Next Generation
Electronic Warfare
Modeling and Simulation

Dr. Randall Janka
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Support to Military Operations
Agenda

- Introductions & background
- I2WD’s next gen EW technology & mission drivers
- Scheduling & control for optimizing concurrent ES & EA
- Scheduling algorithm design
- Simulation framework design
- Demo
- Some performance observations
- Conclusion
Introductions & Background
Who Is Zeta?

A Leading Intelligence Contractor

- Prime NRO contractor for:
  - SIGINT processing (Both SE and SI)
  - Enterprise Integration
  - COMINT system acquisition
  - COMINT solutions
- Highly valued provider for:
  - Military airborne signal processing
  - Special SIGINT programs
  - Collection products and survey tools to the IC

>300 Talented & Motivated Employees

Engineering Staff’s Education
Highest Degree Earned

- 99% with clearances
- 99% retention rate
- 20 years average experience

Strategically Positioned

- Enterprise Integrator
- Pioneering work on NRO Strategic Framework
- Agility of our software solutions
- Leveraging of solutions to DOD

Embedded with the customer worldwide
Zeta’s EW Mission Partner: USA’s I2WD

• Zeta program support for USA/I2WD
  – SIGINT provider for USA’s RC-12 Guardrail
  – Entering our third phase of next gen ES/EA scheduling & control applied R&D
    • Urban Sabre
      – M&S
    • IRON Symphony
      – Architecture development
      – M&S
      – Prototyping

• Recent collaborations
  – 54th JEWC (9/09)
  – 46th Annual AOC International Symposium & Convention Technical Poster Session (10/09)
I2WD’s Vision of Army EW Into the Future

“Future Fight” Targets

- Communications Systems
- Sensors
- Information Systems and Infrastructure (Comms)
- Positioning, Nav & Timing Systems
- Weapons of Mass Destruction
- Unmanned Aerial Vehicles
- Shoulder Launched Rockets
- Fused Projectiles
- Hard and Deeply Buried Targets
- Small, Highly Mobile Attack Teams
- Conventional Large Forces

“Current Fight” Target Set

Radio Controlled Improvised Explosive Devices (RCIEDs)

Army EW Must Address Broader Target Sets Than IEDs
I2WD’s Next Gen EW Technology & Mission Drivers
Urban Sabre Vision

Provide an on-the-move (OTM) urban environment capability to—

Detect
Identify
Classify
Geolocate
Engage
— enemy C4ISR nodes in an urban environment

I2WD Division/POC
INO Division/Matt Bajor—Matthew.bajor@us.army.mil
Perform detect/ID/classification/geolocation/attack of a broad set of high priority wireless devices to regain & maintain control of the RF spectrum
Scheduling & Control for Optimizing Concurrent ES & EA
Problem & Solution Spaces

**The Problem Space**

- Need for concurrent execution of ES & EA missions
  - Important: ES & EA against diverse $C^2$
  - Critical: EA against RCIEDs
    - But defer this mission coverage to EP platforms
- Current inventory of legacy stovepiped ES & EA resources
  - Not easily adapted to rapidly changing EW space
  - Inhibit ability to schedule and coordinate ES & EA missions in real time
    - Lack sufficient processing resources in a given ES or EA resource
    - Do not have the necessary scheduling algorithms
    - Lack interoperability
- Cannot manage both resources in a unified fashion
  - Spectral fratricide

**The Solution Space**

- Develop new real-time scheduling approach(es) to enable simultaneous execution of ES & EA missions
  - Concurrent control of ES & EA resources
    - Optimal utilization of HW/SW resources
    - Compliant with user-defined policies
  - Autonomous control in real-time
    - Optimize its target engagement schedule
    - Maximize effectiveness & efficiency
- Construct an open architecture
  - Dynamic management of HW/SW resources
    - Low-frequency configuration management
    - High-frequency application of resources to targets
  - Allow rapid integration of new EA/ES techniques against emerging targets
  - Based on industry best practices
- Allow for extension to the net-centric operations

Innovative Engineering Solutions
High-Level State Diagram

- **Basic template**
  - E.g., could include HVT SOIs for immediate EA

- **Pre-mission plan to be loaded:**
  - SOI list for ES to prosecute
  - EA plan for SOIs
    - Techniques (M:N)
    - Policy
      - Priority order of techniques
      - Definition of resolution, i.e., when do you declare victory or defeat, then what?
  - Quiescent schedule
    - Default ES schedule policy when not processing reactive EA jobs
    - Policy for rescheduling

- **For this CONOP, we need to model & optimize:**
  - Planning
  - Scheduling
The Scheduler’s View of the World

Scheduler’s Interface to the World

Controller handles low-level behavior management, assignment and execution
Scheduling Algorithm Design
Theoretic-based Scheduling Algorithms

- **Theoretic = “AIOR” (AI + OR) or “AO”**
  - AI = Artificial Intelligence
  - OR = Operations Research

- **AI-based planning for creating EA tasks**
  - Pragmatic AI approach
  - Use Partial Order Planning (POP) based on the Hierarchical Task Network (HTN) notion
  - Re EA task creation, this reduces to probabilistic-based ranking of techniques

- **OR-based scheduling for ordering the EA tasks w.r.t. time and processor**
  - Classical OR approach to optimize the use of resources, typically w.r.t. time
  - Applied flexible scheduling approaches
  - Leveraging the TORSCHE MATLAB scheduling toolbox from the Czech Technical University in Prague
AIOR Scheduling: Problem Definitions

- Problem descriptions reduce to three scheduling problems of the same form but different heuristics:
  - Problem description uses standard form: \( \alpha | \beta | \gamma \)
  - \( \alpha = \) “Machine environment”; i.e., the target platform
  - \( \beta = \) Processing characteristics & constraints; e.g., precedence, preemption, etc.
  - \( \gamma = \) Objective to be optimized

- \( Pm | | C_{\text{max}} \)
  - Using SPT, WSPT & LPT

- \( Pm | | \Sigma C_j \)
  - Using ECT & EST

- \( Pm | | \Sigma w_j C_j \)
  - Using ECT & EST

**Objective Functions (\( \gamma \))**
- \( C_{\text{max}} = \) makespan; i.e., \( \sim \) completion time of last EA task (min \( C_{\text{max}} \) implies good utilization)
- \( \Sigma C_j = \) total completion time
- \( \Sigma w_j C_j = \) total weighted completion time

**Heuristic Strategies**

<table>
<thead>
<tr>
<th>Heuristic</th>
<th>Description</th>
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<tbody>
<tr>
<td>SPT</td>
<td>Shortest processing time first</td>
</tr>
<tr>
<td>WSPT</td>
<td>Weighted SPT first</td>
</tr>
<tr>
<td>LPT</td>
<td>Longest processing time first</td>
</tr>
<tr>
<td>ECT</td>
<td>Earliest completion time first</td>
</tr>
<tr>
<td>EST</td>
<td>Earliest start time first</td>
</tr>
</tbody>
</table>
• Pragmatic Algorithms
  – Best Effort (BE)
    • Discovered and adapted during study phase
  – Best Effort Optimized (BEO)
    • Improved BE developed during M&S

• Best Effort (BE)
  – Greedy scheduling algorithm
  – Pre-Simulation creates a look up table for techniques available to each SOI type and channel pair and orders them by their effectiveness level
  – Ranks each individual SOI type and channel pair according to priority allocated for each new SA report received
  – Guarantees the highest value targets will get scheduled first
  – Guarantees highest value targets will utilize most effective techniques for given SOI

• Best Effort Optimized (BEO)
  – Similar to BE
  – Starts to look at the group as a whole
  – Pre-Simulation creates a look up table for techniques available to each SOI type and channel pair and orders them by their effectiveness level
  – Ranks each individual SOI type and channel pair according to priority allocated for each new SA report received
  – Re-orders look up table created pre-simulation due to the number of SOI type and channel pairs contained in the SA report
  – Rest of algorithm matches BE
MOE & BDA

• MOE: Scheduler metric
  – Measures the number of SOIs successfully scheduled versus the number of SOIs reported in the SA reports.

\[
MOE = \sum \frac{SOIs\_scheduled}{SOIs\_reported} (\|priority\_vec\|)
\]

• BDA: System metric
  – Measures the number of SOIs successfully attacked and destroyed versus the number of SOIs reported in the SA report

\[
BDA = \sum \frac{SOIs\_destroyed}{SOIs\_reported} (\|priority\_vec\|)
\]
Simulation Framework Design
Modeling & Simulation (M&S) Initial Thoughts

- Initial analysis
  - Wanted to use MATLAB (M/L) for rapid evaluation whenever possible
    - Modeling and evaluation of algorithms
    - Associated data models
  - Expected to have to port non-M/L algos into M/L for analysis
    - C/C++ (algos?)
    - Java (UI?)

- Simulation framework
  - After we had modeled the simulation…
    - I/O
    - Signal environment
    - Simulation dynamics
  - …Then we would know what kind of DE-based framework to use
    - Roll-your-own M/L DE engine?
    - Simulink—possibly with Stateflow a/o SimEvents?
  - UI for front and back ends
    - User inputs: Scenario, EA lib & POP updates, etc.
    - Display: Data logging (TBD), MOE display, etc.

- View towards rapid prototyping
  - Use Embedded M/L (EML) if/when possible to make porting to prototype easier
Modeling Tools and Approach Evolution

- Tool considerations
  - Preferences
    - Right level of granularity & of fidelity and able to interface with M/L
  - M/L Toolbox candidates for modeling behaviors
    - From the MathWorks
      - Statistics, Optimization, Direct Search & Genetic Algorithm
    - From third parties
      - TORSCHÉ (Time Optimisation, Resources, SCHEduling)
        » Recommended by the Godfather of Scheduling (Prof. Michael Pinedo)
      - Czech Technical University in Prague (“Czech Tech”)
      - Educational freeware ⇒ didn’t know its limitations
        » You always get what you pay for with freeware!
  - M/L-friendly simulation tools if at all possible for ease of integration
    - Simulink? SimEvents a/o Stateflow?
- Use a model driven architecture approach that is rapid prototype friendly
  - Use Embedded M/L (EML) coding style
  - Possibly use Simulink with Stateflow a/o SimEvents and Real-Time Workshop (RTW) for rapid prototyping
Simulation Tools and Approach Evolution

• Development platform
  – Mathworks’ MATLAB/Simulink

• Embedded MATLAB (EML) code
  – Easily translated into either C or C++
  – All schedulers and deliverable code

• SimEvents
  – Discrete modeling environment
  – SOIs can be modeled as events that happen over time
    • Events are modeled as Entities
  – Flexible for expansion in later phases

• StateFlow
  – Model state based transitions in the environment
    • Determine when to create SA reports
    • Determine when to execute a produced schedule
Simplified Component View

- **Test harness**
  - Environment sampled by ES resources
  - Generates SA reports

- **Composer**
  - Consumes SA reports and generates an optimal schedule based on user EW Policy and resources
  - Best Effort & AIOR

- **Conductor**
  - Executing schedule against signal targets
  - Simulated in the framework

**Algorithms**
- Best Effort
- Theoretic hybrid
Simulation Flow Chart

**t = 1**
- **Assign Attributes**
  1. SOI Type
  2. ISOI Info
  3. GUID
  4. Time Present in Environment
  5. Additional Information as needed
- **Time Out Attribute Assigned to Time Present**
- **Combine Paths**
- **Combined Q**
- **Gate**
- **Read Attributes**
- **Wait Q**
- **Request for SA report sent from system.**
- **New SA report created and is sent to the scheduler.**

**t = 2**
- **New Entity Created**
- **t = 3**
- **Assign Attributes**
  1. Box
  2. Processor
  3. Processing Time
  4. Start Time
  5. Scheduled Flag
  6. Additional Information as needed
- **Path Divider**
- **Technique Not Scheduled**
- **Technique Not Successful**
- **t = 4**
- **SOI Destroyed Sink**
- **Path Divider**
- **Processor**
- **Success**
- **t = 5**
- **Path Divider**
- **Technique Scheduled**
- **Controller Assigning information received from scheduler.**
- **Scheduler finished creating schedule and has passed info to Controller.**
Description of Flow Chart

• t = 1 (SOI Creation)
  – SOIs created in the environment
  – Identification information added to SOIs in the form of attributes
  – SOIs added to the combined queue
    • Queue represents the SOIs currently in the environment

• t = 2 (SA Creation)
  – SOIs contained in the queue released
  – Information is read from the attributes
  – SA report is created
  – SOIs are placed in a wait queue

• t = 3 (Schedule SOIs)
  – Schedule is created by the algorithm
  – Controller interprets schedule and attaches information about execution via attributes
  – SOIs scheduled are flagged and sent to processors
  – SOIs not scheduled are sent back to the combined environment queue

• t = 4 (Executing Techniques)
  – Techniques scheduled to process for the amount of time required

• t = 5 (BDA)
  – Techniques marked as successful are destroyed
  – Techniques not successful are returned to the combined environment queue
Demo
Datasets

- Multiple datasets created to exercise scheduling algorithms
- Realistic data
  - SimData
- Synthetic data to stress the sim framework
  - NormCondsData
    - SimData with lower dynamic range of Sp
    - Techniques for every stealth level for every SOI
  - FastTimeout
    - SOIs up and down within schedule’s dwell
    - Produces large number of SOIs
  - LowSuccessRate
    - Low $P_k$’s
    - More signals survive and show up in subsequent SAs
  - OverloadedSOIs
    - High SOI count
    - Overwhelms the scheduler
  - UnderAllocated
    - Not all processors are allocated
    - Also stresses the scheduler
Control Panel Pre-Run
### Parameter Data Entry

#### Microsoft Excel - SimData.xls

<table>
<thead>
<tr>
<th>Variable</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
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<td></td>
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<tr>
<td>Proc</td>
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</tbody>
</table>

**Box(1) Proc:** Enter Box Count [1-4]
**Box(2) Proc:** Total number of supported target signals [1-4]
**Box(3) Proc:** Number of EAI processors in Box #1
**Box(4) Proc:** Number of EAI processors in Box #2

**Box(1) Proc:** Enter Target S0I for each processor [1-4]

<table>
<thead>
<tr>
<th>BOX</th>
<th>PROCESSOR</th>
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<tbody>
<tr>
<td>1</td>
<td>1111</td>
</tr>
<tr>
<td>2</td>
<td>2222</td>
</tr>
<tr>
<td>3</td>
<td>3333</td>
</tr>
<tr>
<td>4</td>
<td>4444</td>
</tr>
</tbody>
</table>

**Stealth Level:**
1 = Don't care about stealth
2 = Moderate stealth
3 = Maximum stealth

<table>
<thead>
<tr>
<th>Stealth Level</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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**SimParameters:**

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<tbody>
<tr>
<td>SigGen min</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>SigMix</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Stealth Level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
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</tr>
</tbody>
</table>

**Significance:**
1 = Non-Adjustable
2 = Adjustable

**Timeout Information:**

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<th>B</th>
<th>C</th>
<th>D</th>
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**Default Schedule Duration:**

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**Random Seed:** 12345

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**Innovative Engineering Solutions**
### Signal & Technique Parameters Data Entry

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<td>Variable</td>
<td>Descriptions</td>
<td>Input Values</td>
<td>Notes</td>
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<tr>
<td>2</td>
<td>TT(1).Mohans</td>
<td>14</td>
<td>Number</td>
<td></td>
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<tr>
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<tr>
<td>5</td>
<td>NumSVCChan</td>
<td>3</td>
<td>Number</td>
<td></td>
</tr>
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<td>6</td>
<td>HVChan Number</td>
<td>7</td>
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<td>8</td>
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<td>9</td>
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<td>10</td>
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<tr>
<td>11</td>
<td>HVChan Value</td>
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<th>A</th>
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<td>Input Values</td>
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<td>4</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>5</td>
<td>TT(1,1).Sp</td>
<td>34.0E-8</td>
<td></td>
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</tr>
<tr>
<td>6</td>
<td>TT(1,2).PercentSuccess</td>
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<tr>
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<tr>
<td>8</td>
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<td>-3</td>
<td>DN = 3, TX = -2, TXall = -1</td>
<td></td>
</tr>
<tr>
<td>9</td>
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<td>DN = 3, TX = -2, TXall = -1</td>
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<td>15</td>
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<td>23</td>
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<td>TT(1,8).MultiTarget</td>
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<td>DN = 3, TX = -2, TXall = -1</td>
<td></td>
</tr>
</tbody>
</table>

Innovative Engineering Solutions
Control Panel Post-Run

Simulation Controls

- Scheduling Algorithm
  - Default (default)

- File Info
  - BW Workbook: SimuliLabs
  - Results file: my_result.out

- Execution Control
  - Execute

Measurement Of Effectiveness
Overall MGE = 0.83821

Situation Awareness Report

Electronic Attack Status

Resource Pool

Innovative Engineering Solutions
Some Performance Observations
Some MOE Performance Data

| Data Set           | BE | BEO | \( P_m | C_{\text{max}} \) | \( P_m | \Sigma C_j \) | \( P_m | \Sigma w_j C_j \) |
|-------------------|----|-----|-------------------|----------------|----------------|
|                   | SPT | WSPT | LPT | ECT | EST | ECT | EST |
| Fast Timeout      | 97.8 | 99.9 |     |     |     |     |     |
| Low Success       | 95.6 | 92.5 |     |     |     |     |     |
| Norm Conditions   | 40.4 | 55.9 |     |     |     |     |     |
| Over-loaded       | 81.7 | 98.2 |     |     |     |     |     |
| Priorities        | 99.1 | 98.0 |     | 95.3 |     |     |     |
| SimData           | 83.6 | 83.6 |     |     | 97.2 |     |     |
| Under-allocated   | 43.3 | 73.0 |     |     | 97.2 |     |     |

| Low Success       | 64.4 |     |     |     |     |     |     |
| Norm Conditions   | 55.9 |     |     |     |     |     |     |
| Over-loaded       | 98.6 |     |     |     |     |     |     |
| Priorities        | 95.3 |     |     |     |     |     |     |
| SimData           | 83.4 |     |     |     |     |     |     |
| Under-allocated   | 71.3 |     |     |     |     |     |     |
Observations & Possible Solutions

• Some obvious observations present themselves
  – The system can suffer from dead space since the SOI with the longest suppression times will bound the schedule
    • Can EA processors handle more than one SOI to improve techniques coverage?
  – The AIOR is bound by the inability to interleave techniques’ bursts
    • What agility can be expected from the Controller?
  – The AIOR variants all behave the same because AI planning always picks the highest rank technique in a memoryless system
    • Employ memory
• More can be found using the sim framework
  – Very multi-dimensional
Performance Bound for Single SOI/Proc

Sim Parameters
- SimData
- SchedDur = 12
- SigGen = [50:100]
- SigMix = 25%/SOI
- Box = 4 x 4
- Stealth Level = 1
- Early AIOR

Observations
- Lost EA jobs
  SOI#1: Proc1
  SOI#4: Pros 1-3
- Idle Pros
  SOI#2: Pros 1-4
  SOI#3: Pros 2-4
Performance Improvement for Flexible Processor

Sim Parameters
- SimData
- SchedDur = 12
- SigGen = [50:100]
- SigMix = 25%/SOI
- Box = 4 x 4
- Stealth Level = 1
- Early AIOR—BUT all processors are able to prosecute all four SOIs

Observations
- NO Lost EA jobs
- Still have some idle processors Procs 3-13
Road Map for Next Gen EW Scheduling

Effectiveness
(Increasing target count & $P_e$)

Adaptability
(Increasing ease of updating techniques)

Legacy Stovepipe Systems

Fixed architecture
Static target set
Human-driven scheduling

Urban Sabre
Flexible but static architecture (1 SOI/proc)
Static target set
Autonomous (Round Robin?) scheduling

Urban Sabre with Composer
Flexible but static architecture (1 SOI/proc)
Static target set
Optimizing autonomous scheduling (BE/O & AIOR)

Urban Sabre with v.2 Composer, Agile Conductor Dynamic Personalities
Flexible & dynamic architecture (≥1 SOI/proc)
*Static target set
Advanced Optimizing autonomous scheduling (BE/O & AIOR**)

*Could be reprogrammable over-the-air per JTRS/SDRF
**Increase technique density via interleaving bursts
Conclusion
Some M&S Lessons Learned

• The nits will always get you
  – Whether you roll your own framework
  – Or build on someone else’s framework

• Pay attention to dynamic range
  – Numerically
    • ILP limitations using TORSCHE (use other ILP solvers?)
  – Temporally
    • When some techniques are measured in μs and some in tens of seconds, it can be a problem

• Read the fine print—especially w.r.t. freeware
  – Did not catch that TORSCHE could not run in a M/L block inside Simulink
    • EML must be used in M/L blocks
    • TORSCHE is NOT; it’s object based (.: utilizes dynamic variables) and cell arrays
  – Fortunately, ∃ workaround to run the TORSCHE-based AIOR routines in the simulation
    • EML routine that calls TORSCH-based AIOR routines is Scheduling.m
    • Scheduling.m must declare AIOR #\( n \) as an EML extrinsic routine \textbf{before} calling AIOR \#\( n \): \texttt{eml.extrinsic('AIORn')}
      – When going to prototype C/C++ equivalents of TORSCHE routines will be required.

• When in doubt…
  – Call MathWorks tech support for help; don’t waste time spinning your wheels
Wrapping Up…

• Summary
  – EW M&S
  – Lessons learned
• Any more questions???
• Thanks for attending!
  – We hope you found this very helpful
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