MARINE CORPS TACTICAL SYSTEMS SUPPORT ACTIVITY

Technical Excellence...Tactical Value

Combinatorial Testing Applied to LINK 16 Standards Conformance Testing

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Assumptions

- Current methods for testing Link 16 can be rushed and inconsistent
  - Size of the Link 16 “test space” can be overwhelming
- Link 16 testing can be influenced by:
  - Varying tactical experience
  - Specific expertise (e.g., ground versus air)
- The biases are due largely MIL-STD-6016E, being complicated and sometimes too vague
  - Leads to confusion and dual interpretations of the standard.

Goal

- The goal is to implement an unbiased and statistically based test methodology for Link 16 standards conformance that can ensure repeatability with a quantifiable increase in test space coverage.

Background

- Historical and Traditional Approach to Link 16 Testing
  - Numerous requirements
  - Not all message fields are evaluated
  - Large data sets to analyze

Background

- Link 16 in our SUT has been evaluated twice
  - Contractor Demos
    - Tested using our normal processes and procedures
    - Had a lot of TADIL requirements to cover in a limited time

ID	[redacted] Increment I SSS Revision E (thru SCN 015)	COMMENTS
	TDL-J SPECIFIC – 11	
SSS-2774	The [redacted] shall provide the capability to function as a C2 JU on TDL-J, in accordance with the requirements of the current MIL-STD-6016.	Complete procedure Step 8
SSS-2776	The [redacted] shall provide operators with the capability to manage a TDL-J link in accordance with the requirements of the current CJCSM 6120.01.	Complete procedure Step 8
SSS-2782	The [redacted] shall support the Network Participation Groups (NPGs) specified in the current MIL-STD-6016, in which the USMC participates.	Complete procedure – no steps
SSS-2807	The [redacted] shall process the TDL-J messages shown in the current [redacted] SV-6, Data Exchange Matrix.	Complete procedure – no steps
SSS-2263	The [redacted] shall provide [redacted] operators with the capability to initialize a MIDS (Threshold) LVT at designated operator workstations.	During integration Step 5
SSS-2265	The [redacted] shall provide the operator with the ability to view, modify, and save the terminal initialization load.	During integration Step 5

A Legacy Test Case

- Total of seven J3.2 messages tested

25	00:01.30	SUA verify receipt of NRT air tracks (J3.2) with the identities specified below:											
		TRACK #	**ID**	**PLAT**	**PA**	**SPEC TYPE**	**SZ**	**CRS**	**SPD**	**ALT**	**MI**	**MII**	**MIII**	**MIV**
		CA000 SRN0010	PEND	NS	NS	NS	1	115	300	26K	NS	NS	NS	NS
		CA001 SRN0011	UNK	NS	NS	NS	1	185	400	33K	22	7641	3441	INT, NO RESP
		CA002 SRN0012	ASMD-FRND	HELO	NS	NS	3	020	120	9K	02	0210	6677	INT, NO RESP
		CA003 SRN0013	FRND	FTR	CAP	F-18	2	110	200	25K	11	2222	3333	VALID
		CA004 SRN0014	NEUT	CIV	NS	NS	2	265	225	45K	NS	1200	NS	NOT INT
		CA005 SRN0015	SUSP	NS	NS	NS	4	320	350	13K	NS	NS	NS	INT, INVALID
		CA006 SRN0016	HOST	FTR	NS	SU-27	2	010	450	33K	NS	NS	NS	INT, NO RESP
26	Director	Verify receipt of data as specified above.												3

A Lot More to a J3.2

I Word

- I_EXERCISE_INDICATOR
- I_PPLI_TRACK_NUMBER_AND_IDENTITY_IND
- I_FORCE_TELL_INDICATOR
- I_EMERGENCY_INDICATOR
- I_SPECIAL_PROCESSING_INDICATOR
- I_SIMULATION_INDICATOR
- I_TRACK_NUMBER_REFERENCE
- I_STRENGTH
- I_ALTITUDE_SOURCE
- I_FEET_ALTITUDE
- I_IDENTITY_DIFFERENCE_INDICATOR
- I_TRACK_QUALITY
- I_IDENTITY
- I_SPECIAL_INTEREST_INDICATOR

E0 Word

- E0_DEGREES_LATITUDE
- E0_DEGREES_LONGITUDE
- E0_PASSIVE_ACTIVE_INDICATOR
- E0_DEGREES_COURSE
- E0_DATA_MILES_PER_HOUR_SPEED

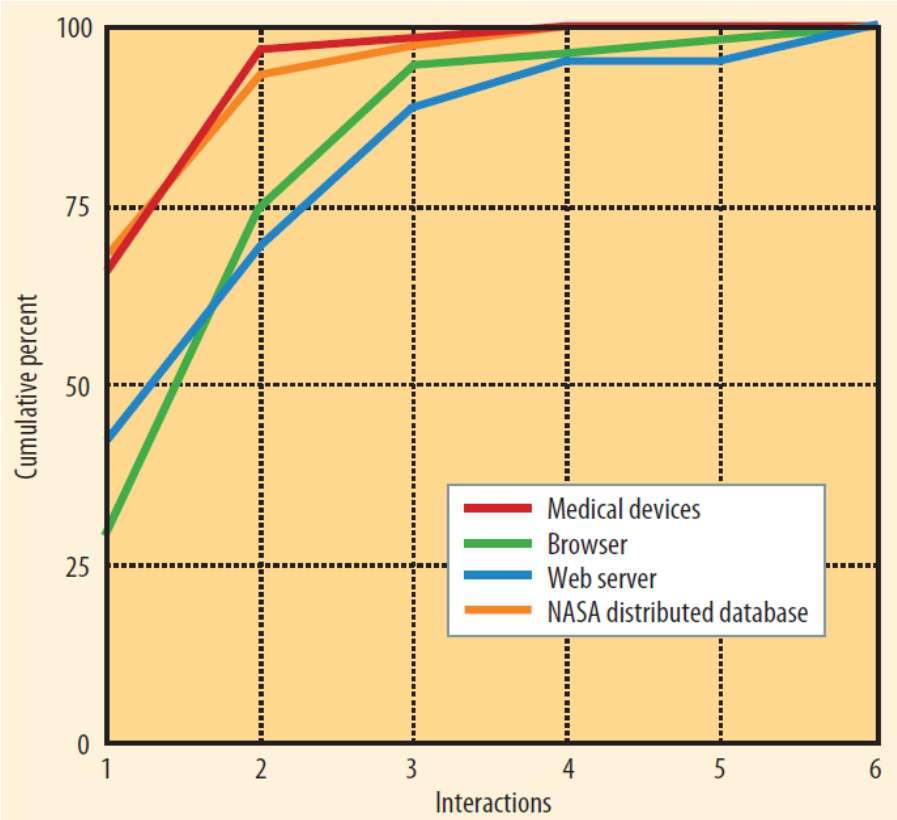
C1 Word

- C1_MODE_I
- C1_MODE_II
- C1_MODE_III
- C1_MODE_IV_INDICATOR
- C1_AIR_PLATFORM
- C1_AIR_PLATFORM_ACTIVITY
- C1_AIR_SPECIFIC_TYPE
  C1_Mode_5_Indicator
- C1_Minute
- C1_Hour

A Better Test Is Available

- A Statistical Test and Analysis Technique called Combinatorial Testing can be used for Link 16 testing
  - Reduces human bias
  - Covers all message fields thoroughly
  - Expands on pairwise testing concepts that the software testing community already uses
  - Empirical studies have shown that three-way interactions, or combinations, can effectively find up to 90 percent of the software faults and with fewer test cases than exhaustive manual testing.

The Studies Show…

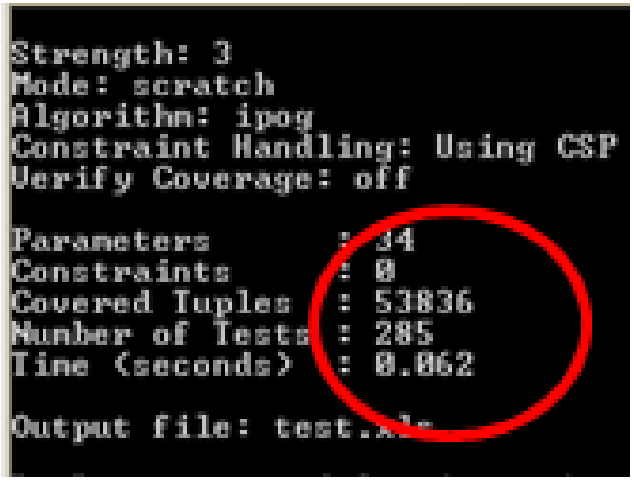


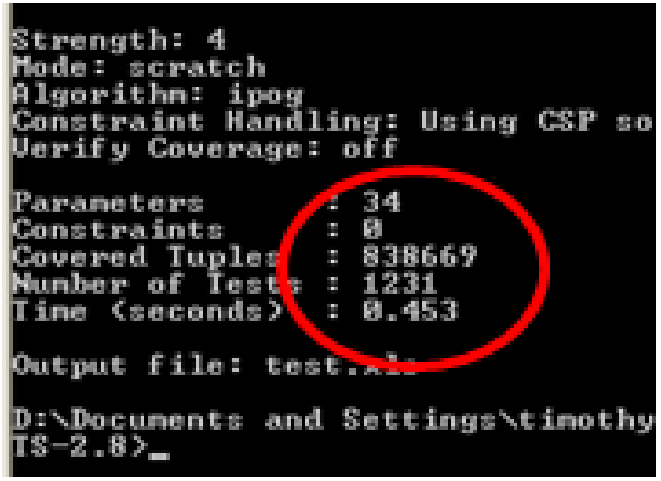
"Interaction Rule: Most failures are induced by single factor faults or by the joint combinatorial effect (interaction) of two factors, with progressively fewer failures induced by interactions between three or more factors."*

*http://csrc.nist.gov/groups/SNS/acts/index.html

Let's Apply CT to a J3.2

- For the J3.2, there are 371,589,120 valid test combinations of the 34 message fields
- Using combinatorial methods, that large number of test cases can be reduced to 285 test cases if testing all three-way combinations.





Let's Apply CT to a J3.2

- For just the Emergency Ind, Simulation Ind, and the Special Processing Ind there are 8 tests (2 X 2 X 2 = 8)

Test Case	Emergency Indicator	Simulation Indicator	Special Processing Indicator
1	Non-Emergency	Non-Simulation	Non-Special Processing
2	Non-Emergency	Non-Simulation	Special Processing
3	Non-Emergency	Simulation	Non-Special Processing
4	Non-Emergency	Simulation	Special Processing
5	Emergency	Non-Simulation	Non-Special Processing
6	Emergency	Non-Simulation	Special Processing
7	Emergency	Simulation	Non-Special Processing
8	Emergency	Simulation	Special Processing

Let's Apply CT to a J3.2

- By pairing values together, it is possible to test all eight combinations in four test cases because every field value is interacting with the other field values at least once.

Test Case	Emergency Indicator	Simulation Indicator	Special Processing Indicator
1	Non-Emergency	Non-Simulation	Non-Special Processing
2	Non-Emergency	Simulation	Special Processing
3	Emergency	Non-Simulation	Special Processing
4	Emergency	Simulation	Non-Special Processing

J3.2 Course Values

- The J3.2 has more possible values than just standard course values
  - 0-359 are valid field values
  - 360-510 are valid field values but interpreted as illegal
  - 511 is a valid field value for “No Statement”

- MIL-STD-6016E, paragraph 5.6.10.1
  - Illegal values should be converted to “no statements” and other legal values in the message should be processed unless the illegal value invalidates the entire message.

The Key is ECP

- Equivalence Class Partitioning (ECP)
  - A Software testing technique that divides the input data of a software unit into partitions of equivalent data from which test cases can be derived

```
371  015    COURSE                                          INDICATES THE DIRECTION OF TRAVEL OF
             ------                                            AN OBJECT IN DEGREES WITH RESPECT
                                                               TO TRUE NORTH.
                  0 THROUGH 359 DEGREES     0 THROUGH 359    IN 1 DEGREE INCREMENTS.
                  ILLEGAL                   360 THROUGH 510
                  NO STATEMENT              511

367  018    SPEED                                           THE RATE OF CHANGE OF POSITION.
             -----
                  0 THROUGH 4092 DATA       0 THROUGH 2046   EXPRESSES GROUND SPEED IN 2 DATA
                    MILES PER HOUR                             MILES PER HOUR INCREMENTS.
                  NO STATEMENT              2047
```

  - Three equivalence classes were used for the “course” and two equivalence classes were used for “speed” because these ranges of values should be treated differently by the software.

Negative Test Cases

- When using CT, care must be taken when using illegal values in messages.
- If the MIL-STD-6016E receive tables establish that a system must discard a message when an illegal value is encountered, then valid combinations contained within that same message will be discarded when the system invalidates the entire message.
- For this reason, only messages with valid values are generated, and negative test cases are not ignored, but are handled separately, and in addition to, all of the valid test cases.

Constraints

- In producing every possible three-way combination of message values, there will be times when certain combinations of field values violate MIL-STD-6016E rules.
- For example, in a J3.2 message, if the track quality is greater than zero, then the track's course and speed must be legal values and cannot include the "no statement" value.
- In a situation such as this, Advanced Combinatorial Testing System (ACTS) allows constraints to be added to the algorithm that produces the combinations

```
[Constraint]
--If I_Track_Quality >0 then E0_Course & E0_Speed must be legal non-NS values.
I_TRACK_QUALITY > 0 => E0_DEGREES_COURSE = "legal0-359"
I_TRACK_QUALITY > 0 => E0_DATA_MILES_PER_HOUR_SPEED = "0-4092"

--If I_Track_Quality >0, then C1_Min & C1_Hour must be NS.
I_TRACK_QUALITY > 0 => C1_Minute = "NS"
I_TRACK_QUALITY > 0 => C1_Hour = "NS"

--If I_Track_Quality =0, then C1_Min & C1_Hour must be legal non-NS values.
I_TRACK_QUALITY = 0 => C1_Minute = "0-59"
I_TRACK_QUALITY = 0 => C1_Hour = "0-23"
```

Lessons Learned

- Successful test methodology however…
  - This method produced a large number of low priority test incident reports because more of the test space was evaluated
  - Injected multiple versions of messages in a grid pattern
    - Easily see if a message was dropped by looking for a hole in the grid
  - An automated method of verification needs to be developed
    - Currently Marines have to manually locate each track and match the truth data to the actual data)
  - Versioning of the test cases is extremely important in order to maintain the integrity of the combinations
  - Reuse of test cases has been extremely valuable

Resources

- LINK STANDARD MIL-STD-6016E
- MLST3 03.14 (Scenario Developer/Test Control)
- MANDRIL for Multi-Links version 12.1
- ACTS software http://csrc.nist.gov/groups/SNS/acts/index.html
- Microsoft Office Excel
- MIDS LVT2/11
- JREAP STD Mil-Std-6040
- Diagnostic Support Tool (MIDS terminal data collection)
- System Under Test

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Questions?

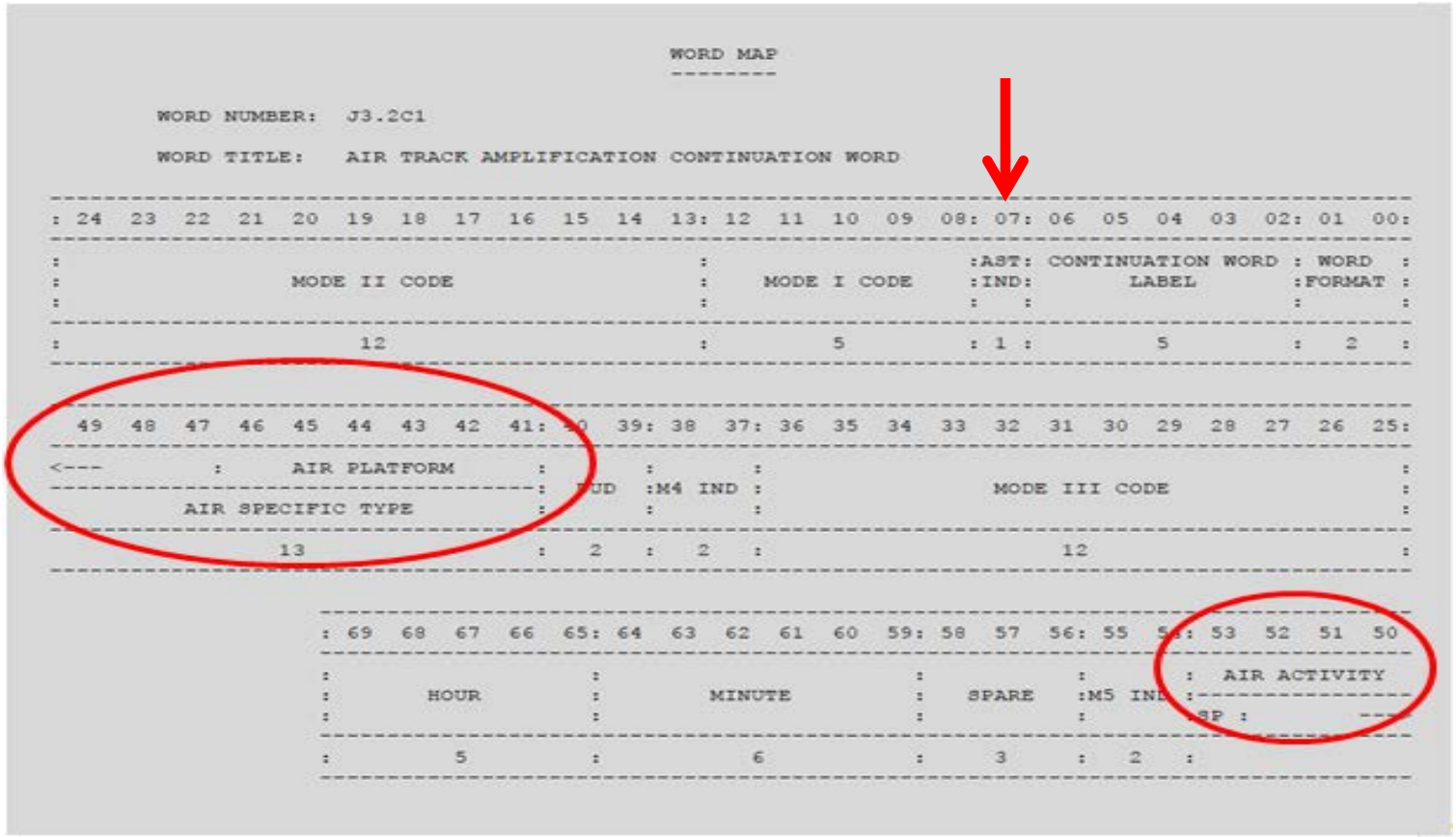
Overview of the Process

- Picked a Link 16 Message to process
- Created Equivalency Classes
- Created a script in Notepad for the ACTS software
- Ran ACTS to produce the test cases
- Used Excel on the ACTS output to input valid field values
- Created a VBA scripts and Macros in Excel to produce MLST-3 input scripts.
- Used MLST-3 to inject the Link 16 messages into the system under test
- Manually verified the values compared to truth data
- Analyzed the results
- Produced the TIRS as required

Overlapping Values in Messages

- There are times when the message fields overlap in the same bit range.
- For example, in the J3.2 C1 word, bits 41-53 can have two meanings depending upon the “air specific type” switch value in bit seven.
- If bit seven is a zero, then an “air activity” is being reported in bits 41-53, and if bit seven is a one, then an “air specific type” is being reported

Overlapping Values in Messages



WORD MAP

WORD NUMBER: J3.2C1

WORD TITLE: AIR TRACK AMPLIFICATION CONTINUATION WORD

24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	09	08	07	06	05	04	03	02	01	00
MODE II CODE												MODE I CODE					AST IND	CONTINUATION WORD LABEL					WORD FORMAT	
12												5					1	5					2	

49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25
AIR PLATFORM																								
AIR SPECIFIC TYPE																								
13										2		2												

69	68	67	66	65	64	63	62	61	60	59	58	57	56	55	54	53	52	51	50
HOUR					MINUTE						SPARE			M5 IND		AIR ACTIVITY			
5					6						3			2					

- By separating the zero message value in the air specific type field into its own equivalency class, the air specific type switch is represented.

Link-16 Results

Internal TDL TIR #	TIR #	Description	MCTSSA proposed priority
TDL 2	161	Discarding J2.0s when C2 with TN FL field set to 77 & 7777	2
TDL 62	296	Fails to process ID & Exercise Ind when ID Diff is set	1
TDL 63	297	Fails to process J3.2 when ID = UNDEFINED	1
TDL 64	298	Track List inconsistent display checks vs true	4
TW-7		DERG display of Meters Depth incorrect	4
TW-14		J2.0 Activity of Shadow not displayed	4
TW-15		Displays Received J2.0 Course incorrectly	4
TW-16		Displays Received J2.0 Unit Type of TOC as ASWOC	4
TW-17		Point Amp	
TW-18		Time Function	
TW-19		Time Function-Activation	
TW-20		Hour & Minutes	
TW-21		Point Type	
TW-22		Point Amp	
TW-23		J3.1 Time Function	
TW-24		J3.1 Hour and Minutes	
JB-1		J2.4 depth displayed as negative feet vice meters	
JB-2	203	Incorrect display of J2.2 Time Qual	4
JB-3	213	Geodetic Pos Qual value 5 displayed incorrectly	4
JB-9	210	Flight Lead Indicator not displayed	4
JB-12	287	Incorrect display of J2.0 speed	4

VMF Results

- **SUT cannot send a Third-Party K03.6 Mayday message**
  - The SUT K03.6 Mayday Message Composer has no available fields to create and transmit a Third-Party Mayday. SUT should be able to report a Mayday (Emergency) on a third party.

- **SUT does not set the MESSAGE SUBTYPE field in the K03.6 Mayday message Header for MIL-STD 6017B and later**
  - When SUT transmits a K03.6 Own Party Mayday, the message is received as INVALID at the VTT. Upon further analysis it was discovered that the MESSAGE SUBTYPE field is not being set when using MIL-STD version 6017B, 6017C, and 6017C+. The MESSAGE SUBTYPE field must be set to match the respective case.

- **SUT does not implement all valid values for PERSONNEL INVOLVED in the K03.6 Mayday message.**
  - In the K03.6 Mayday message composer the user can only select FEW (13), MANY (14), and GREATER (15) for the Personnel Involved. All MIL-STD versions DFI 1643 allow for individual values of 1 through 12 to be exchanged. The user should be given the option to select and transmit values 1-12.

- **K03.6 Mayday message composer should not allow for manipulation of the SenderURN field**
  - The SUT K03.6 Message composer allows for selection of other URNs when creating a Mayday message. SenderURN should not be selectable and should always be transmitted using the Own Unit URN regardless of MAYDAY TYPE. Manipulation of the SenderURN creates the potential for incorrect data being exchanged causing confusion or incorrect SA during an Emergency situation.