Towards an Interactive Game-based Assessment of FSS Concepts

October 14, 2014
2nd Workshop on Federated Satellite Systems

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Overview

- FSS design challenges
- Overview of gaming approaches
- FSS model and game implementation
  - Context and event models
  - Federation and federate models
  - System and subsystem models
- Insights from play-testing *Orbital Federates*
- Future work and extensions
FSS Design Challenges

- **SE: a hierarchical process to meet complex project objectives**
  - Requirements Definition
  - Decomposition
  - Integration
  - Verification
  - Validation
  - Flow-down
  - Design
  - Implementation

- **Limited control in FSS breaks the SE process**
  - Independent operation and management
  - Need design tools to reflect/express challenge
  - Develop methods to improve collaboration
Research Objective

How can design tools assess FSS concepts involving collaborative behaviors?

• Develop interactive game-based model with:
  1. Independent operation
  2. Down-link constraints
  3. On-orbit communication
  4. Design constraints
  5. Uncertain demands
  6. Failure events

• Evaluate through game-play:
  – How do players perceive/assess FSS concepts?
  – What mechanisms or incentives could support collaboration as a federation?
(War) Gaming Approaches

- 1800s: table-top Kriegsspiel (war games) in Prussia
- WWI: differential equation models of force strength
- WWII: operations research
- 1950s: game theory and political-military games
- 1960s: computerized models
- 1990s: distributed simulation

FSS Simulation Toolkit (Grogan et al., 2014)

• Open source libraries:
  – Distributed simulation (OpenHLA, Portico)
  – 3D visualization (NASA World Wind)
  – Spacecraft flight dynamics (Orekit)

• Limited use for games:
  – Costly and time-consuming to develop
  – Fixed to operational-level decisions due to orbital propagation
Triadic Game Design (Harteveld, 2010)

Activity for FSS players to independently act with the option to collaborate

Address intellectual questions for strategic design of FSS

Meaning Enlightenment

Reality Embodiment

Representative model of key FSS concepts
Game Development Method

Common features of FSS and games

Generic Model

Abstraction & Realization

FSS Model

Game Model

Set of similar FSS

Set of similar games

One FSS instance

One game instance

Level of Abstraction

Concepts
Generic FSS Model – Structure

Context

Federation

Contract

System

Subsystem

Future SE

Advanced SE

Standard SE

Data

Payload

Comm.

Surface

Orbit

Location
Context Model

Contextual processes:

- Federation operations – one or more actors operating systems for revenue
- Disturbances – events impacting operations
- (Third party) contracts – source of demands
2D aggregated context model:
• 6 sectors
• 4 layers:
  A. Surface
  B. LEO (+2/turn)
  C. MEO (+1/turn)
  D. GEO
• Events revealed in sectors each turn
• Multi-scale decisions
  – 1 turn operations
  – 2-6 turn tactics
  – 6-24 turn strategy
Event Model

- Events drawn from a distribution
- Disturbance: minor or major effect on spacecraft in sector
- Contract: solicitation to sense data in sector and later down-link
  - Phenomena (IR, VIS, SAR) with rush and standard service levels
  - Open auction format bidding
  - Resolved as unfulfilled, completed, or defaulted
<table>
<thead>
<tr>
<th>Event</th>
<th>Reward (Deadline)</th>
<th>Default Penalty</th>
<th>Count</th>
<th>% Total</th>
</tr>
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<tr>
<td></td>
<td>Rush</td>
<td>Standard</td>
<td></td>
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<tr>
<td>Radar (SAR) Solicitation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAR P1</td>
<td>500 (1)</td>
<td>400 (4)</td>
<td>50</td>
<td>8</td>
</tr>
<tr>
<td>SAR P2</td>
<td>450 (2)</td>
<td>350 (5)</td>
<td>100</td>
<td>12</td>
</tr>
<tr>
<td>SAR P3</td>
<td>400 (3)</td>
<td>300 (6)</td>
<td>150</td>
<td>23</td>
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<tr>
<td>Visual Light (VIS) Solicitation</td>
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<td></td>
</tr>
<tr>
<td>VIS P1</td>
<td>600 (1)</td>
<td>500 (4)</td>
<td>50</td>
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<tr>
<td>VIS P2</td>
<td>500 (2)</td>
<td>400 (5)</td>
<td>100</td>
<td>17</td>
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<tr>
<td>VIS P3</td>
<td>450 (3)</td>
<td>350 (6)</td>
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<tr>
<td>Infrared (IR) Solicitation</td>
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<td>IR P1</td>
<td>800 (1)</td>
<td>500 (4)</td>
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<tr>
<td>IR P2</td>
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<tr>
<td>IR P3</td>
<td>600 (3)</td>
<td>400 (6)</td>
<td>150</td>
<td>4</td>
</tr>
<tr>
<td>Disturbance</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Minor</td>
<td></td>
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<tr>
<td>Major</td>
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<td></td>
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</table>
Federation & Federate Models

- Federation: game session
- Forming: start of game
- Dissolving: end of game

- Federate: player
- Entering: receive initial capital
- Exiting: calculate final return-on-investment
Player operations mat limits:

- 1-3 players to 4 spacecraft + 3 ground stations
- 4-6 players to 3 spacecraft + 2 ground stations

Player-to-player contracts may be negotiated at any time during a game
System Model

- Design with generic template and custom subsystems
- Commission ground stations:
  - Right to build in a surface sector
  - Open auction to highest bidder
- Commission spacecraft:
  - Launch into orbit above sector
  - Increasing cost with altitude
- Decommission: liquidate asset
<table>
<thead>
<tr>
<th>System</th>
<th>Cost</th>
<th>Surface</th>
<th>LEO</th>
<th>MEO</th>
<th>GEO</th>
<th>Subsystems</th>
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<tbody>
<tr>
<td>Small Spacecraft</td>
<td>200</td>
<td>-</td>
<td>0</td>
<td>+100</td>
<td>+200</td>
<td>2</td>
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<tr>
<td>Medium Spacecraft</td>
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<td>0</td>
<td>+150</td>
<td>+300</td>
<td>4</td>
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<tr>
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<td>-</td>
<td>0</td>
<td>+200</td>
<td>+400</td>
<td>6</td>
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<tr>
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<td>500</td>
<td>Auction</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
</tbody>
</table>

- System templates placed on player operations mat
- Subsystem tokens placed on system template
- Token placed on game board
Subsystem Model: Payload

- Generate (G) data
  - SAR, VIS, or IR data
  - Store data in memory

- Retrieve (R) data

Cost: 250

SAR  

VIS  

IR  

Cost: 300

Cost: 350
Subsystem Model: Data

- Allows multiple sensor use before downlink
- Store (S) data
- Retrieve (R) data

Cost: 50 100
Subsystem Model: Comm.

- Availability based on:
  - SGL: s/c above station
  - ISL: s/c within 1 sector
  - Proprietary vs. standard

- Transmit (TX) data
- Receive (RX) data

<table>
<thead>
<tr>
<th>TX?</th>
<th>Yes</th>
<th>RX?</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>Transfer Data</td>
<td>No</td>
<td>Receive Data</td>
</tr>
<tr>
<td>Yes</td>
<td>Transmit Data</td>
<td>Yes</td>
<td>Transfer Data</td>
</tr>
</tbody>
</table>

- Cost:
  - TX: SGL - 50, ISL - 200
  - RX: SGL - 150, ISL - 300
Orbital Federates Prototype

- Custom game printing from The Game Crafter
  - Version 1.0
    - (pictured)
    - 1-4 players
    - Play-tested
  - Version 2.0
    - (described)
    - 1-6 players
    - In progress

The Game Crafter: [http://thegamecrafter.com](http://thegamecrafter.com)
Insights from Play-testing

• Re-balancing to avoid:
  – Dominant strategies
  – Not-fun aspects

• Few player-to-player contracts observed
  – Legacy hardware major barrier to FSS
  – Return-on-investment limits collaboration
  – Players under-estimate network cost, complexity and robustness
Future Work

• Game improvements:
  – Revise/expand end-of-game and win conditions
  – Improve mechanics of tracking time (contracts)
  – Reduce variance of achievable contracts

• Extended play-testing
  – Keio SDM in Japan
  – Business games course

• Research extensions:
  – Assess other bidding mechanisms and incentives such as cost-sharing
  – Couple with computer-based planning module
  – Analyze expected value of alternative strategies and compare with typical game-play results

Play-testing session TOMORROW, 11:00am
Acknowledgements

• Research funded in part by the FSS project under a Skoltech Faculty Development Program (FDP) grant

• Thank you to the play-testers:
  – (v.0) Alessandro Golkar, Christian Prothmann
Appendix
Strengths of Gaming (Mayer, 2009)

• Experi(m)ent(i)al, rule-based, interactive environment

• Players learn by:
  – Taking actions
  – Experiencing effects
  – Feedback mechanisms deliberately built into and around the game

• Similar to public policy making:
  – No unitary body which optimizes solutions to well-defined problems
  – Facts are disputed, knowledge is negotiated
Empire Builder (Mayfield Games, 1982)

• Railroad design game
  – One of the first “pick up and deliver” games

• New lines to connect cities
  – Geographically accurate hex-grid of mile markers
  – Upgrade engine speed/capacity

• Draw resource demand cards
  – Pick up resources along route (historically accurate)
  – Deliver to corresponding location for revenue
  – Endure disturbances (floods, derailments, etc.)