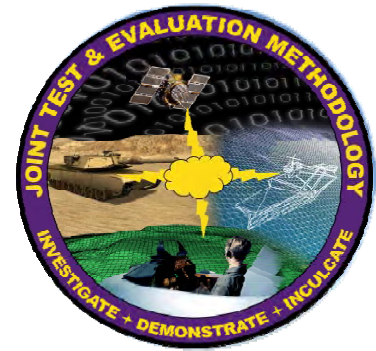




International Test & Evaluation LVC Conference

Capability Test Design and Analysis

January 13, 2009

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Capability Test Design & Analysis Objectives



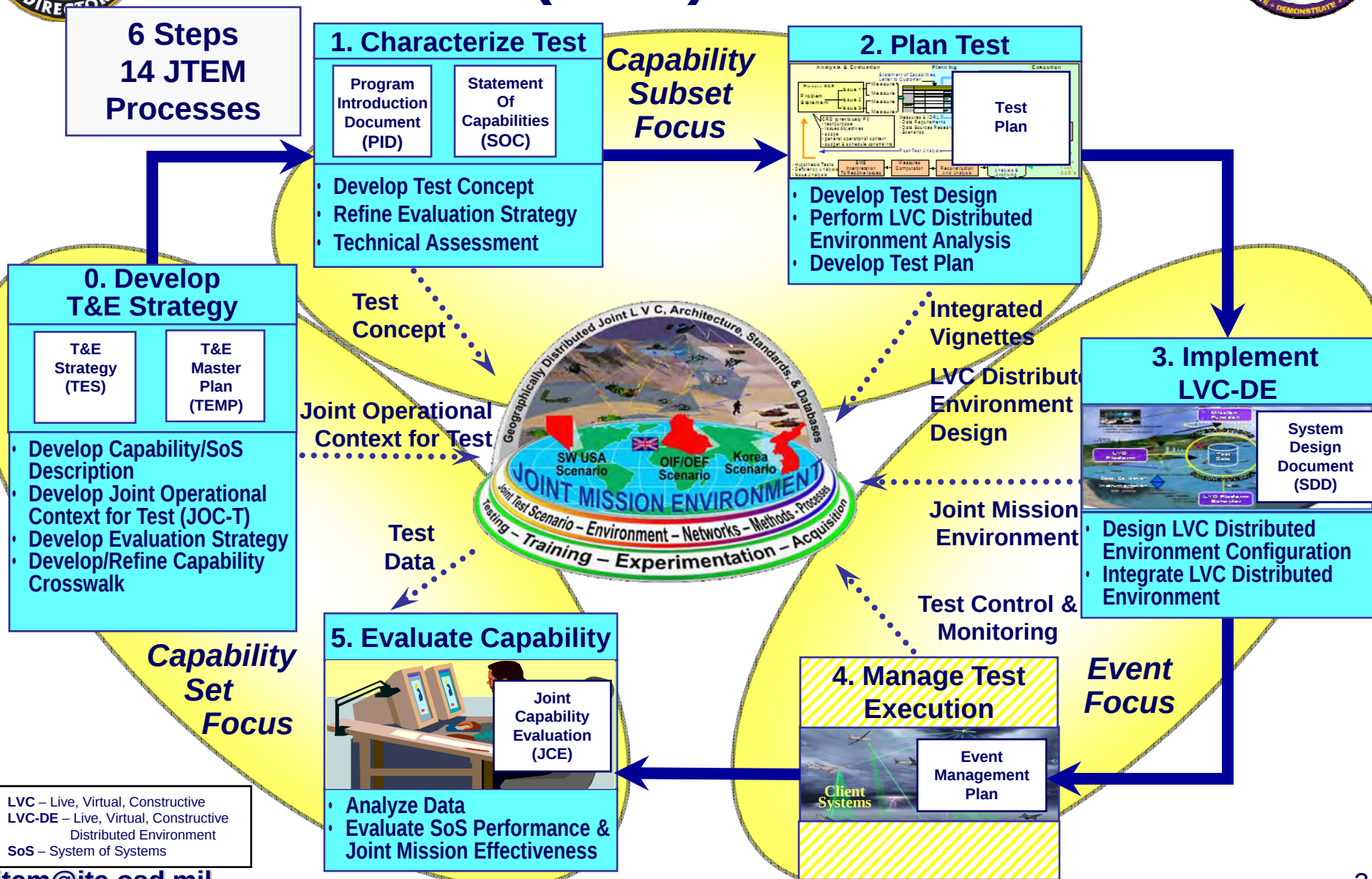
- 1. Discuss the concept of conducting a capability evaluation strategy refinement process for testing in a joint environment (TIJE)**
- 2. Review the methods and processes for an evaluation strategy refinement process**
- 3. Review potential design of experiment techniques for large number of factors**
- 4. Review tools and techniques for an evaluation strategy refinement process**
- 5. Step through a “case study” example of an evaluation strategy refinement process**
- 6. Review potential issues and insights**



JTEM Capability Test Methodology (CTM) v2.0



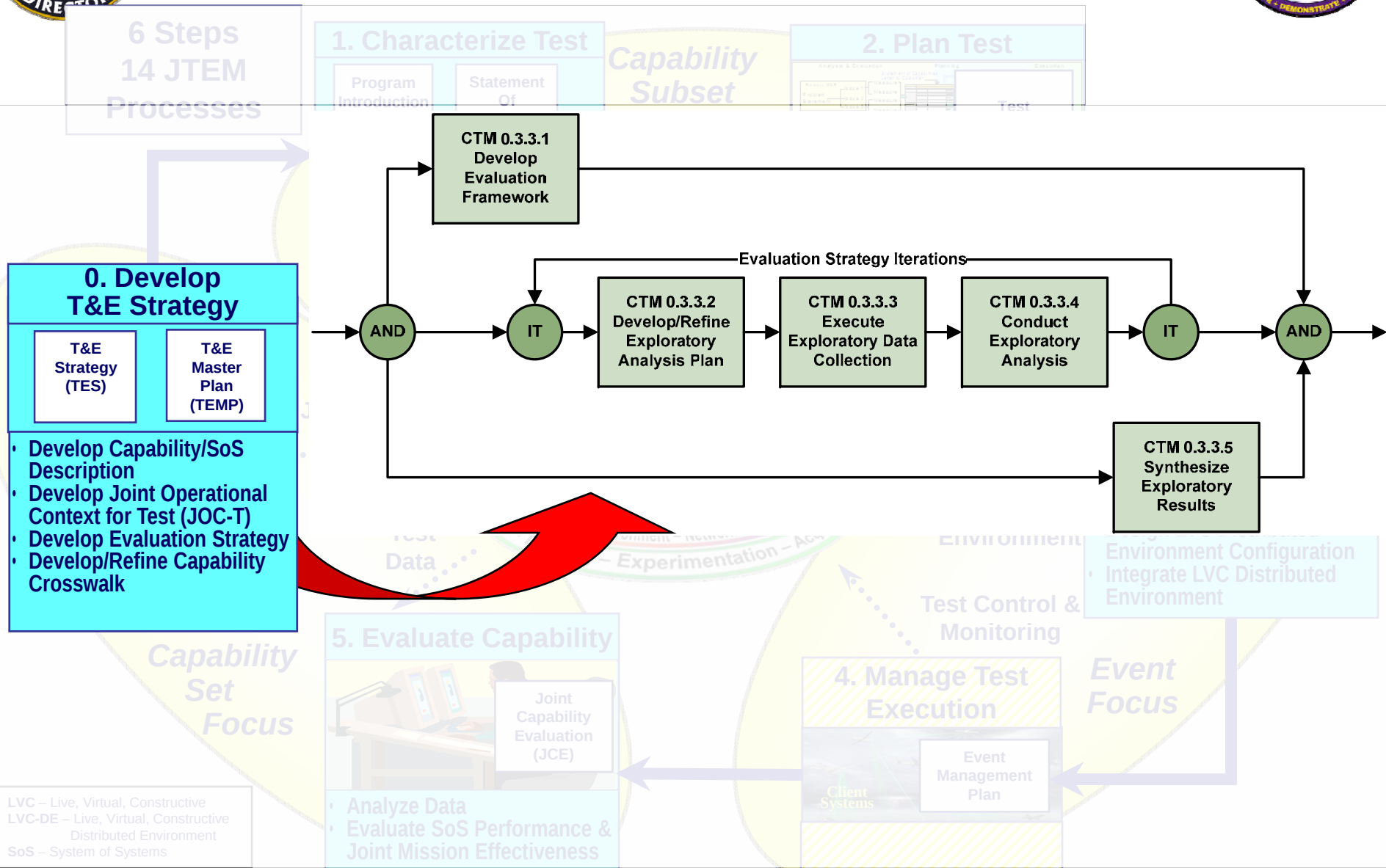
6 Steps
14 JTEM
Processes





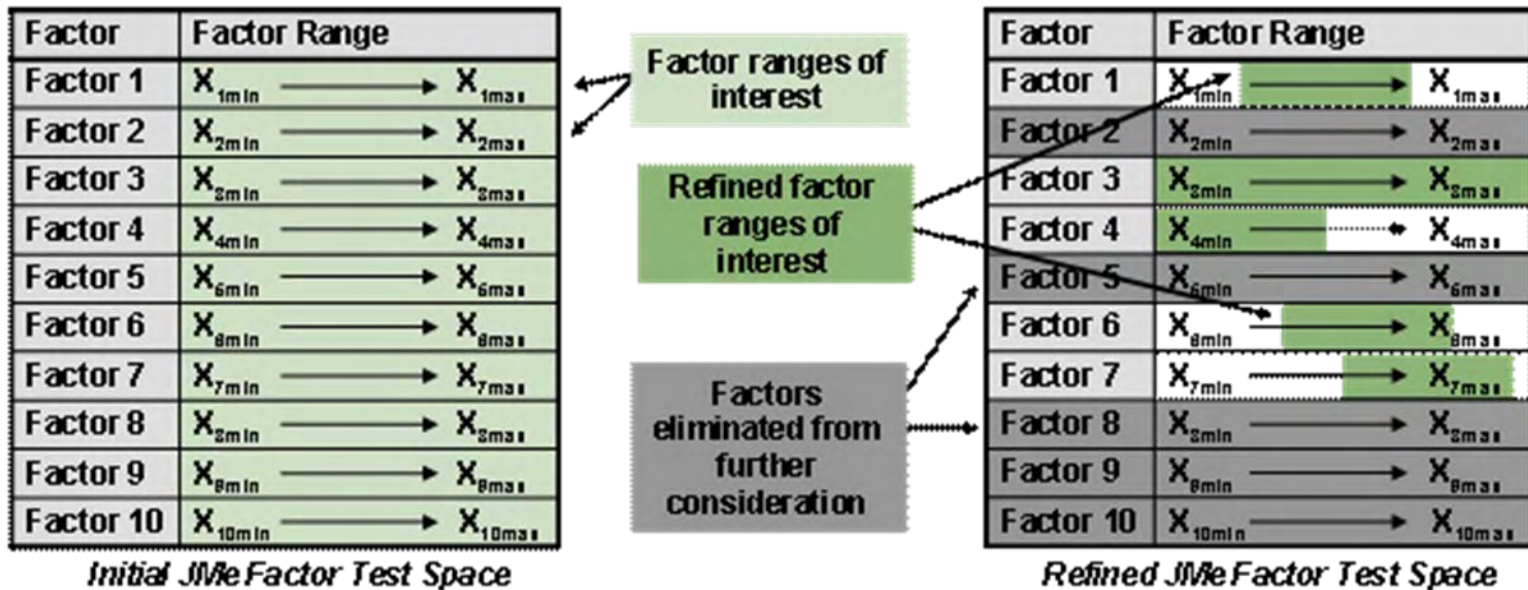
JTEM CTM 0.3.3

(Develop Evaluation Strategy)





Exploratory Analysis Purpose

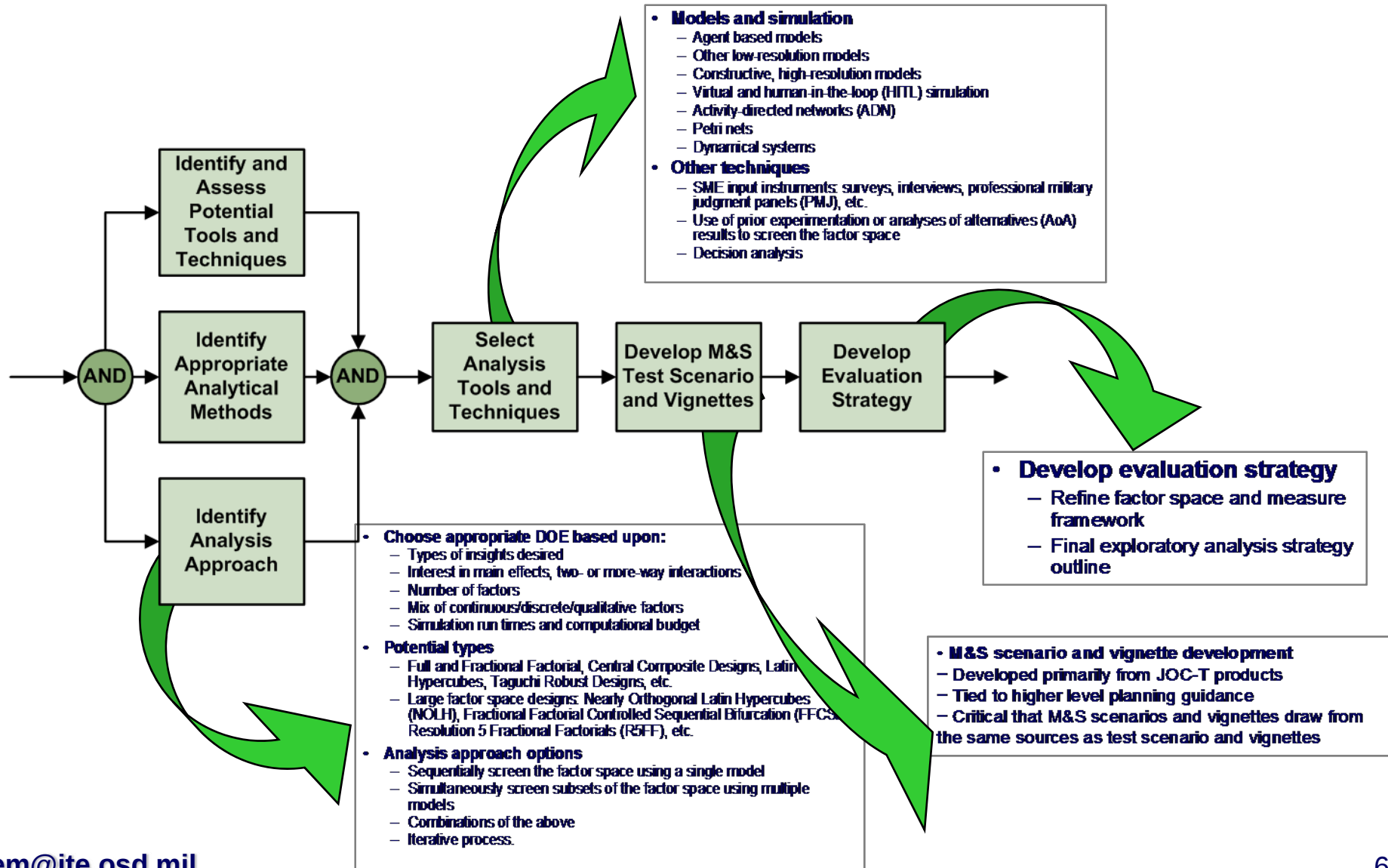


Purpose is three-fold:

- To explore a wide range of possible factors and levels that might affect joint mission effectiveness (JMe), referred to as the initial JMe factor test space;
- To identify those combinations of factors that have the greatest impact on JMe, referred to as the refined JMe factor test space; and
- To recommend potential factor combinations of interest from the refined JMe factor test space for subsequent test events, referred to as potential test trial sets.

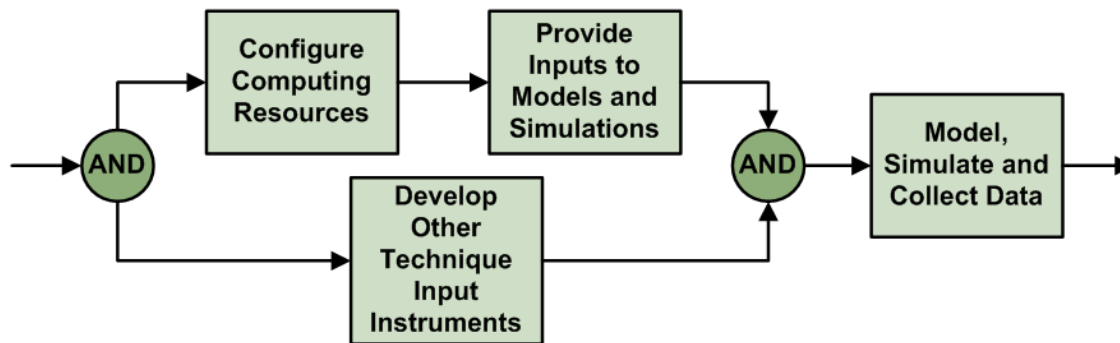


CTM 0.3.3.2: Develop/Refine Exploratory Analysis Plan





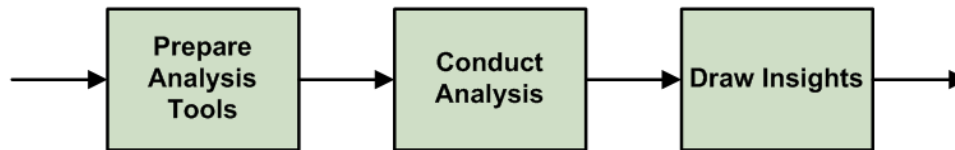
CTM 0.3.3.3: Execute Exploratory Data Collection



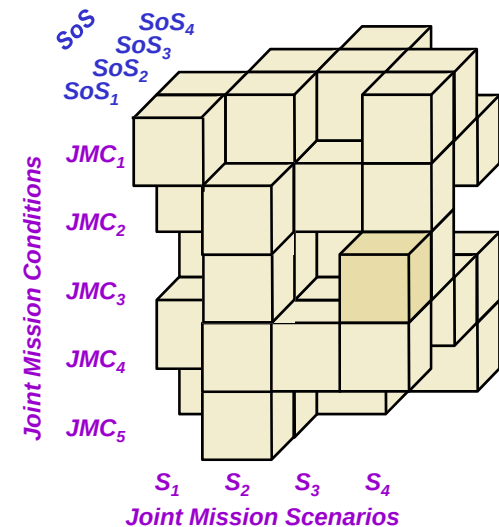
- Depending upon tools and methods chosen, configuration of computing resources may be quite involved.
- Other instruments of data collection are also developed here (surveys, interview scripts, PMJ panel planning, etc.).
- Analysts develop model inputs (scenario files, DOE input files, data output specifications, etc.) to execute the data collection.
- Model runs and data collection are executed according to exploratory analysis strategy.



CTM 0.3.3.4: Conduct Exploratory Analysis



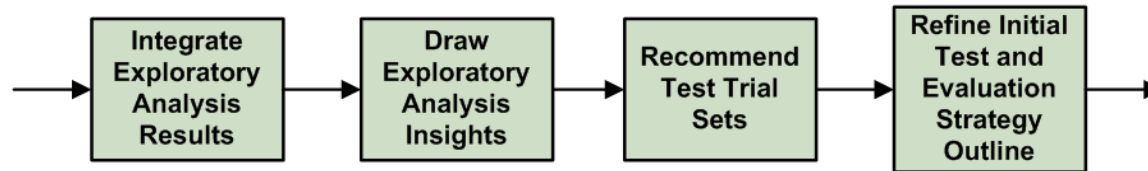
- Identify and select appropriate tools and techniques to conduct the analysis.
- Evaluate measure responses from exploratory runs to refine the JMe factor test space.
- Identify factors to explore during next iteration, as required.
- Potential analyses involved in these steps will be discussed in more detail as part of CTM 5, Evaluate Capability, since similar analytic methods will be used as part of both processes.



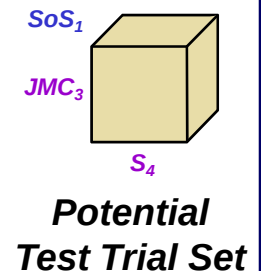
**Refined JMe Factor
Test Space**



CTM 0.3.3.5: Synthesize Exploratory Analysis Results



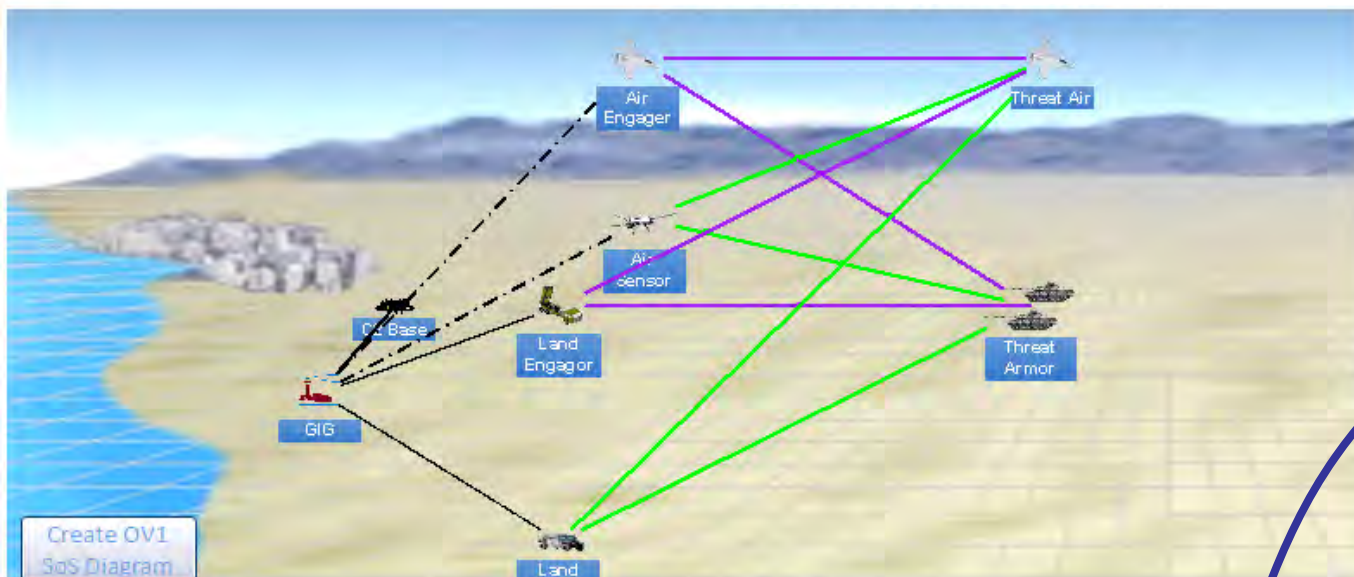
- This set of processes integrates the analyses conducted during the multiple exploratory iterations to draw insights about the “probable” factor space and the measure framework.
- The result should be a final refined factor space consisting of potential test trial sets of interest for subsequent testing.
- Must integrate model related data and qualitative data obtained from SMEs.
- Insights from the analysis will help inform the risk assessment conducted in the next step of the CTM.
 - Potential contributors to risk include the assumptions made during modeling, the capabilities of the models, the measures chosen, etc.
 - Subsequent tests can help validate assumptions made.





Case Study Example

High Level Operational View (OV-1)



System of Systems
(SoS)

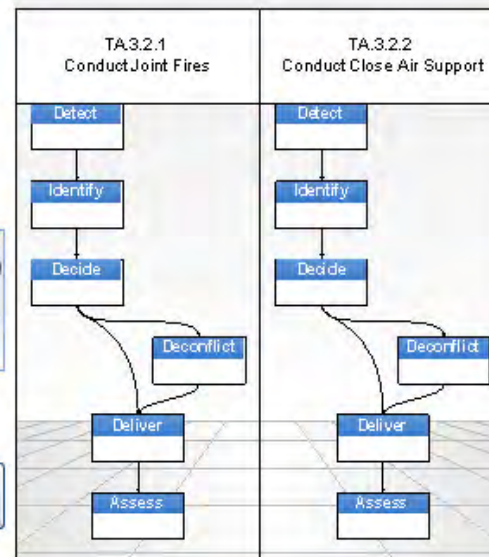
Task

SystemSoS	SystemSoS Name
IDFW SoS 1	C2 Capability System of Systems
Record: 1 of 1	No Filter Search

to perform

UJTL Number	Task Name
TA.3.2.1	Conduct Joint Fires
TA.3.2.2	Conduct Close Air Support
Record: 1 of 2	No Filter Search

Create OV1
Task Diagram



to achieve

Desired Effect	Desired Effect Name
IDFW MDE 1	Threat Platform Ineffectiveness
Record: 1 of 1	No Filter Search

Mission Desired Effect



Develop Evaluation Framework



Case Study Example

Mission Measures of Effectiveness

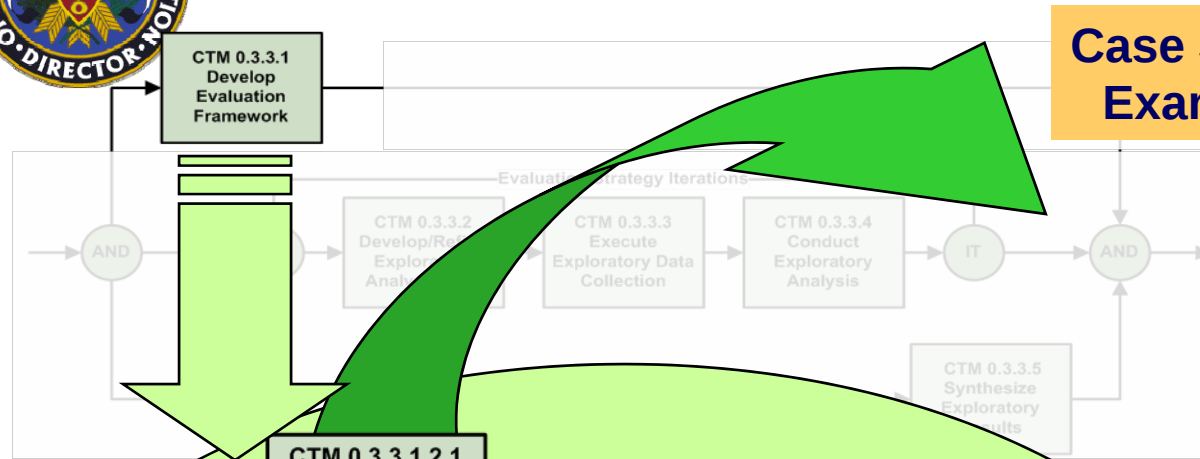
1. Threat Systems Combat Ineffectiveness
2. Cumulative ineffectiveness time Threat Systems in JOA

Task Measures of Performance

1. Time to C2 indirect fires (IF)
2. Time to get ordnance on target for JCAS
3. Time to get ordnance on target for JFIRES

Measures of System of Systems Attributes

1. Speed of CFF Decisions
2. Speed of CFF Deconfliction



CTM 0.3.3.1.2.1
Identify Mission
Measures of
Effectiveness
(Mission MOE)

CTM 0.3.3.1.2.2
Identify Task
Measures of
Performance
(Task MOP)

CTM 0.3.3.1.2.3
Identify System
of System
Attributes

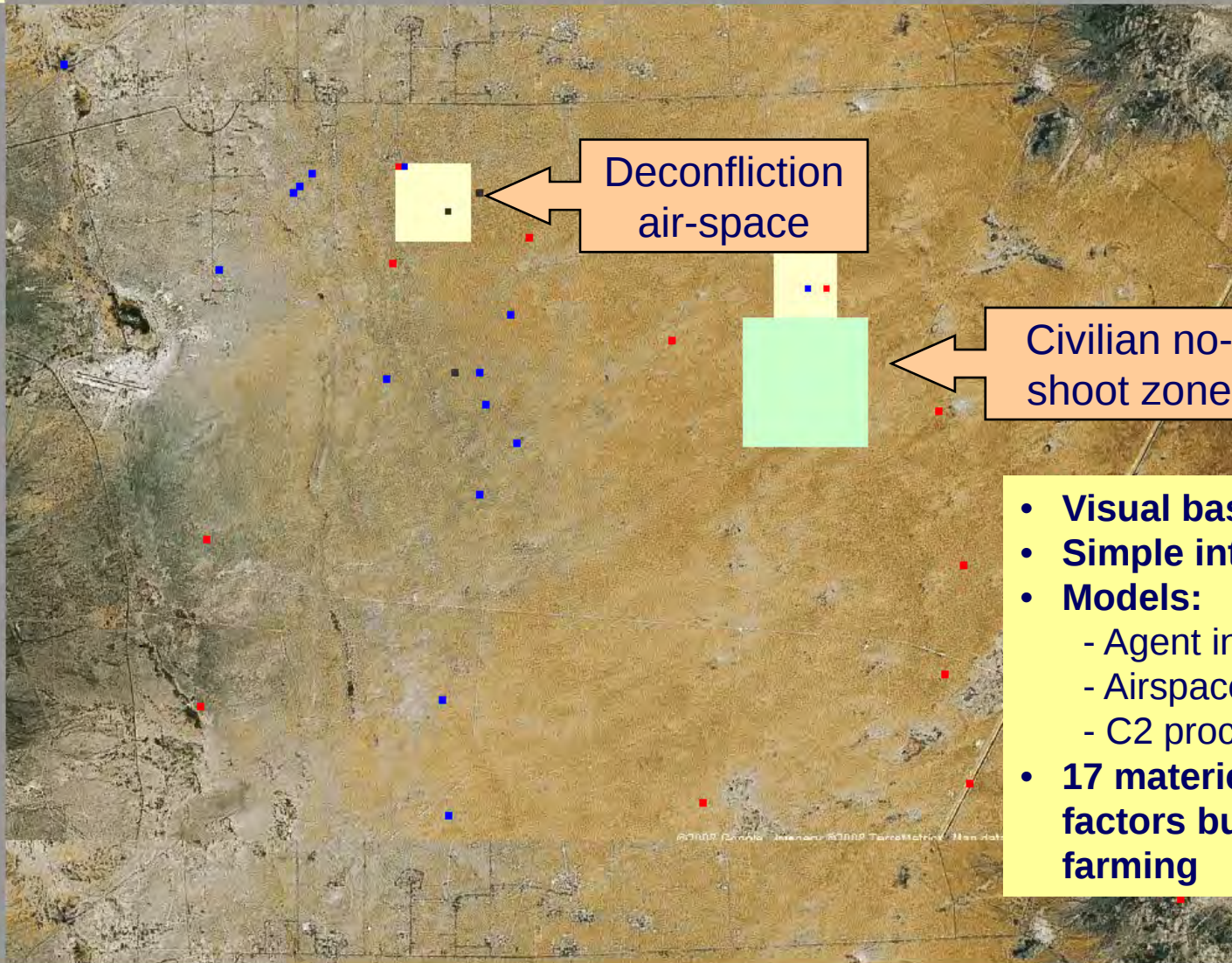
CTM 0.3.3.1.2.4
Determine
Feasible Levels/
Regions for
Measures

CTM 0.3.3.1.2.5
Structure the
Measures



Agent Based Model

Case Study Example



Run

Trial # = 1

Run # = 1

Time = 4,440

- Visual basic code
- Simple interface
- Models:
 - Agent interactions
 - Airspace deconflictions
 - C2 processes
- 17 materiel and non-materiel factors built in for data farming



Factor Capability Crosswalk SME Estimates



Crosswalk Dimension	Crosswalk Sub Dimension	Factor	Levels	Factor Type
Study Sample System of Systems	Materiel	1. Global Information Grid (GIG)?	Yes/No	Categorical
		2. Blue Speed	1/2 (Multiplier)	Continuous
		3. Blue Monitor	1/2 (Multiplier)	Continuous
		4. Blue Fires	1/2 (Multiplier)	Continuous
	Non-materiel: Doctrine	5. Multiple Trackers?	Yes/No	Categorical
		6. Expedited Call For Fire?	Yes/No	Categorical
		7. Call For Fire type Decision	A/C	Categorical
		8. Expedite Move	Yes/No	Categorical
		9. Restricted Op. Zone Type	Restrictive/Permissive	Categorical
		10. ROZ Size	1/2 (Multiplier)	Continuous
		11. ROZ Expiration	Yes/No	Categorical
		12. ROZ Slack Time	1/2 (Add. Time Increments)	Continuous
		13. Multi-Service Wait time	1/2 (Add. Time Increments)	Continuous
Condition	Environmental	14. Adverse Weather?	Yes/No	Categorical
		15. Civilian Zone?	Yes/No	Categorical
		16. Civilian Zone Size	20/40	Continuous
		17. Civilian Zone Location	1/2	Categorical
		17 Factors with 3 dependencies		7 Continuous/ 10 Categorical

**Case Study
Example**



Step 1: “Quick Look” Analysis

Dependent Variable: Number Threat Kills

Independent Variables: 17 factors (decision & conditional)

DOE: Resolution III Fractional Factorial (80 trials, 20 runs each)

Analysis tools: Stepwise Regression Model

SME
Estimate

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
Blue Speed	29.0625	1.409628	20.62	<.0001*
ROZ Size	-26.1625	1.409628	-18.56	<.0001*
CFF Type of Decision[A]	-12.39375	0.704814	-17.58	<.0001*
ROZ Type[P]	10.71875	0.704814	15.21	<.0001*
Multiple Trackers?[No]	-5.81875	0.704814	-8.26	<.0001*
ROZ Slack Time	9.3875	1.409628	6.66	<.0001*
GIG?[Off]	-3.81875	0.704814	-5.42	<.0001*
Civilian Zone?[3]	-6.58125	1.409628	-4.67	<.0001*
ROZ Expiration[No]	-2.79375	0.704814	-3.96	0.0001*
Expedite Move[No]	-2.63125	0.704814	-3.73	0.0003*
Blue Fires	4.8375	1.409628	3.43	0.0008*
Blue Monitor	4.4375	1.409628	3.15	0.0020*
Expedited CFF?[No]	-2.21875	0.704814	-3.15	0.0020*
Adverse Weather?[No]	-2.11875	0.704814	-3.01	0.0031*
Multi-service Wait time	-1.5875	1.409628	-1.13	0.2620
Civilian Zone?[4]	-1.175	1.409628	-0.83	0.4059
Civilian Zone?[1]	0.41875	1.409628	0.30	0.7669
Civilian Zone?[2]	0.0125	1.409628	0.01	0.9929

Significant
factors

Non-
Significant
factors

Findings:

- 14 factors significant, 3 factors not significant
- Adverse weather factor non-intuitive



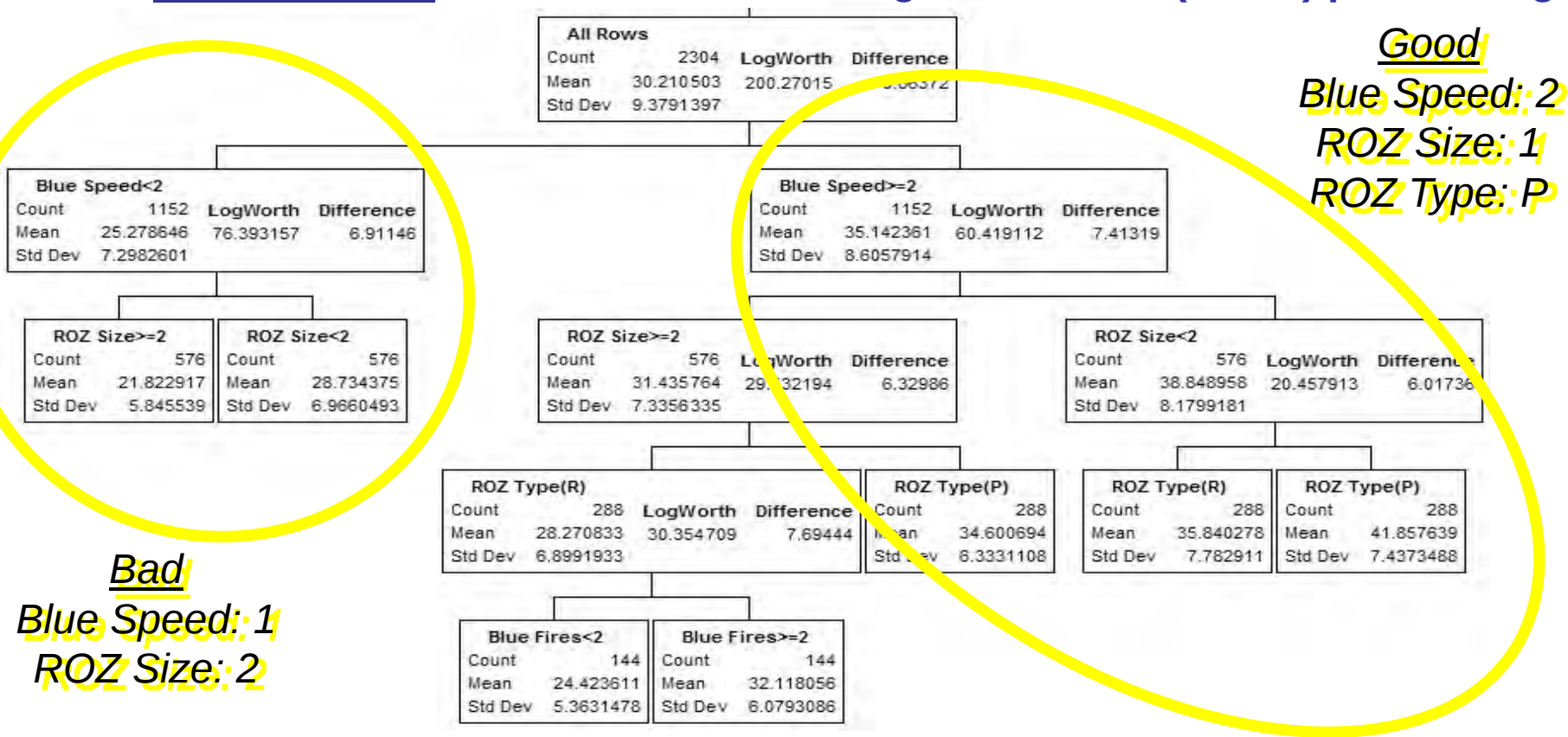
Step 2: Main Effects Analysis

Dependent Variable: Number Threat Kills

Independent Variables: 14 factors (decision & conditional)

DOE: Resolution V Fractional Factorial (2304 trials, 3 runs each)

Analysis tools: Classification and Regression Tree (CART) partitioning



Findings:

- Stressing factors (Blue speed, ROZ size, ROZ type)



Step 2: Main Effects Analysis

Dependent Variable: Number Threat Kills

Independent Variables: 14 factors (decision & conditional)

DOE: Resolution V Fractional Factorial (2304 trials, 3 runs each)

Analysis tools: Stepwise Regression Model

SME
Estimate

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
Blue Speed	9.8637153	0.243801	40.46	<.0001*
ROZ Size	-7.162326	0.243801	-29.38	<.0001*
ROZ Type[P]	2.4657118	0.1219	20.23	<.0001*
GIG?[Off]	-1.751302	0.1219	-14.37	<.0001*
CFF Type of Decision[A]	-1.508247	0.1219	-12.37	<.0001*
Multiple Trackers?[No]	-1.313802	0.1219	-10.78	<.0001*
Civilian Zone?[No]	1.3897569	0.172393	8.06	<.0001*
Civilian Zone?[Yes20]	1.0837674	0.172393	6.29	<.0001*
Expedite Move[No]	-0.455295	0.1219	-3.73	0.0002*
Adverse Weather?[No]	0.3658854	0.1219	3.00	0.0027*
Expedited CFF?[No]	-0.30599	0.1219	-2.51	0.0121*
ROZ Expiration[No]	-0.325087	0.172393	-1.89	0.0595
Blue Monitor	-0.426215	0.243801	-1.75	0.0806
Multi-service Wait time	-0.243924	0.243801	-1.00	0.3172
Blue Fires	0.0894097	0.243801	0.37	0.7139
ROZ Expiration[Yes1]	-0.03342	0.172393	-0.19	0.8463

Significant
factors

Non-
Significant
factors

Findings:

- 10 factors significant
- Blue fires no longer significant
- Adverse weather factor intuitive



Step 2: Main Effects & Two-way Interaction

Dependent Variable: Number Threat Kills

Independent Variables: 14 factors (decision & conditional)

DOE: Resolution V Fractional Factorial (2304 trials, 3 runs each)

Analysis tools: Stepwise Regression Model

SME

Estimate

Sorted Parameter Estimates					
Term	Estimate	Std Error	t Ratio		Prob> t
Blue Speed	9.8637153	0.202018	48.83		0.0000*
ROZ Size	-7.162326	0.202018	-35.45		<.0001*
ROZ Type[P]	2.4657118	0.101009	24.41		<.0001*
(Blue Fires-1.5)*ROZ Type[P]	-4.063368	0.202018	-20.11		<.0001*
GIG?[Off]	-1.751302	0.101009	-17.34		<.0001*
Civilian Zone?[Yes40-Yes20&No]	-1.855143	0.107136	-17.32		<.0001*
CFF Type of Decision[A]	-1.508247	0.101009	-14.93		<.0001*
Multiple Trackers?[No]	-1.313802	0.101009	-13.01		<.0001*
Adverse Weather?[No]*ROZ Type[P]	1.2773438	0.101009	12.65		<.0001*
(Blue Monitor-1.5)*ROZ Type[P]	1.7161458	0.202018	8.49		<.0001*
(Blue Speed-1.5)*ROZ Type[P]	1.2421875	0.202018	6.15		<.0001*
GIG?[Off]*ROZ Expiration{No-Yes1}	-0.6875	0.123711	-5.56		<.0001*
(Civilian Zone?[Yes40-Yes20&No]+0.33333)*(ROZ Size-1.5)	1.1803385	0.214273	5.51		<.0001*
(Civilian Zone?[Yes40-Yes20&No]+0.33333)*ROZ Type[P]	-0.57194	0.107136	-5.34		<.0001*
CFF Type of Decision[A]*ROZ Type[P]	0.531684	0.101009	5.26		<.0001*
Adverse Weather?[No]*CFF Type of Decision[A]	0.5099826	0.101009	5.05		<.0001*

Significant factors

Findings:

- 6 main effect factors significant
- 5 additional factors significant in two-way interactions
- Blue fires & adverse weather part of two-way interactions



Step 3: Aggregated Conditional Factors

Dependent Variable: Number Threat Kills

Independent Variables: 10 factors (9 decision, 1 conditional)

DOE: Resolution V Fractional Factorial (128 trials, 3 runs each)

Analysis tools: Classification and Regression Tree (CART) partitioning

Case Study Example

Bad

Stressing Factor: Most

Blue Speed: 1

GIG?: Off

Good

Stressing Factor: Least

Blue Speed: 2

CFF Type Decision: C

ROZ Type: P

RSquare	II	Number of Splits
0.771	128	9

All Rows			
Count	128	LogWorth	Difference
Mean	102.375	13.892196	35.1875
Std Dev	31.096497		

(5 Factor Least Stressing Levels)

Count	64	LogWorth	Difference
Mean	84.78125	5.994603	23.5
Std Dev	22.648781		

Blue Speed<2			
Count	32	LogWorth	Difference
Mean	73.03125	4.1947918	21.9375
Std Dev	18.767653		

Blue Speed>=2			
Count	32	LogWorth	Difference
Mean	96.53125	2.9392673	20.4375
Std Dev	20.130196		

GIG?(Off)		GIG?(On)	
Count	16	Count	16
Mean	62.0625	Mean	84
Std Dev	10.266247	Std Dev	19.127641

GIG?(Off)		GIG?(On)	
Count	16	Count	16
Mean	71.3125	Mean	106.75
Std Dev	11.284748	Std Dev	17.774514

ROZ Type(R)		ROZ Type(P)	
Count	8	Count	8
Mean	92.75	Mean	120.75
Std Dev	9.6473534	Std Dev	11.658841

(5 Factor Least Stressing Levels)

Count	64	LogWorth	Difference
Mean	119.96875	12.671298	38.125
Std Dev	28.415829		

Blue Speed<2			
Count	32	LogWorth	Difference
Mean	100.90625	4.2290919	20.4375
Std Dev	17.43256		

Blue Speed>=2			
Count	32	LogWorth	Difference
Mean	139.03125	2.7937483	24.0625
Std Dev	24.225399		

CFF Type of Decision(A)		CFF Type of Decision(C)	
Count	16	Count	16
Mean	90.6875	Mean	111.125
Std Dev	14.286211	Std Dev	14.183911

CFF Type of Decision(A)		CFF Type of Decision(C)	
Count	16	Count	16
Mean	127	Mean	151.0625
Std Dev	24.144012	Std Dev	17.920077

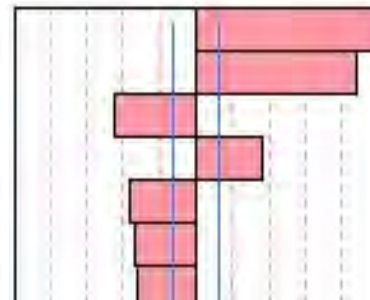
ROZ Type(R)		ROZ Type(P)	
Count	8	Count	8
Mean	110	Mean	144
Std Dev	14.696938	Std Dev	19.302109



Step 3: Aggregated Conditional Factors Results

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
(5 Factor Least Stressing Levels)	17.59375	1.122227	15.68	<.0001*
Blue Speed	30.8125	2.244455	13.73	<.0001*
(Blue Fires-1.5)*ROZ Type[P]	-15.8125	2.244455	-7.05	<.0001*
ROZ Type[P]	6.375	1.122227	5.68	<.0001*
CFF Type of Decision[A]	-6.296875	1.122227	-5.61	<.0001*
GIG?[Off]	-5.90625	1.122227	-5.26	<.0001*
Multiple Trackers?[No]	-5.59375	1.122227	-4.98	<.0001*



Dimension	Sub Dimension	Priority/Factor	Levels	Factor Type
System of Systems	Materiel	1. Blue Speed	1/2 (Multiplier)	Continuous
		2. Blue Fires	1/2 (Multiplier)	Continuous
		5. Global Information Grid (GIG)?	Yes/No	Categorical
	Non-materiel: Doctrine	3. Restricted Op. Zone Type	Restrictive/Permissive	Categorical
		4. Call For Fire type Decision	A/C	Categorical
		6. Multiple Trackers?	Yes/No	Categorical
		Most Stress 1. ROZ Size	1 (Multiplier)	Continuous
		Most Stress 2. ROZ Expiration	No	Categorical
		Most Stress 3. Multi-Service Wait time	2 (Additional Time Increment)	Continuous
		Most Stress 4. Adverse Weather?	Yes	Categorical
		Most Stress 5. Civilian Zone?	Yes (Size = 40)	Categorical
Condition	Environmental			

Findings:

- One aggregated condition factor significant
- Six decisional factors significant



Step 1: Measures Relationship Table



Case Study Example

Green: Direct relationship
Red: Indirect relationship
No color: No relationship

		Case Study Example																								
Green: Direct relationship Red: Indirect relationship No color: No relationship		M M O E 1	M M O E 2	T M O P 1	T M O P 2	T M O P 3	M O S A 1	M O S A 2	M M O E 1	M M O E 2	M M O E 3	M M O E 1	M M O E 2	M M O E 3	M M O E 1	M M O E 2	M M O E 3	M M O E 1	M M O E 2	M M O E 3	T M O P 1	T M O P 2	T M O P 3	T M O P 1	T M O P 2	T M O P 3
Factors	Values	1	2	1	2	3	1	2	1	2	3	1	2	3	1	2	1	2	1	2	1	2	1	2	1	2
GIG	Off or On	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	0	1	0	1	0	1	0	1	0	1
Blue Speed	1 or 2	1	1	1	0	0	1	0	1	0	0	1	0	0	1	0	1	0	1	0	1	0	0	0	0	0
Blue Monitor	1 or 2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Blue Fires	1 or 2	1	1	0	-1	0	1	-1	0	-1	0	0	-1	0	1	-1	1	-1	0	0	-1	1	0	0	0	0
Civilian Zone	Off or On	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	1
Civilian Zone Size	Small or Large	-1	-1	-1	0	0	-1	0	1	0	0	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0
Multiple Trackers	No or Yes	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Adverse Weather	No or Yes	1	1	1	1	0	0	1	1	1	0	1	1	0	0	1	0	1	0	1	0	1	0	0	0	0
Expedited CFF	No or Yes	1	1	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
CFF Type of Decision	Closest or Available	-1	-1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1
Expedite Move	No or Yes	1	1	1	-1	0	1	0	1	-1	0	1	-1	0	1	0	1	0	1	0	1	0	-1	0	0	0
ROZ Type	Restrictive or Permissive	1	1	1	1	1	1	-1	1	1	1	1	1	1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1
ROZ Size	1 or 2	-1	-1	-1	0	0	-1	1	1	0	0	1	0	0	1	-1	1	-1	1	-1	1	-1	0	0	0	0
Multi-service Wait time	1 or 2	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
ROZ Expiration	No or Yes	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	1
ROZ Slack Time	1 or 2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Civilian Zone Location	1 or 2	0	0	-1	0	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	1

Findings (Direct and Indirect relationships):

- Direct relationship for all measures: Blue Monitor, Multiple Trackers, ROZ Slack Time
- Indirect relationship for MMOEs and TMOPs/MOSAs: CFF Type of Decision, ROZ Expiration
- Direct relationship across both MMOEs



Insights into Exploratory Analysis



- Resolution V DOE needed for assessing two-way interactions
 - Resolution III does not confound main effects with one another, but does confound main effects with 2-factor interactions
 - Resolution V does not confound main effects and 2-factor interactions, but confounds main with 4-factor and 2-factor with 3-factor
- Factor prioritization is an iterative process
 - Initial DOE and data farming may provide first insights into significant measures
 - May require further exploration to validate initial findings
 - May differ across multiple measures and require retaining uncertain factors in the second design
 - Iterative farming can provide additional prioritization of factors
- Factors with more than two discrete levels requires additional farming to assess their impact
 - Requires crossing with additional factors
 - May wish to assume two levels for initial design
- Multiple measures (dependent variables) adds significant complexity to determining factors with highest impact
 - Requires evaluation of factors across measures
 - Constructing relationship tables provides insights on measure impacts



Summary



- Exploratory analysis requires an iterative process for prioritizing factors
- Factors can be analyzed across multiple dependent variables (measures)
- Automated tools for DOE and modeling can help to simplify the exploratory analysis process
- Non-materiel factors can be equally important to testing a System of Systems



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Abstract

The Joint Test and Evaluation Methodology (JTEM) project has been collaborating with various government organizations and academia to develop enhanced Design of Experiment (DOE) modeling and analysis approaches for Testing in a Joint Environment (TIJE). This paper discusses the applied research that has been conducted in this area over the past three years, as well as its application to JTEM test events. Discoveries involving enhanced data farming techniques and technology applications have proven to be catalysts for test and evaluation of complex adaptive systems. Hybrid DOE models for large factor test designs (e.g., Fractional Factorial Controlled Sequential Bifurcation, Resolution Five Fractional Factorial, Nearly Orthogonal Latin Hypercube) have demonstrated success in refining robust Joint test spaces. Innovative application of analytical models and methodologies (e.g., Advanced Response Surface Methodology, Classification and Regression Tree) have improved our ability to analyze Critical Capability Issues (CCI) involving multiple responses. Agent based model simulation prototypes (e.g., Tester, MANA, Pythagoras) have been modified and/or developed by our academic and government partners to enable enhanced test design and evaluation of capabilities in a Joint environment. Proof of concept efforts in this collaboration has included International Data Farming Workshop (IDFW) events, where various techniques and tools have been explored for use in Testing in a Joint Environment (TIJE). Key research techniques and selected results are presented in the context of a use case that is based upon JTEM test events.