. Set up a table assigning a value of 0 to 6 for the operations described below. States may use the following example table or modify the example by reordering the bit operations:

Numeric Assignment	Bit Operation	Description
0	$\ll 1$	1 Left Shift plus 0 bit
1	$(\ll 1)+1$	1 Left Shift plus 1 bit
2	\sim	Logical Not
3	$\ll 1 \sim$	1 Left Shift plus 0 bit followed by a Logical Not
4	$\sim \ll 1$	Logical Not followed by a 1 Left Shift plus 0 bit
5	$(\ll 1)+1 \sim$	1 Left Shift plus 1 bit followed by a Logical Not
6	$\sim (\ll 1)+1$	Logical Not followed by a 1 Left Shift plus 1 bit

2. Select an encryption key. The encryption key should be as long as the State case ID. The key should be kept secure and only be accessible to authorized State personnel.
3. Apply the following steps to the State case IDs:
 - a. Determine the ASCII value of the first character of the key.
 - b. Apply a MOD 7 operation to the ASCII value of that character. (In other words, divide the value by 7 and take the whole number remainder, which will be either 0,1,2,3,4,5, or 6).
 - c. Using the chart developed in Step 1, go to the modal value (0-6) and select the corresponding bit operation.
 - d. Determine the bit representation of the first character of the State case ID.

- e. Apply the bit operation(s) to the first character of the State case ID number. The resulting character will be the first number encrypted.
- f. Apply the same steps to each character in the ID, using the second character of the key to transform the second character of the State case ID, the third for the third, etc.

The following is an illustration of these steps applied to the first letter of State case ID "BD5-983E25N5" using the key "Change code.":

- a. "C" is the first letter of the key; its ASCII value is 67.
- b. $67 \text{ MOD } 7 = 4$.
- c. The corresponding bit operation is $\sim \ll 1 + 0$.
- d. "B" is the first character of the State case ID. Its ASCII value is 66; the binary representation of 66 is 01000010.
- e. Applying $\sim \ll 1 + 0$ to 01000010 will yield 01111010 or 122. 122 is the ASCII number for "z".

The following table details the conversion for each character of the ID:

Key	ASCII Value	MOD 7	Bit Operation	Case ID Character	ASCII Codes /Bit Values	Transformed ASCII Code /Bit Values	Encrypted Character
C	67	4	$\sim \ll 1$	B	66/01000010	122/01111010	z
H	104	6	$\sim (\ll 1)+1$	D	68/01000100	119/01110111	w
A	97	6	$\sim (\ll 1)+1$	5	53/00110101	149/10010101	ò
N	110	5	$(\ll 1)+1 \sim$	-	45/00101101	164/10100100	ñ
G	103	5	$(\ll 1)+1 \sim$	9	57/00111001	140/10001100	î
E	101	3	$\ll 1 \sim$	8	56/00111000	143/10001111	Å
<space>	32	4	$\sim \ll 1$	3	51/00110011	152/10011000	ÿ
c	99	1	$(\ll 1)+1$	E	69/01000101	139/10001011	ï
o	111	6	$\sim (\ll 1)+1$	2	50/00110010	155/10011011	ç
d	100	2	\sim	5	53/00110101	202/11001010	□
e	101	3	$\ll 1 \sim$	N	78/01001110	99/01100011	C
.	46	4	$\sim \ll 1$	5	53/00110101	148/10010100	Ö

We will now change the position of the encrypted characters using the following table of rules:

Transpose the 1st and 12th character
 Transpose the 2nd and 11th character
 Transpose the 3rd and 10th character
 Transpose the 4th and 9th character
 Transpose the 5th and 8th character
 Transpose the 6th and 7th character

In the first transposition, z and ö are switched to produce the character set:

ö w ò ñ î Åÿ ï ç □ c z

In the second transposition, w and c are switched to produce the character set:

ö c ò ñ î Åÿ ï ç □ w z

In the third transposition, ò and □ are switched to produce the character set:

ö c □ ñ î Åÿ ï ç ò w z

In the fourth transposition, ñ and ç are switched to produce the character set:

ö c □ ç î Åy ï ñ ò w z

In the fifth transposition, î and ï are switched to produce the character set:

ö c □ ç ï Åy î ñ ò w z

In the sixth transposition, Å and y are switched to produce the final character set:

ö c □ ç ïy Å î ñ ò w z

The final character set now represents the unique encrypted character set.

VI. REVERSING THE ENCRYPTION ALGORITHM

A. Introduction

As mentioned in the *Guidelines*, be sure that the selected encryption method can be reversed to produce the original client ID for any AFCARS record number.

B. Sample Reversal Algorithm

We will use the algorithm described in section V.B. (substitution with transposition) to illustrate the process. Let us work backwards starting with the second encryption method(transposition of digit pairs). Our first step is to reverse the order of the digit pairs that were transposed. With each digit pair, reverse the switching order to produce the following table of rules:

Transpose the 2nd and 1st digits
 Transpose the 4th and 3rd digits
 Transpose the 3rd and 2nd digits
 Transpose the 4th and 1st digits

In the first transposition, 5 and 1 are switched to produce the number 5197.

In the second transposition, 7 and 9 are switched to produce the number 5179.

In the third transposition, 7 and 1 are switched to produce the number 5719.

In the fourth transposition, 5 and 9 are switched to produce the number 9715.

We will now change 9715 back to the original number (1234) by reversing the original substitution method. The number line will not change. Using the original table of rules, reverse the direction for each rule to produce the following table of rules:

9 0 8 2 3 6 7 4 1 5
 L <—————> R

1 st digit right:	8 positions
2 nd digit left:	3 positions
3 rd digit left:	4 positions
4 th digit right:	8 positions

On the number line, locate 9 and move eight positions to the right to get 1.

On the number line, locate 7 and move three positions to the left to get 2.

On the number line, locate 1 and move four positions to the left to get 3.

On the number line, locate 5 and move nine positions to the right to get 4.

As stated in the *Guidelines*, be sure that the encrypted number is scanned so that the ASCII control numbers (0-31) and ASCII characters 35, 36, 37, and 64 are not being used.

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