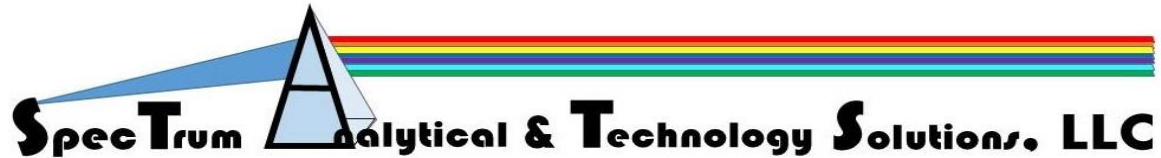


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R&M EFFECTS ON OPERATIONAL AVAILABILITY USING A DESIGNED EXPERIMENT WITH LogSIM

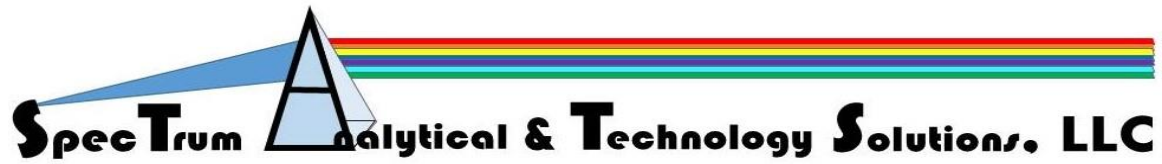
Presented to:

Society of Reliability Engineers
Huntsville RAM XV Training Summit
November 1-2, 2023

Russ Alexander, PhD, PE
President
SpecTrum A&T Solutions, LLC

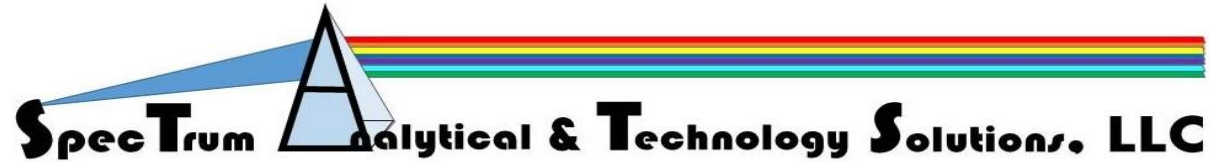
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INTRODUCTION

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Purpose: Study the effect and statistical significance of 8 R&M parameters and ALDT on operational availability with a 2^{k-p} fractional factorial design using LogSIM

Nine Factors:

A = Mean Time Between System Abort (MTB_SA)

B = Mean Time Between Essential Maintenance Action (MTB_EMA)

C = Mean Time Between Unscheduled Maintenance Action (MTB_UMA)

D = Mean Time Between Scheduled Maintenance (MTB_SM)

E = Mean Time to Repair System Abort (MTTR_SA)

F = Mean Time to Repair Essential Maintenance Action (MTTR_EMA)

G = Mean Time to Repair Unscheduled Maintenance Action (MTTR_UMA)

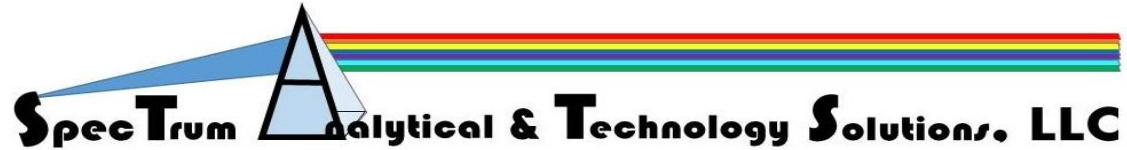
H = Mean Time to Repair Scheduled Maintenance (MTTR_SM)

J = Administrative and Logistics Downtime (ALDT)

Experimental Design

2^{9-4}_{IV} fractional factorial design (resolution IV)

- Only high/low estimates required for factors (screening design)
- Only requires 2^5 simulation runs (32 runs vs 512)
- Resolution IV: No main effects are aliased with each other or 2 factor interactions



Run	Treatment Combination	A	B	C	D	E	F=BCDE	G=ACDE	H=ABDE	J=ABCE
							F	G	H	J
1	(1)	-1	-1	-1	-1	-1	1	1	1	1
2	a	1	-1	-1	-1	-1	1	-1	-1	-1
3	b	-1	1	-1	-1	-1	-1	1	-1	-1
4	ab	1	1	-1	-1	-1	-1	-1	1	1
5	c	-1	-1	1	-1	-1	-1	-1	1	-1
6	ac	1	-1	1	-1	-1	-1	1	-1	1
7	bc	-1	1	1	-1	-1	1	-1	-1	1
8	abc	1	1	1	-1	-1	1	1	1	-1
9	d	-1	-1	-1	1	-1	-1	-1	-1	1
10	ad	1	-1	-1	1	-1	-1	1	1	-1
11	bd	-1	1	-1	1	-1	1	-1	1	-1
12	abd	1	1	-1	1	-1	1	1	-1	1
13	cd	-1	-1	1	1	-1	1	1	-1	-1
14	acd	1	-1	1	1	-1	1	-1	1	1
15	bcd	-1	1	1	1	-1	-1	1	1	1
16	abcd	1	1	1	1	-1	-1	-1	-1	-1
17	e	-1	-1	-1	-1	1	-1	-1	-1	-1
18	ae	1	-1	-1	-1	1	-1	1	1	1
19	be	-1	1	-1	-1	1	1	-1	1	1
20	abe	1	1	-1	-1	1	1	1	-1	-1
21	ce	-1	-1	1	-1	1	1	1	-1	1
22	ace	1	-1	1	-1	1	1	-1	1	-1
23	bce	-1	1	1	-1	1	-1	1	1	-1
24	abce	1	1	1	-1	1	-1	-1	-1	1
25	de	-1	-1	-1	1	1	1	1	1	-1
26	ade	1	-1	-1	1	1	1	-1	-1	1
27	bde	-1	1	-1	1	1	-1	1	-1	1
28	abde	1	1	-1	1	1	-1	-1	1	-1
29	cde	-1	-1	1	1	1	-1	-1	1	1
30	acde	1	-1	1	1	1	-1	1	-1	-1
31	bcde	-1	1	1	1	1	1	-1	-1	-1
32	abcde	1	1	1	1	1	1	1	1	1



Design Generators

F=BCDE G=ACDE H=ABDE J=ABCE

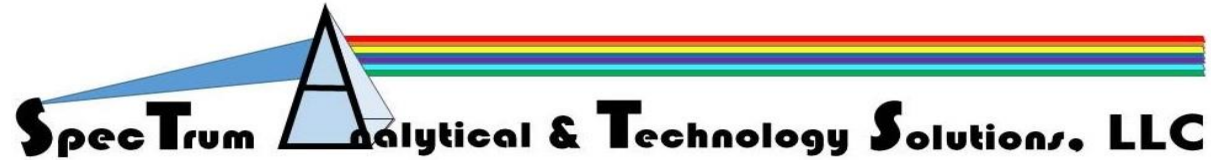
Defining relation: I = BCDEF = ACDEG = ABFG = ABDEH = ACFH = BCGH = DEFGH = ABCEJ
 = ADFJ = BDGJ = CEFGJ = CDHJ = BEFHJ = AEGHJ = ABCDEFHJ

Aliases

A = BFG = CFH = DFJ
 B = AFG = CGH = DGJ
 C = AFH = BGH = DHJ
 D = AFJ = BGJ = CHJ
 E =
 F = ABG = ACH = ADJ
 G = ABF = BCH = BDJ
 H = ACF = BCG = CDJ
 J = ADF = BDG = CDH
 AB = FG = DEH = CEJ
 AC = DEG = FH = BEJ

AD = CEG = BEH = FJ
 AE = CDG = BDH = BCJ = GHJ
 AF = BG = CH = DJ
 AG = CDE = BF = EHJ
 AH = BDE = CF = EGJ
 AJ = BCE = DF = EGH
 BC = DEF = GH = AEJ
 BD = CEF = AEH = GJ
 BE = CDF = ADH = ACJ = FHJ
 BH = ADE = CG = EFJ

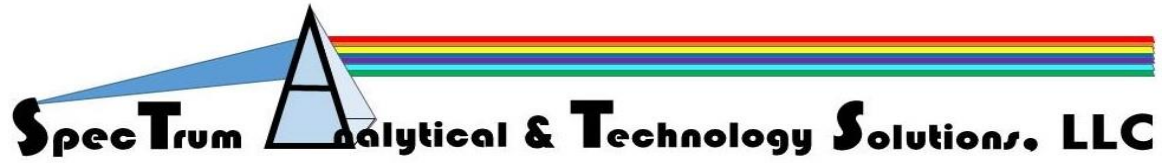
BJ = ACE = DG = EFH
 CD = BEF = AEG = HJ
 CE = BDF = ADG = ABJ = FGJ
 CJ = ABE = EFG = DH
 DE = BCF = ACG = ABH = FGH
 EF = BCD = DGH = CGJ = BHJ
 EG = ACD = DFH = CFJ = AHJ
 EH = ABD = DFG = BFJ = AGJ
 EJ = ABC = CFG = BFH = AGH
 AEF = BEG = CEH = DEJ



Factor		Factor Settings (in Hours)	
		Low (-1)	High (+1)
A	MTB_SA	8.32	832
B	MTB_EMA	0.25	25
C	MTB_UMA	0.1	8.9
D	MTB_SM	10	200
E	MTTR_SA	0.42	42
F	MTTR_EMA	0.35	35
G	MTTR_UMA	0.22	22
H	MTTR_SM	10	200
J	ALDT	11	1127

All other control variables in LogSIM were held constant

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RESULTS

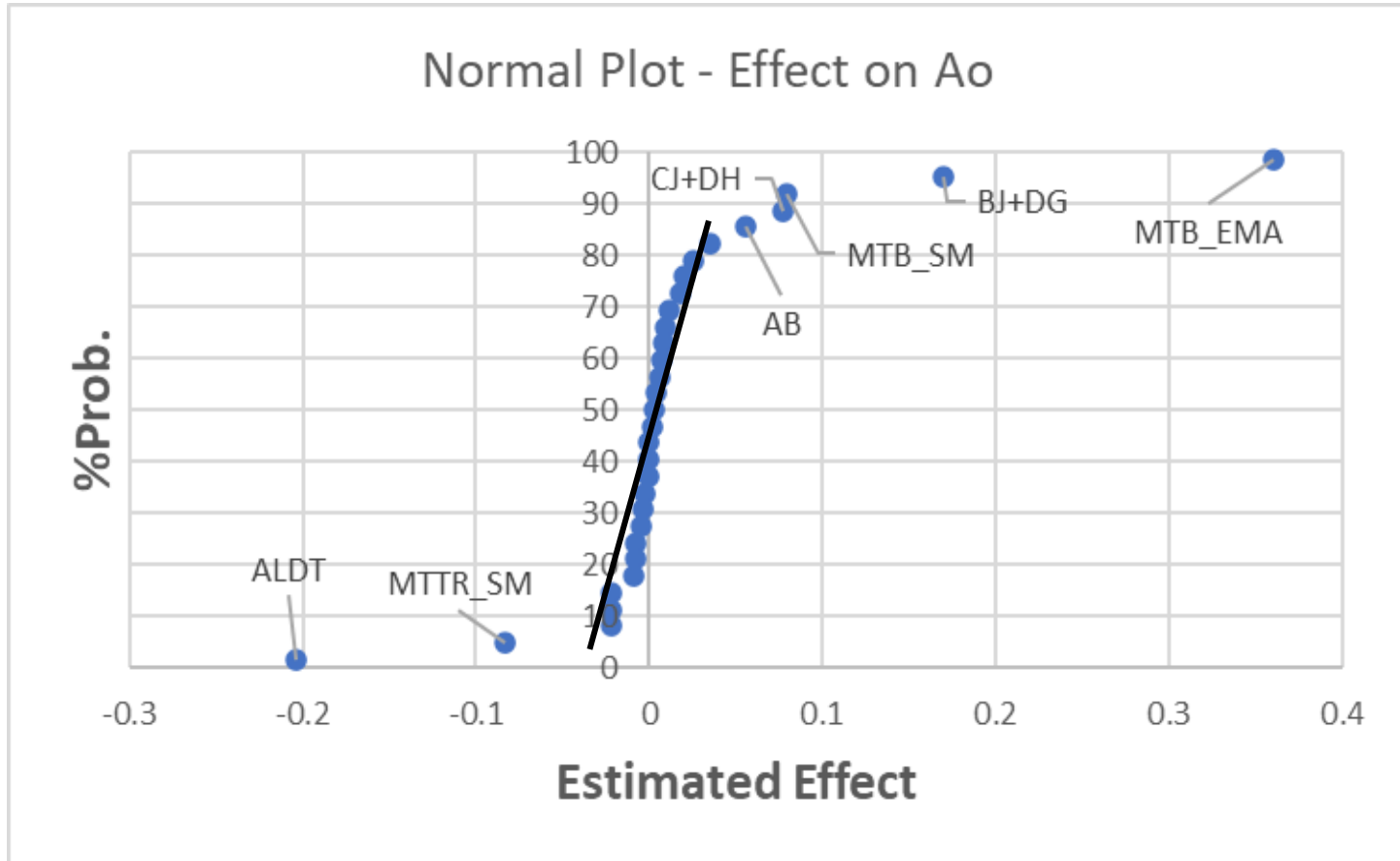
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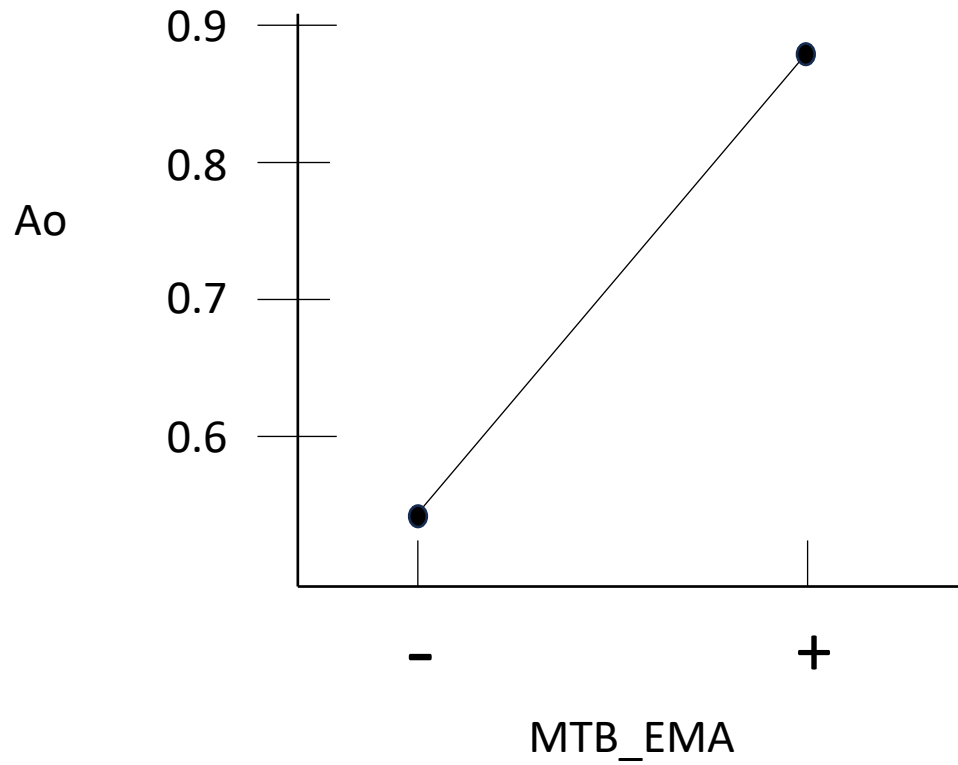


Run	Treatment Combination	Ao	Contrast	Estimated Effect	Sum of Squares	% Contribution
1	-1	0.3047				
2	a	0.7721	0.555382	0.0347114	0.009639	0.53%
3	b	0.9216	5.765192	0.3603245	1.038670	57.10%
4	ab	0.8104	0.880828	0.0550518	0.024246	1.33%
5	c	0.5622	-0.35431	-0.022145	0.003923	0.22%
6	ac	0.3428	-0.01139	-0.000712	0.000004	0.00%
7	bc	0.8555	0.289912	0.0181195	0.002627	0.14%
8	abc	0.8291	0.088268	0.0055167	0.000243	0.01%
9	d	0.3607	1.270648	0.0794155	0.050455	2.77%
10	ad	0.7627	-0.05225	-0.003266	0.000085	0.00%
11	bd	0.9154	0.106498	0.0066561	0.000354	0.02%
12	abd	0.9698	-0.14477	-0.009048	0.000655	0.04%
13	cd	0.7799	0.400836	0.0250523	0.005021	0.28%
14	acd	0.3462	-0.00342	-0.000214	0.000000	0.00%
15	bcd	0.8555	-0.35671	-0.022294	0.003976	0.22%
16	abcd	0.9817	-0.07534	-0.004709	0.000177	0.01%
17	e	0.7786	-0.12623	-0.007889	0.000498	0.03%
18	ae	0.2804	0.036744	0.0022965	0.000042	0.00%
19	be	0.6805	-0.05003	-0.003127	0.000078	0.00%
20	abe = cj = dh	0.9764	1.227182	0.0766989	0.047062	2.59%
21	ce	0.3673	0.174896	0.010931	0.000956	0.05%
22	ace = bj = dg	0.5130	2.720368	0.170023	0.231263	12.71%
23	bce	0.7136	0.142466	0.0089041	0.000634	0.03%
24	abce = j	0.9636	-3.26992	-0.20437	0.334136	18.37%
25	de	0.7709	0.123522	0.0077201	0.000477	0.03%
26	ade	0.3432	-0.12891	-0.008057	0.000519	0.03%
27	bde	0.8681	0.02982	0.0018638	0.000028	0.00%
28	abde = h	0.9688	-1.34054	-0.083784	0.056157	3.09%
29	cde	0.3693	0.053354	0.0033346	0.000089	0.00%
30	acde = g	0.7705	0.320582	0.0200364	0.003212	0.18%
31	bcde = f	0.9257	-0.00666	-0.000417	0.000001	0.00%
32	abcde	0.9542	-0.34728	-0.021705	0.003769	0.21%

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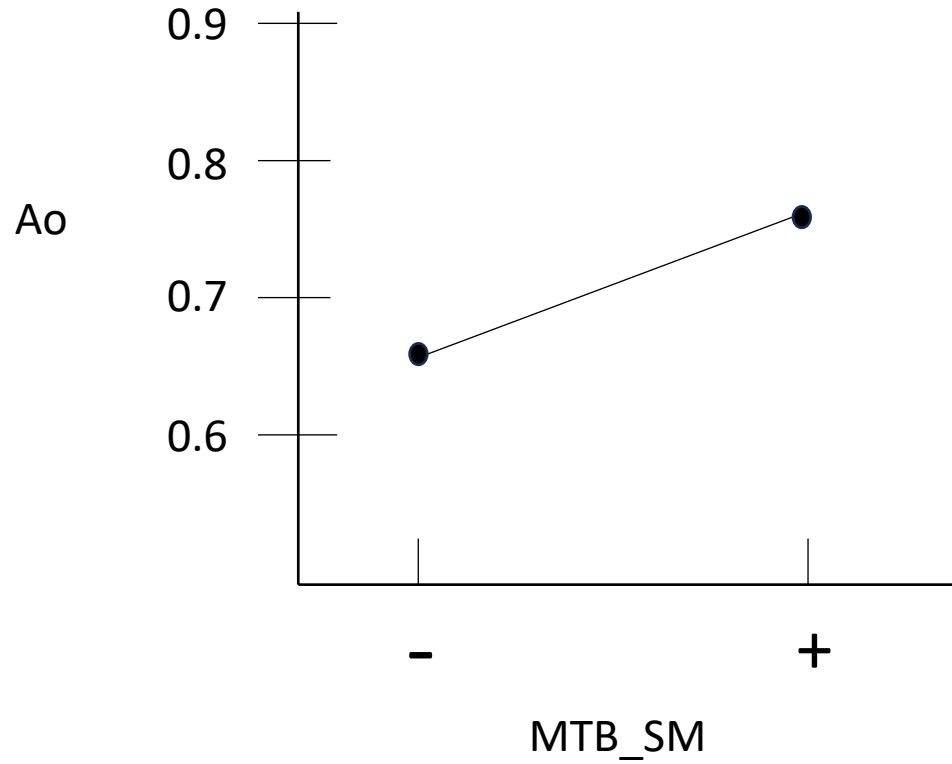


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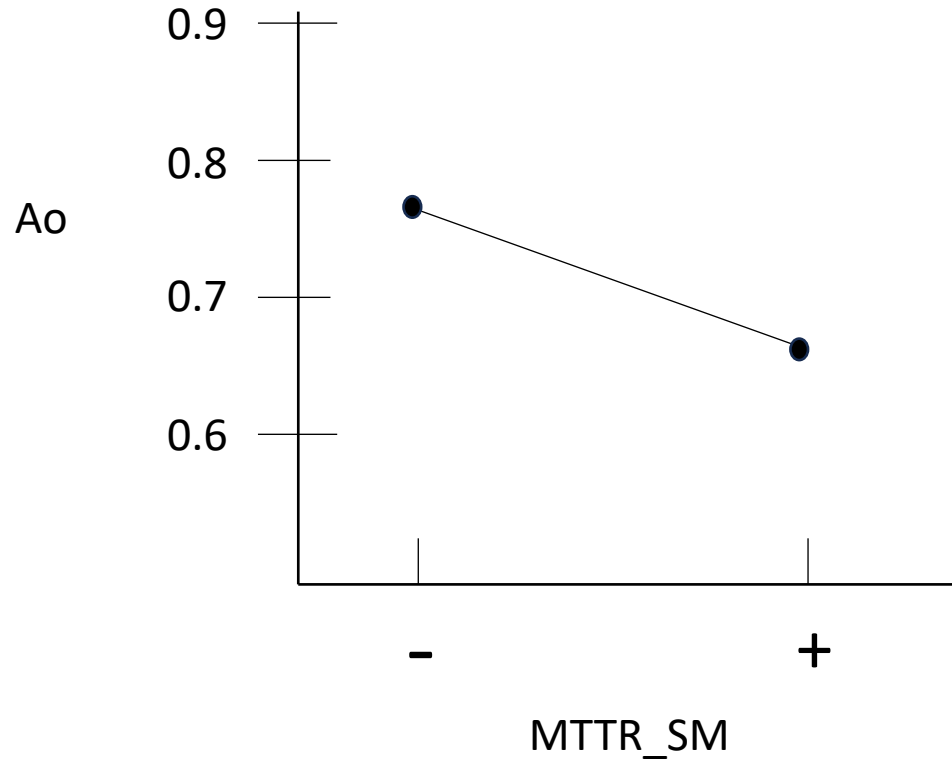


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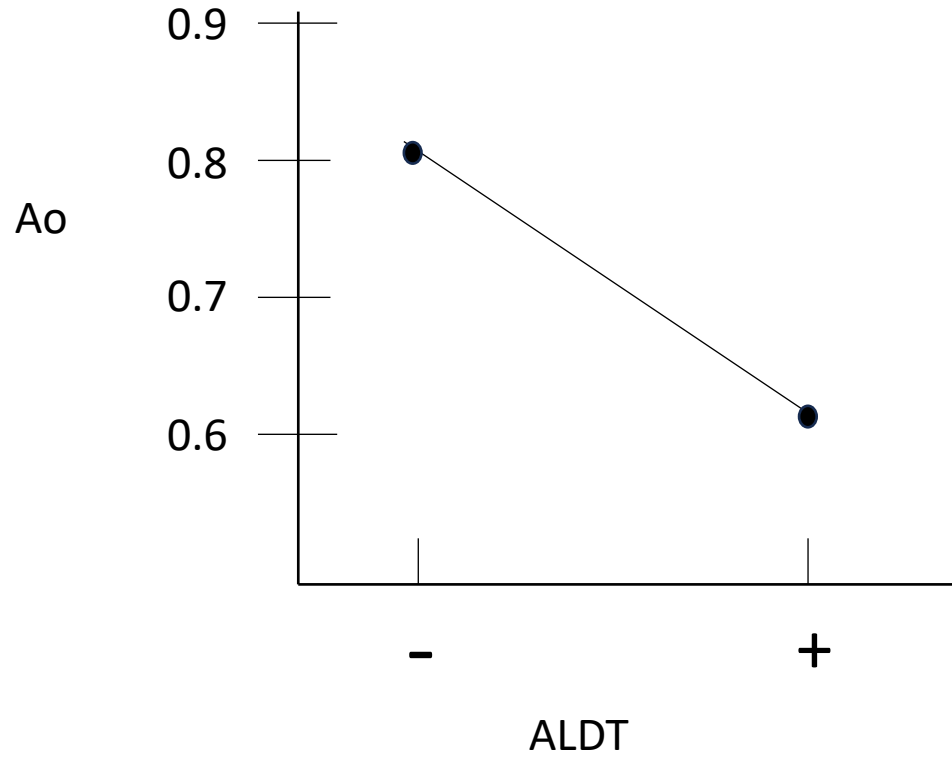
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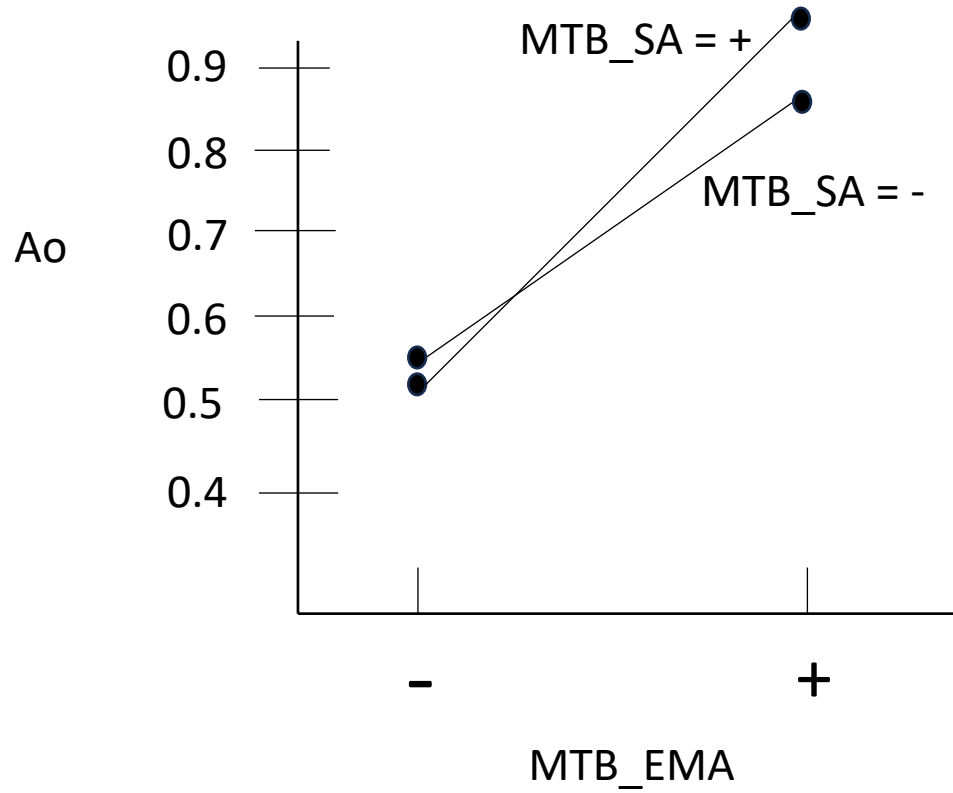
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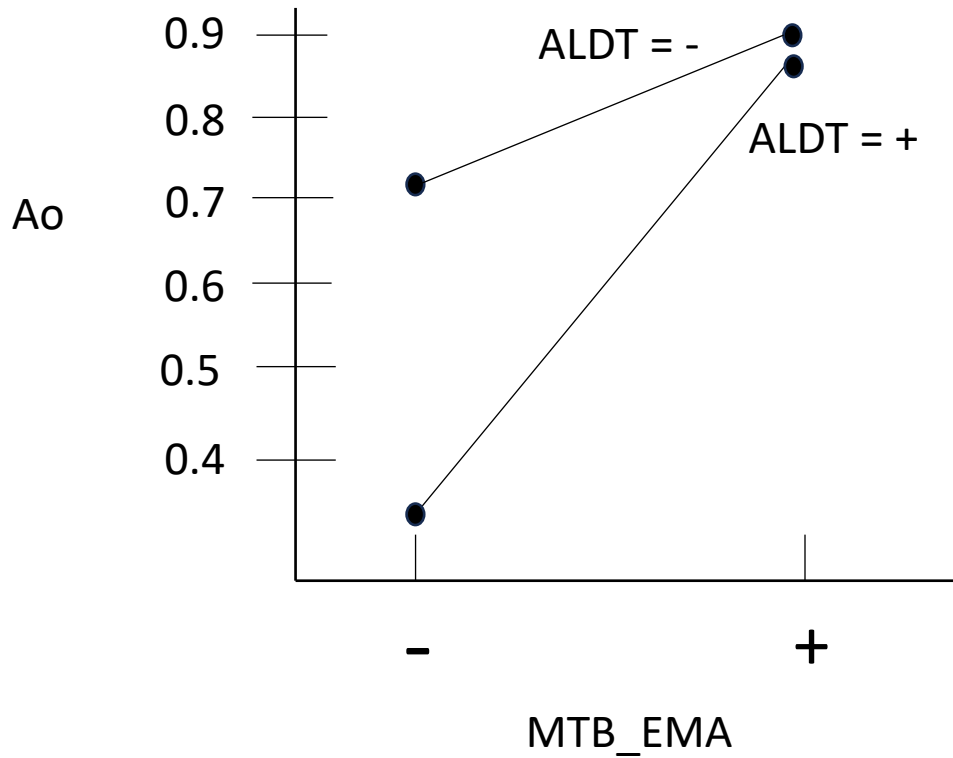


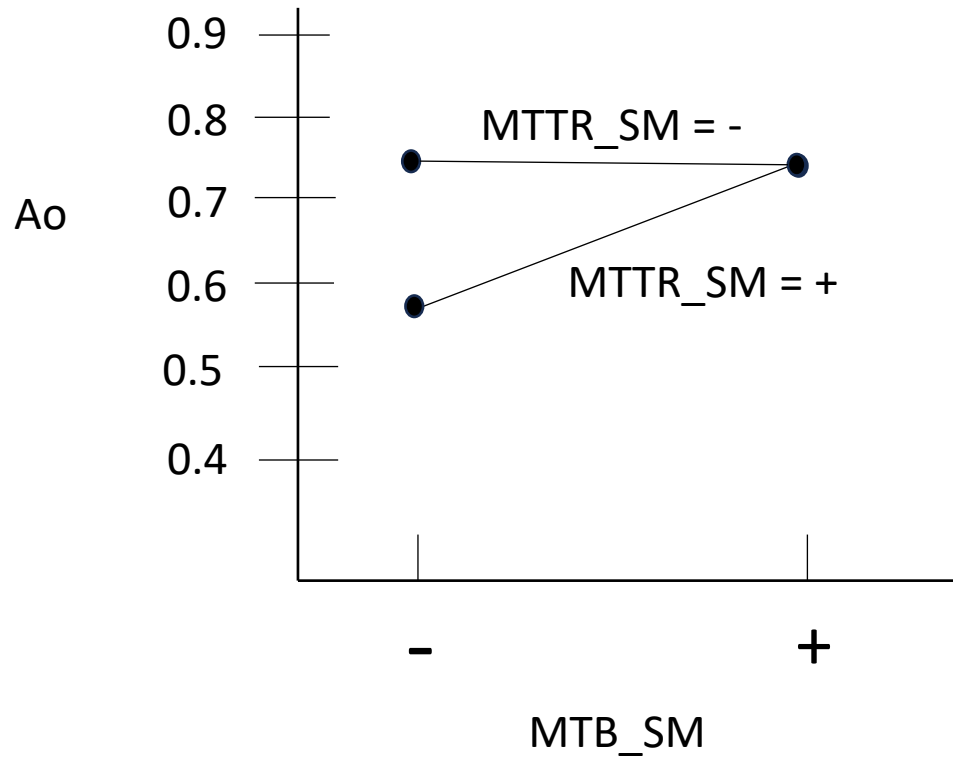
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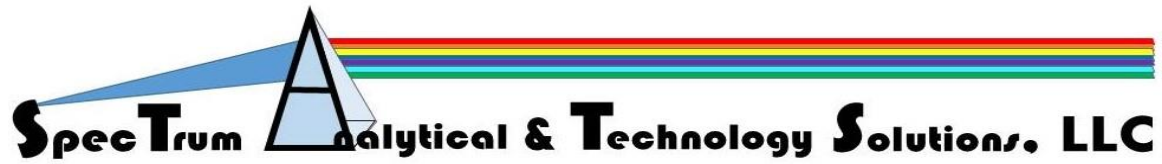
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ANALYSIS

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Analysis of Variance

Factor	SoV	Regression Coefficient	Estimated Effect	Sum of Squares	df	Mean Square	F	p-value
	Overall Average	0.706704						
A	MTB_SA	0.017356	0.03471	0.009639	1	0.009639	8.10	9.15E-03
B	MTB_EMA	0.180162	0.36032	1.038670	1	1.038670	872.83	8.53E-20
D	MTB_SM	0.039708	0.07942	0.050455	1	0.050455	42.40	1.21E-06
H	MTTR_SM	-0.041892	-0.08378	0.056157	1	0.056157	47.19	5.27E-07
J	ALDT	-0.102185	-0.20437	0.334136	1	0.334136	280.79	2.20E-14
AB (+FG)	MTB_SAxMTB_EMA	0.027526	0.05505	0.024246	1	0.024246	20.37	1.56E-04
BJ (+DG)	MTB_EMAxALDT	0.085012	0.17002	0.231263	1	0.231263	194.34	1.05E-12
DH (+CJ)	MTB_SMxMTTR_SM	0.038349	0.07670	0.047062	1	0.047062	39.55	2.04E-06
	Error			0.027370	23	0.001190		
	Total			1.818997	31			



Regression Model

$$\hat{A}_o = 0.7067 + 0.017356 \text{ MTB_SA} + 0.180162 \text{ MTB_EMA} + 0.039708 \text{ MTB_SM} - 0.041892 \text{ MTTR_SM} - 0.102185 \text{ ALDT} + 0.027526 \text{ MTB_SA} \times \text{MTB_EMA} + 0.085012 \text{ MTB_EMA} \times \text{ALDT} + 0.038349 \text{ MTB_SM} \times \text{MTTR_SM}$$

$$R^2 = \sim 0.98495$$

$$R^2_{\text{adj}} \sim 0.9797$$

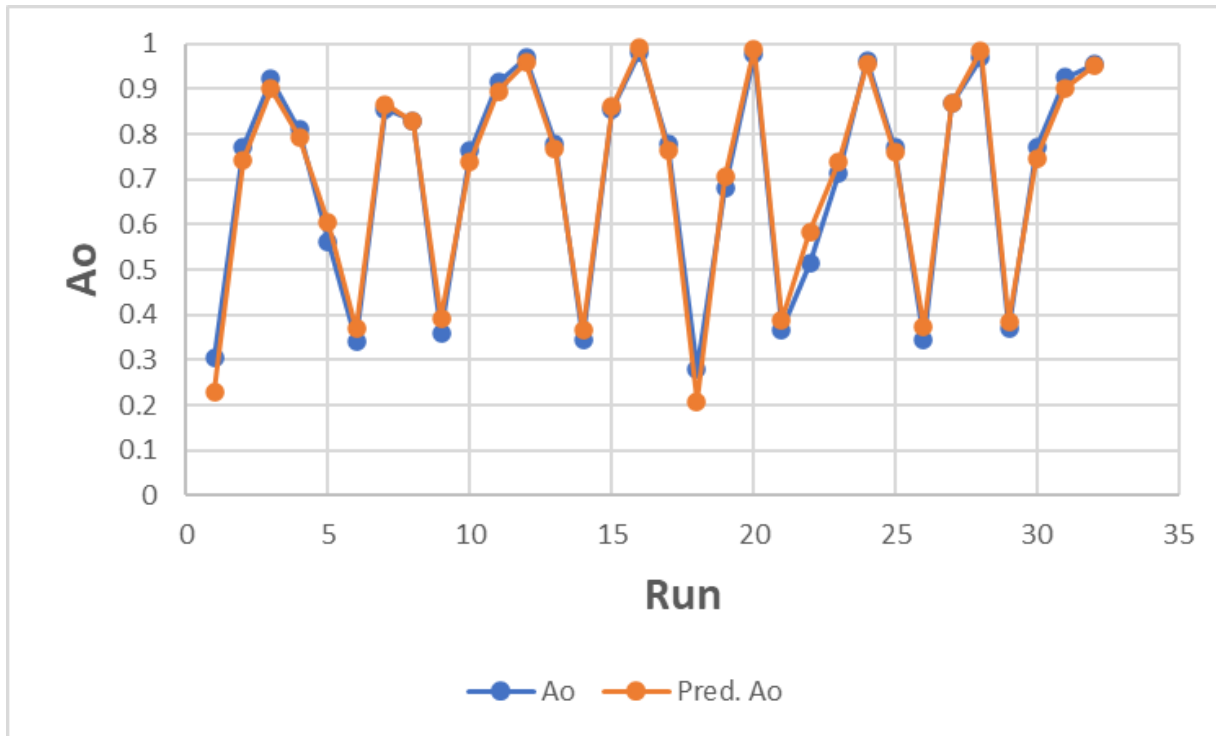
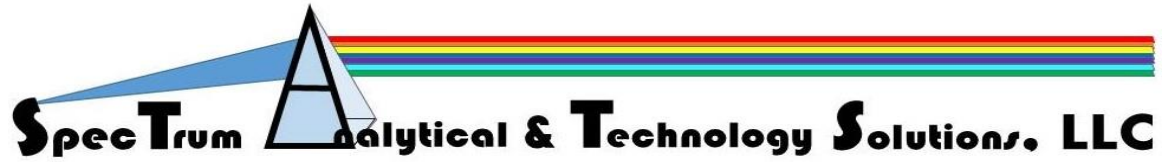
Example: Predicted Ao when MTB_SA(+1), MTB_EMA(+1), MTB_SM(+1), MTTR_SM(-1), ALDT(-1)

$$\hat{A}_o = 0.7067 + 0.017356(+1) + 0.180162(+1) + 0.039708(+1) - 0.041892(-1) - 0.102185(-1) + 0.027526(+1)(+1) + 0.085012(+1)(-1) + 0.038349(+1)(-1) = \underline{0.992172}$$

Example: Predicted Ao when MTB_SA(-1), MTB_EMA(-1), MTB_SM(-1), MTTR_SM(+1), ALDT(+1)

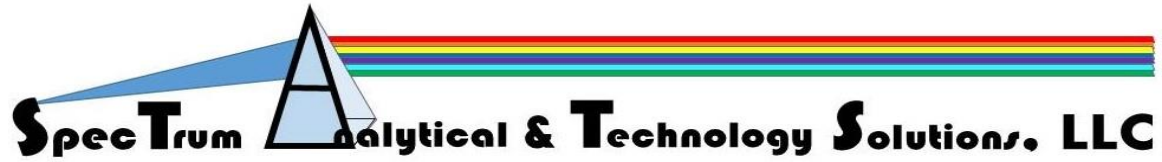
$$\hat{A}_o = 0.7067 + 0.017356(-1) + 0.180162(-1) + 0.039708(-1) - 0.041892(+1) - 0.102185(+1) + 0.027526(-1)(-1) + 0.085012(-1)(+1) + 0.038349(-1)(+1) = \underline{0.229566}$$

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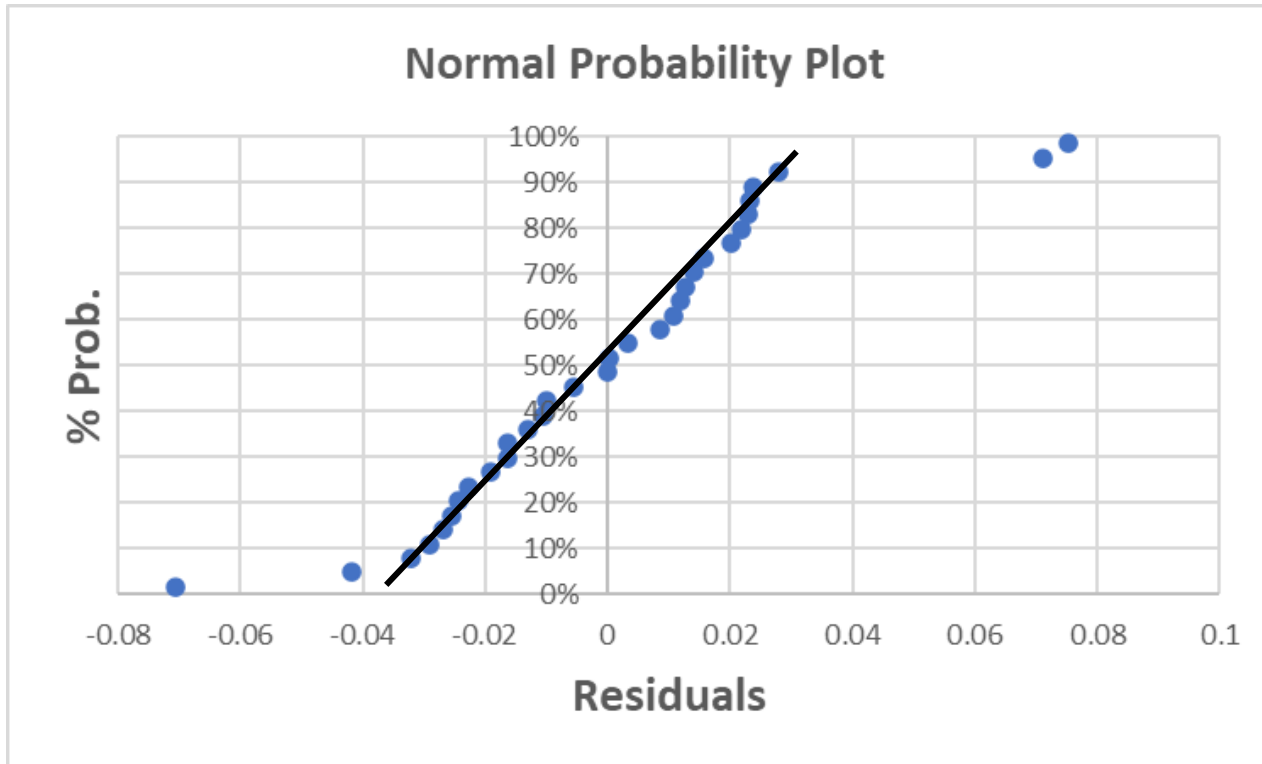
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MODEL ADEQUACY

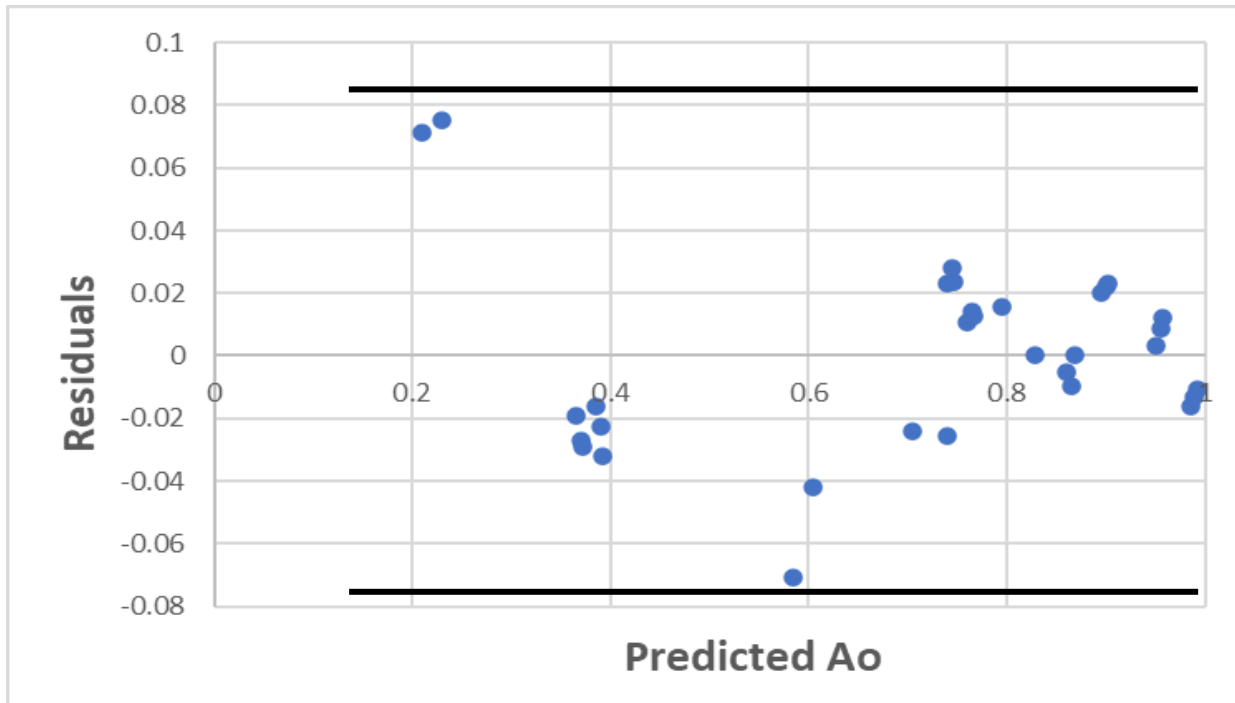
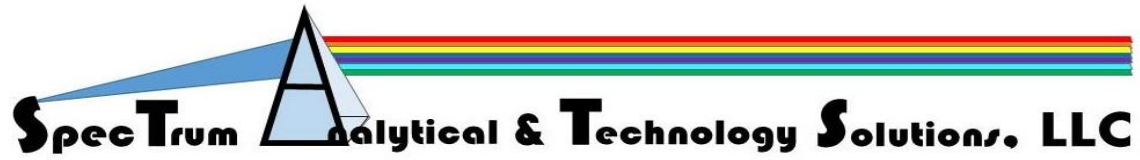
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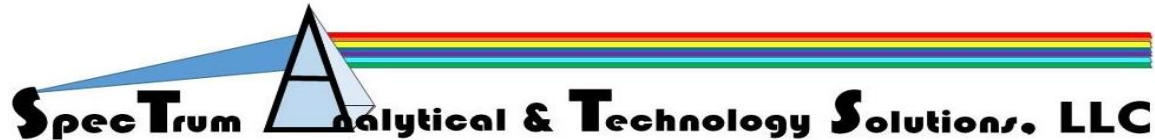


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CONCLUSIONS

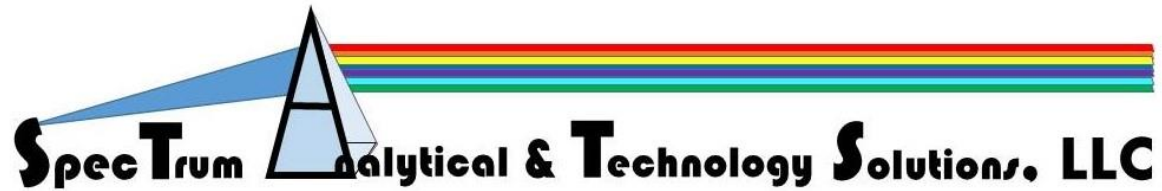
- *MTB_SA, MTB_EMA , MTB_SM, MTTR_SM , ALDT, and interactions between MTB_SA x MTB_EMA, MTB_EMA x ALDT and MTB_SM x MTTR_SM have significant effects on Ao*
- *Analysis of residuals indicate that model assumptions were not violated*

RECOMMENDATION

- *2^{k-p} fractional factorial designs are “screening” designs, more analysis is needed to refine the effects of significant factors*

LogSIM is a very useful tool to study the effects of control variables on outcomes related to RAM. Experimental design of simulation runs (experiments) can maximize the amount of information obtained.

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