Design of Experiments – Artillery Howitzer Example

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

Factors	**Factor Levels**	**Test Events**	
		LUT /OA	IOT
Ammo-Lethal	Projectile 1(P1), Projectile 2(P2)	SV	SV
Ammo-Non Lethal	Smoke, Illum	Non-Lethal limited # missions	Non-Lethal limited # missions
Time	Day, Night	SV	SV
Range Band	C1 + C2, C3, C4, C5	SV	SV
Traverse	0-15, 15-45, Out of Sector	SV (0-15, 15-45), Out of Sector (limited # missions)	SV (0-15, 15-45), Out of Sector (limited # missions)
Angle	Low, High	SV	SV
Fuze	Time Delay (TD), Point Detonation(PD), Multi-option fuse (MOF)	SV	SV
MOPP	0, IV	HC-MOPP 0, MOPP IV limited # missions	HC-MOPP O, MOPP IV limited # missions
Test Elements	# of test elements	HC (1 Element)	SV (3 Elements)
IA	None, Red team	None	HC-None, Red team excursion at end of test
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)			

*Low Angle of Fire – Below maximum range Quadrant of Elevation(<~800mils)

*IA – Information Assurance

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

Critical Responses	Accuracy (Miss Distance in meters, CEP)
	Timeliness (Time to Complete Mission in seconds)
	Reliability (Mean Time between Failure)

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

Factor	Levels	Control
Projectile	P1, P2	Hard, Systematic
Time	Day, Night	Hard, Systematic
Range Band	C1 + C2, C3, C4, C5	Hard, Systematic
Traverse Angle	0-15, 15-45	Hard
Angle of Fire	Low, High	Easy
Fuze Type	TD, PD, MOF	Hard

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

	Range	Charge	P1 Missions	P2 Missions	Illum Missions	Smoke Missions	Total Missions
DOE	4 - 9 KM	1/2L	16	0	-	-	16
	9-12 KM	3H	16	0	-	-	16
	12-15 KM	4H	16	20	-	-	36
	16.4 - 20 KM	5H	-	28	-	-	28
Non-Lethal	TBD	TBD	-	-	3	3	6
Emergency firings	16.4 - 20 KM	5H	-	12	-	-	12
MOPP IV	16.4 - 20 KM	5H	-	8	-	-	8
Additional Long range for RAM	16.4 - 20 KM	5H	-	26	-	-	26
Out of Sector	TBD	TBD	-	12	-	-	12
Total	-	-	48	108	3	3	160

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

Day	Time	Projectile	Range Band	Traverse	Angle	Fuze
1	Day	P1	C1 + C2	0-15	High	TD
1	Day	P1	C1 + C2	0-15	Low	TD
1	Day	P1	C1 + C2	0-15	Low	TD
1	Day	P1	C1 + C2	0-15	High	TD
1	Day	P1	C1 + C2	0-15	High	PD
1	Day	P1	C1 + C2	0-15	Low	PD
1	Day	P1	C1 + C2	0-15	Low	PD
1	Day	P1	C1 + C2	0-15	High	PD

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Day	Time	Projectile	Range Band	Traverse	Angle	Fuze
1	Day	P1	C3	30-45	Low	PD
1	Day	P1	C3	30-45	High	PD
1	Day	P1	C3	30-45	Low	PD
1	Day	P1	C3	30-45	High	PD
1	Night	P1	C3	0-15	High	TD
1	Night	P1	C3	0-15	High	TD
1	Night	P1	C3	0-15	Low	TD
1	Night	P1	C3	0-15	Low	TD
1	Night	P1	C4	30-45	High	TD
1	Night	P1	C4	30-45	High	TD
1	Night	P1	C4	30-45	Low	TD
1	Night	P1	C4	30-45	Low	TD
1	Day	P1	C4	0-15	Low	MOF
1	Day	P1	C4	0-15	Low	MOF
1	Day	P1	C4	0-15	High	MOF
1	Day	P1	C4	0-15	High	MOF
2	Day	P2	C4	30-45	High	MOF
2	Day	P2	C4	30-45	Low	MOF
2	Day	P2	C4	30-45	Low	MOF
2	Day	P2	C4	30-45	High	MOF
2	Day	P2	C4	30-45	Low	TD
2	Day	P2	C4	30-45	High	TD
2	Day	P2	C4	30-45	Low	TD
2	Day	P2	C4	30-45	High	TD
2	Night	P2	C5	30-45	Low	MOF
2	Night	P2	C5	30-45	Low	MOF
2	Night	P2	C5	30-45	Low	MOF
2	Night	P2	C5	30-45	Low	MOF
2	Night	P2	C5	30-45	Low	PD

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Day	Time	Projectile	Range Band	Traverse	Angle	Fuze
2	Night	P2	C5	30-45	Low	PD
2	Night	P2	C5	30-45	Low	PD
2	Night	P2	C5	30-45	Low	PD
2	Night	P2	C5	0-15	Low	TD
2	Night	P2	C5	0-15	Low	TD
2	Night	P2	C5	0-15	Low	TD
2	Night	P2	C5	0-15	Low	TD
2	Night	P2	C5	30-45	Low	TD
2	Night	P2	C5	30-45	Low	TD
2	Night	P2	C5	30-45	Low	TD
2	Night	P2	C5	30-45	Low	TD
3	Day	P2	C5	0-15	Low	MOF
3	Day	P2	C5	0-15	Low	MOF
3	Day	P2	C5	0-15	Low	MOF
3	Day	P2	C5	0-15	Low	MOF
3	Day	P2	C5	30-45	Low	PD
3	Day	P2	C5	30-45	Low	PD
3	Day	P2	C5	30-45	Low	PD
3	Day	P2	C5	30-45	Low	PD
3	Day	P2	C5	0-15	Low	TD
3	Day	P2	C5	0-15	Low	TD
3	Day	P2	C5	0-15	Low	TD
3	Day	P2	C5	0-15	Low	TD
3	Day	P2	C4	0-15	High	PD
e	Day	P2	C4	0-15	High	PD
3	Day	P2	C4	0-15	Low	PD
3	Day	P2	C4	0-15	Low	PD
3	Night	P2	C4	0-15	Low	MOF
3	Night	P2	C4	0-15	High	MOF

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Day	Time	Projectile	Range Band	Traverse	Angle	Fuze
3	Night	P2	C4	0-15	Low	MOF
3	Night	P2	C4	0-15	High	MOF
3	Night	P2	C4	0-15	Low	PD
3	Night	P2	C4	0-15	High	PD
3	Night	P2	C4	0-15	Low	PD
3	Night	P2	C4	0-15	High	PD
3	Night	P1	C4	0-15	High	PD
3	Night	P1	C4	0-15	Low	PD
3	Night	P1	C4	0-15	High	PD
3	Night	P1	C4	0-15	Low	PD
4	Day	P1	C4	30-45	Low	MOF
4	Day	P1	C4	30-45	High	MOF
4	Day	P1	C4	30-45	High	MOF
4	Day	P1	C4	30-45	Low	MOF
4	Day	P1	C3	30-45	Low	TD
4	Day	P1	C3	30-45	Low	TD
4	Day	P1	C3	30-45	High	TD
4	Day	P1	C3	30-45	High	TD
4	Night	P1	C3	30-45	High	MOF
4	Night	P1	C3	30-45	High	MOF
4	Night	P1	C3	30-45	Low	MOF
4	Night	P1	C3	30-45	Low	MOF
4	Night	P1	C1 + C2	30-45	High	PD
4	Night	P1	C1 + C2	30-45	Low	PD
4	Night	P1	C1 + C2	30-45	Low	PD
4	Night	P1	C1 + C2	30-45	High	PD
4	Night	P1	C1 + C2	0-15	Low	MOF
4	Night	P1	C1 + C2	0-15	High	MOF
4	Night	P1	C1 + C2	0-15	High	MOF

Day	Time	Projectile	Range Band	Traverse	Angle	Fuze
4	Night	P1	C1 + C2	0-15	Low	MOF

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

Effect	Variance	Power (90% Confidence, S:N=2)	Power (80% Confidence, S:N=1)
Intercept	0.228	0.994	0.789
Time	0.303	0.974	0.701
Range Band 1	0.333	0.963	0.671
Range Band 2	0.245	0.991	0.767
Range Band 3	0.180	0.999	0.855
Traverse	0.305	0.974	0.699
Angle	0.018	1.000	1.000
Fuze 1	0.208	0.997	0.816
Fuze 2	0.194	0.998	0.836
Projectile	0.390	0.937	0.624
Time*Range Band 1	0.559	0.842	0.524
Time*Range Band 2	0.273	0.984	0.733
Time*Range Band 3	0.147	1.000	0.906
Time*Traverse	0.208	0.997	0.816
Time*Angle	0.016	1.000	1.000
Time*Fuze 1	0.095	1.000	0.974
Time*Fuze 2	0.269	0.985	0.738
Time*Projectile	0.464	0.897	0.574
Range Band*Traverse 1	0.299	0.976	0.705
Range Band*Traverse 2	0.257	0.988	0.752
Range Band*Traverse 3	0.222	0.995	0.797

Effect	Variance	Power (90% Confidence, S:N=2)	Power (80% Confidence, S:N=1)
Traverse*Angle	0.016	1.000	1.000
Angle*Fuze 1	0.016	1.000	1.000
Angle*Fuze 2	0.014	1.000	1.000
Traverse*Fuze 1	0.145	1.000	0.908
Traverse*Fuze 2	0.182	0.999	0.852
Projectile*Angle	0.018	1.000	1.000

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.