DESIGN OF EXPERIMENTS (for a Milestone B Artillery Howitzer)

Design of Experiments (DOE) Overview

The purpose of this appendix is to provide a framework for the OTA’s Design of Experiments (DOE) methodology in support of a howitzer acquisition. The OTA will plan and conduct both the LUT/OA/OA and the IOT using DOE principles. This method of assessment will provide a systematic approach to assess the effects of pre-determined factors on key performance aspects of the howitzer. The design goal is to vary key factors that affect measurable system characterizations such as timeliness and accuracy. Table D.1 below shows how the factors and factor levels will be controlled during each test event.

Table D.1: DOE Campaign Strategy

<table>
<thead>
<tr>
<th>Factors</th>
<th>Factor Levels</th>
<th>Test Events</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>LUT /OA</td>
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<tr>
<td>Ammo-Lethal</td>
<td>Projectile 1(P1), Projectile 2(P2)</td>
<td>SV</td>
</tr>
<tr>
<td>Ammo-Non Lethal</td>
<td>Smoke, Illum</td>
<td>Non-Lethal limited # missions</td>
</tr>
<tr>
<td>Time</td>
<td>Day, Night</td>
<td>SV</td>
</tr>
<tr>
<td>Range Band</td>
<td>C1 + C2, C3, C4, C5</td>
<td>SV</td>
</tr>
<tr>
<td>Traverse</td>
<td>0-15, 15-45, Out of Sector</td>
<td>SV (0-15, 15-45), Out of Sector (limited # missions)</td>
</tr>
<tr>
<td>Angle</td>
<td>Low, High</td>
<td>SV</td>
</tr>
<tr>
<td>Fuze</td>
<td>Time Delay (TD), Point Detonation (PD), Multi-option fuse (MOF)</td>
<td>SV</td>
</tr>
<tr>
<td>MOPP</td>
<td>0, IV</td>
<td>HC-MOPP 0, MOPP IV limited # missions</td>
</tr>
<tr>
<td>Test Elements</td>
<td># of test elements</td>
<td>HC (1 Element)</td>
</tr>
<tr>
<td>IA</td>
<td>None, Red team</td>
<td>None</td>
</tr>
</tbody>
</table>

Notes/Definitions:

*HC-Held Constant                    *SV – Systematically Varied                            *C1-MACS 1 or equivalent
*C2-MACS 2 or equivalent         *C3-MACS 3 or equivalent                             *C4-MACS 4 or equivalent
*High Angle of fire – Above maximum range Quadrant of Elevation(>~800 mils)
LUT/OA:

The objectives of the LUT/OA shall be to evaluate the howitzer interoperability, fire mission accuracy and responsiveness and automotive performance as well as mobility and reliability in support of combat operations. Table D.2 shows critical responses.

**Table D.2: Critical Responses**

<table>
<thead>
<tr>
<th>Critical Responses</th>
<th>Accuracy (Miss Distance in meters, CEP)</th>
<th>Timeliness (Time to Complete Mission in seconds)</th>
<th>Reliability (Mean Time between Failure)</th>
</tr>
</thead>
</table>

This phase of the operational testing will follow a D-optimal split-plot design of experiments approach with some of the hard to control factor systematically controlled to balance DOE and operational realism from the OMS/MP. Table D.3 lists the factors and levels for the two responses: accuracy and timeliness.

**Table D.3: Factors and Levels**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Levels</th>
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<tr>
<td>Projectile</td>
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<td>Hard, Systematic</td>
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<tr>
<td>Time</td>
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<td>Hard, Systematic</td>
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<tr>
<td>Range Band</td>
<td>C1 + C2, C3, C4, C5</td>
<td>Hard, Systematic</td>
</tr>
<tr>
<td>Traverse Angle</td>
<td>0-15, 15-45</td>
<td>Hard</td>
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<tr>
<td>Angle of Fire</td>
<td>Low, High</td>
<td>Easy</td>
</tr>
<tr>
<td>Fuze Type</td>
<td>TD, PD, MOF</td>
<td>Hard</td>
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</tbody>
</table>

If a factor it systematically controlled it was organized in an operationally realistic manner yet based on a D-optimal design. Projectile, Time, and Range were organized so that it followed a scenario where it starts on closest range bands (C1 + C2) and then moves to the C5 range band over the first two 24-hour periods before returning to the initial bands over the next two 24-hour periods. If a factor was hard to control, these factors were randomized over whole plots (blocks of time where the time, Projectile, range band, traverse, and fuze could randomly be assigned). Angle is an easy to control so it could be randomly assigned to the individual missions or within the blocks. The DOE consists of 96 missions, but to meet the reliability requirements, 160 missions are necessary. These additional missions are distributed between special case requirements (Non-Lethal, emergency firings, MOPP IV, Out of Sections, and other long range missions to meet the OMS/MP. These additional missions will be injected into the DOE run matrix at the discretion of the Test Officer to ensure operational realism. For example,
all the Out of Sector and Emergency missions will be conducted right after tactical moves. Table D.4 shows the breakout by mission.

### Table D.4: Factor Breakout By Mission

<table>
<thead>
<tr>
<th></th>
<th>Range</th>
<th>Charge</th>
<th>P1 Missions</th>
<th>P2 Missions</th>
<th>Illum Missions</th>
<th>Smoke Missions</th>
<th>Total Missions</th>
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<tbody>
<tr>
<td><strong>DOE</strong></td>
<td>4 - 9 KM</td>
<td>1/2L</td>
<td>16</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>16</td>
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<tr>
<td></td>
<td>9-12 KM</td>
<td>3H</td>
<td>16</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>16</td>
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<tr>
<td></td>
<td>12-15 KM</td>
<td>4H</td>
<td>16</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>16.4 - 20 KM</td>
<td>5H</td>
<td>-</td>
<td>28</td>
<td>-</td>
<td>-</td>
<td>28</td>
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<td><strong>Emergency</strong></td>
<td>16.4 - 20 KM</td>
<td>5H</td>
<td>-</td>
<td>12</td>
<td>-</td>
<td>-</td>
<td>12</td>
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<td><strong>MOPP IV</strong></td>
<td>16.4 - 20 KM</td>
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<td><strong>Additional</strong></td>
<td>16.4 - 20 KM</td>
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<td>-</td>
<td>26</td>
<td>-</td>
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<td></td>
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<tr>
<td><strong>Out of Sector</strong></td>
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<td>TBD</td>
<td>-</td>
<td>12</td>
<td>-</td>
<td>-</td>
<td>12</td>
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<td><strong>Total</strong></td>
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<td>48</td>
<td>108</td>
<td>3</td>
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<td>160</td>
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</table>

The D-Optimal Split-Split Plot design permits the ability to estimate all main effects, all 2-way interactions with time, and the following additional interactions: range band and traverse, traverse and angle, angle and fuze, traverse and fuze, and projectile and angle. The run matrix, which it the required order that these runs must follow, is shown in table D.5 below.

### Table D.5: LUT/OA D-Optimal Split-Split Plot Run Matrix

<table>
<thead>
<tr>
<th>Day</th>
<th>Time</th>
<th>Projectile</th>
<th>Range Band</th>
<th>Traverse</th>
<th>Angle</th>
<th>Fuze</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Day</td>
<td>P1</td>
<td>C1 + C2</td>
<td>0-15</td>
<td>High</td>
<td>TD</td>
</tr>
<tr>
<td>1</td>
<td>Day</td>
<td>P1</td>
<td>C1 + C2</td>
<td>0-15</td>
<td>Low</td>
<td>TD</td>
</tr>
<tr>
<td>1</td>
<td>Day</td>
<td>P1</td>
<td>C1 + C2</td>
<td>0-15</td>
<td>Low</td>
<td>TD</td>
</tr>
<tr>
<td>1</td>
<td>Day</td>
<td>P1</td>
<td>C1 + C2</td>
<td>0-15</td>
<td>High</td>
<td>TD</td>
</tr>
<tr>
<td>1</td>
<td>Day</td>
<td>P1</td>
<td>C1 + C2</td>
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<tr>
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<td>Day</td>
<td>P1</td>
<td>C1 + C2</td>
<td>0-15</td>
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<tr>
<td>1</td>
<td>Day</td>
<td>P1</td>
<td>C1 + C2</td>
<td>0-15</td>
<td>Low</td>
<td>PD</td>
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</table>
## Design of Experiments – Artillery Howitzer Example

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<th>Range Band</th>
<th>Traverse</th>
<th>Angle</th>
<th>Fuze</th>
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<tbody>
<tr>
<td>1</td>
<td>Day</td>
<td>P1</td>
<td>C3</td>
<td>30-45</td>
<td>Low</td>
<td>PD</td>
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<td>High</td>
<td>PD</td>
</tr>
<tr>
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<td>C1 + C2</td>
<td>30-45</td>
<td>Low</td>
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<td>30-45</td>
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<td>C1 + C2</td>
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</table>
The power of the tests to illustrate how the factors influence the responses are listed below in Table D.6:

**Table D.6: Power Effect on Factors and Responses**

<table>
<thead>
<tr>
<th>Effect</th>
<th>Variance</th>
<th>Power (90% Confidence, S:N=2)</th>
<th>Power (80% Confidence, S:N=1)</th>
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</thead>
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<tr>
<td>Intercept</td>
<td>0.228</td>
<td>0.994</td>
<td>0.789</td>
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<tr>
<td>Time</td>
<td>0.303</td>
<td>0.974</td>
<td>0.701</td>
</tr>
<tr>
<td>Range Band 1</td>
<td>0.333</td>
<td>0.963</td>
<td>0.671</td>
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<tr>
<td>Range Band 2</td>
<td>0.245</td>
<td>0.991</td>
<td>0.767</td>
</tr>
<tr>
<td>Range Band 3</td>
<td>0.180</td>
<td>0.999</td>
<td>0.855</td>
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<tr>
<td>Traverse</td>
<td>0.305</td>
<td>0.974</td>
<td>0.699</td>
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<tr>
<td>Angle</td>
<td>0.018</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Fuze 1</td>
<td>0.208</td>
<td>0.997</td>
<td>0.816</td>
</tr>
<tr>
<td>Fuze 2</td>
<td>0.194</td>
<td>0.998</td>
<td>0.836</td>
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<tr>
<td>Projectile</td>
<td>0.390</td>
<td>0.937</td>
<td>0.624</td>
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<tr>
<td>Time*Range Band 1</td>
<td>0.559</td>
<td>0.842</td>
<td>0.524</td>
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<tr>
<td>Time*Range Band 2</td>
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<td>0.984</td>
<td>0.733</td>
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<td>Time*Range Band 3</td>
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<td>0.906</td>
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<tr>
<td>Time*Traverse</td>
<td>0.208</td>
<td>0.997</td>
<td>0.816</td>
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<tr>
<td>Time*Angle</td>
<td>0.016</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Time*Fuze 1</td>
<td>0.095</td>
<td>1.000</td>
<td>0.974</td>
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<tr>
<td>Time*Fuze 2</td>
<td>0.269</td>
<td>0.985</td>
<td>0.738</td>
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<tr>
<td>Time*Projectile</td>
<td>0.464</td>
<td>0.897</td>
<td>0.574</td>
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<tr>
<td>Range Band*Traverse 1</td>
<td>0.299</td>
<td>0.976</td>
<td>0.705</td>
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<tr>
<td>Range Band*Traverse 2</td>
<td>0.257</td>
<td>0.988</td>
<td>0.752</td>
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<tr>
<td>Range Band*Traverse 3</td>
<td>0.222</td>
<td>0.995</td>
<td>0.797</td>
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</tbody>
</table>
Design of Experiments – Artillery Howitzer Example

<table>
<thead>
<tr>
<th>Effect</th>
<th>Variance</th>
<th>Power (90% Confidence, S:N=2)</th>
<th>Power (80% Confidence, S:N=1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traverse*Angle</td>
<td>0.016</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Angle*Fuze 1</td>
<td>0.016</td>
<td>1.000</td>
<td>1.000</td>
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<tr>
<td>Angle*Fuze 2</td>
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<tr>
<td>Projectile*Angle</td>
<td>0.018</td>
<td>1.000</td>
<td>1.000</td>
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</table>

**IOT:**

The objective of the IOT shall be to evaluate the howitzer interoperability, rate of fire, fire mission accuracy, responsiveness and automotive performance as well as mobility and reliability in support of combat operations. The test results shall support a full rate production decision.

The IOT will follow the same DOE philosophy and have the same factors and levels as the LUT/OA except it will be larger. A split plot design will be created based on the same set of factors and levels. Similarly the factors will be controlled in the same manner with the missions starting out close moving to the C5 ranges and the returning to the initial range bands over the course of the three 96-hour scenarios. Due to the increased number of missions, number of rounds fired and length of the test in the IOT compared to the LUT/OA, more interactions can be estimated, to include main effects and second order interactions. IOT design will ensure a similar balance between statistical capabilities and operational coverage. Similar to the LUT/OA, the IOT will consist of a smaller subset of the total number of required missions compared to the DOE missions. The overall ratio of the DOE to the total number of missions will be the same or very similar. Thus all the non-lethal, emergency firings, out of sector missions, and additional C5 missions needed to meet the OMS/MP, which would again follow tactical moves, and additional C5 missions will be injected into the matrix at the discretion the Test Officer to ensure operational realism.

Red Team excursions will be conducted at the discretion of the IOT Test Officer. These excursions will support Information Assurance evaluation requirements in an operational environment at a system of systems level. Additional information relating to Red Team excursions can be found in paragraph 4.3.2.5 “IOT Events, Scope of Testing and Scenarios” of the TEMP.